FTA RESEARCH

FEDERAL TRANSIT ADMINISTRATION

Use Cases for Unmanned Aircraft Systems (UAS) in Public Transportation Systems

NOVEMBER 2020

FTA Report No. 0176
Federal Transit Administration

PREPARED BY

Jacob Wishart
Tracy Lennertz
Dylan Hasson

John A. Volpe National
Transportation Systems Center

U.S. Department of Transportation
Federal Transit Administration

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U.S. Department of Transportation
John A. Volpe National Transportation Systems Center
55 Broadway
Cambridge, MA 02142-1093

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liter	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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14. ABSTRACT
The application of commercial Unmanned Aircraft Systems (UAS) technology to transit operations can offer benefits in safety and efficiency. UAS (commonly referred to as drones), best-suited for difficult or time-consuming tasks, have been applied to numerous federal agencies and state department of transportation operations. This report seeks to extend the application of UAS technology to transportation systems, focusing on two use cases: infrastructure inspection and disaster response & recovery. This report aims to assist transit agencies in determining whether to apply UAS technology to their operations and provides high-level guidance for the development of UAS programs. Each use case is examined from three perspectives: Air Traffic Management (ATM) for implementing UAS operations, human factors considerations, and cost effectiveness analysis. The focus on these areas may provide public transportation systems with a well-rounded understanding of UAS technology from regulatory, operational, and business case perspectives. Considerations for an evaluation of UAS technology for transit agencies are also provided, including guidelines for the development of operations and metrics for data collection and analysis. Future work may include guidance or assistance to existing UAS applications at transit agencies.

15. SUBJECT TERMS Transit, Unmanned Aircraft Systems, UAS, drones, human factors, air traffic management, cost-effectiveness assessment, use cases.

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ABSTRACT

The application of commercial Unmanned Aircraft Systems (UAS) technology to transit operations can offer benefits in safety and efficiency. UAS, best-suited for difficult or time-consuming tasks, have been applied to numerous federal agencies and state department of transportation operations. This report seeks to extend the application of UAS technology to transportation systems, focusing on two use cases: infrastructure inspection and disaster response & recovery. This report aims to assist transit agencies in determining whether to apply UAS technology to their operations and provides high-level guidance for the development of UAS programs. Each use case is examined from three perspectives: Air Traffic Management (ATM) for implementing UAS operations, human factors considerations, and cost effectiveness analysis. The focus on these areas may provide public transportation systems with a well-rounded understanding of UAS technology from regulatory, operational, and business case perspectives. Considerations for an evaluation of UAS technology for transit agencies are also provided, including guidelines for the development of operations and metrics for data collection and analysis. Future work may include guidance or assistance to existing UAS applications at transit agencies.

EXECUTIVE SUMMARY

The application of commercial Unmanned Aircraft Systems (UAS) technology to public transportation operations can offer benefits in both safety and efficiency. The Federal Aviation Administration (FAA) permits the use of UAS (commonly referred to as drones) for commercial purposes under Title 14 of the Code of Federal Regulations [CFR] Part 107, and this technology has been applied to numerous federal agencies and state department of transportation operations. UAS are best suited for difficult or time-consuming tasks and may allow the automation of some current tasks.[1] This report seeks to extend the application of UAS technology to public transportation systems, focusing on two use cases: infrastructure inspection and disaster response & recovery. This report aims to assist public transportation systems in determining whether to apply UAS technology to their operations and provides high-level guidance for the development of UAS programs by public transportation systems. Although implementation will depend on the specific operations at each public transit agency, the use cases described are intended to apply to a variety of different-size transportation systems and modes of public transportation.

Each use case is examined from three perspectives: Air Traffic Management (ATM) for implementing UAS operations, human factors considerations, and cost-effectiveness analysis. Focusing on these areas may provide public transportation systems with a well-rounded understanding of UAS technology from regulatory, operational, and business case perspectives.

The first perspective, ATM, includes the regulations for operating UAS. It is important to consider ATM in planning UAS operation to determine if they are feasible within the regulatory parameters defined by the FAA. UAS technology for infrastructure inspection or disaster recovery is permitted under Part 107 with few or no additional approvals from the FAA. Waivers need to be obtained for operations in extended or beyond visual line of sight, operations at night, or operations from a moving vehicle. The second perspective, human factors considerations, relates to the design, planning, and implementation of UAS operations to help ensure that procedures are in place for safe operation, to plan for unexpected events, and to define roles and responsibilities. These are several aspects of UAS operation to consider before, during, and after flight. Training should also be specific to the needs of the transit agency. An agency should develop contingency plans in case of a lost link with a UAS or other unexpected events. Finally, the cost-effectiveness analysis provides a framework for evaluating the efficiency gains from using UAS in public transportation applications. The baseline costs of an application are compared to a scenario applying UAS technology, including the cost of data storage, hardware, software, and training. A notional analysis suggests that if an agency has even relatively modest efficiency gains when using UAS, the investment would be cost-effective.

[1] The term "UAS" denotes both one and more than one UAS.

Considerations for an evaluation of UAS technology at a transit agency are also provided, including guidelines for the development of operations and metrics for data collection and analysis. Future work may include guidance or assistance to existing UAS applications at public transportation systems.

SECTION 1

Introduction

The application of commercial Unmanned Aircraft Systems (UAS) operations to industry continues to grow while drastically improving both safety and efficiency. UAS technology that includes a remote operator and an aircraft (that is, a vehicle and its controls) has been applied to agriculture, infrastructure, security, disaster recovery, monitoring, photography, construction, and real estate (DJI White Paper, 2019). The Federal Aviation Administration (FAA) permits the use of UAS for commercial purposes under Title 14 of the Code of Federal Regulations [CFR] Part 107. There is significant interest and experience in applying UAS, typically under Part 107, to operations at state departments of transportation (DOTs) (National Cooperative Highway Research Program [NCHRP], 2018), including recent developments by California, Colorado, Georgia (Irizarry & Johnson, 2019), New York (Kamga et al., 2017), North Carolina (DJI White Paper, 2019), and Utah.[2,3,4] This report seeks to extend the application of UAS technology to public transportation systems, with a focus on two use cases permitted under current regulation: infrastructure inspection and disaster response & recovery.

The application of UAS can offer many benefits to transit operations. UAS (commonly referred to as drones) are best suited for tasks that may be difficult or time-consuming for a human operator. Track inspection is an example. In current operations, inspectors typically walk or ride along the tracks, check conditions, document observations, address areas in need of attention, and document the process (Irizarry et al., 2017). Inspectors may also look for a combination of factors (e.g., frequency of use and age of track) that could create a safety issue (National Academies of Sciences, Engineering, & Medicine [NAS], 2013). In some systems, inspectors also conduct repairs on the tracks during inspections (NAS, 2013). Current challenges in track inspection include scheduling and disruptions in service for passengers and freight (NAS, 2013).

UAS can offer improvements in safety, as inspectors would no longer be required to walk large swaths of track or locations that are dangerous or difficult for a human inspector to access, such as bridges, tunnels, flood zones, steep grades, or electric catenaries (Ni & Plotnikov, 2016). UAS may also yield time savings and increase the efficiency of a given operation (Kim, Irizarry & Costa, 2016). As an example, UAS and accompanying software do not rely only on "human perception and judgment" (Irizarry et al., 2017, p. 676) to

[2]https://dot.ca.gov/programs/aeronautics/unmanned-aircraft-systems.
[3]https://www.codot.gov/programs/aeronautics/FlyUASResponsibly.
[4]https://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:4923.

identify changes, patterns, or areas in need of attention. UAS technology can collect and analyze data not seen by the human eye, such as thermal data to identify cracks, at a significantly increased rate. High-quality data captured by UAS technology can help to identify patterns (NAS, 2013) or changes in infrastructure. Another way that the use of UAS could improve time savings and efficiency is by allowing some current tasks to be automated, allowing inspectors to target areas in need of attention or in-person inspection (Sherrock & Neubecker, 2018). The implementation of UAS technology also "[expands] the use of automated inspection" in line with the recommendations of the Railroad Safety Advisory Committee.

Objective

This report describes two use cases for the application of UAS by public transportation systems. These cases were identified through discussions with current and potential users of UAS technology and in coordination with the Federal Transit Administration (FTA). The goal of this work is to assist transit agencies in determining whether to apply UAS technology to their operations and to provide high-level guidance for the development of UAS programs. Although implementation will depend on the specific operations at each transportation system, the use cases described herein are intended to apply to multiple types of systems, regardless of size or geographic location (e.g., rural or urban).

In what follows, methods are described, and a notional concept of operations for two use cases is presented in Section 2. Each use case is examined from three perspectives: Air Traffic Management (ATM) for implementing UAS operations (Section 3), 2) human factors considerations (Section 4), and 3) cost-effectiveness analysis (Section 6). The focus on these three areas is intended to provide public transportation systems with a well-rounded understanding of UAS technology from regulatory, operational, and business case perspectives. This work may also help agencies determine whether potential applications are viable. An example implementation of each use case considering ATM and human factors is provided in Section 5. Appendix A includes relevant waiver guidelines for FAA regulations related to the commercial use of small UAS (i.e., applying for waivers for certain Part 107 operations).

Methods

To understand the scope of potential UAS applications to public transportation systems, a review of relevant government and industry literature was conducted, including current applications at state DOTs. Following this, feedback was sought on potential needs and data gaps from a diverse set of transportation agencies through semi-structured interviews.

Seven interviews were conducted between July and September 2019 to understand current and potential UAS applications; interviewees included transit agencies, state DOTs, and FTA Regional staff. Respondents covered rural and urban operations, public and private operators, and multiple types of service (i.e., bus, rail, light rail, and ferry).

Based on these discussions, it was observed that most agencies are interested in adopting UAS technology for their current day-to-day operations, with a focus on small UAS (i.e., under 55 lbs). Several use cases for UAS for public transit were identified from these discussions, including 1) inspection (i.e., track, bridge, facility, or pavement inspection), 2) emergency management (disaster response & recovery, trespass monitoring, and traffic incident management), 3) data-gathering (aerial photographs, mapping, construction, traffic, and crowd monitoring), and 4) communications (video communication and training). Based on feedback from FTA, and given the input from discussions with stakeholders, the assessment focused on two notional use cases—track inspection and disaster response & recovery.

SECTION 2

Notional Use Cases

This section describes the notional use cases examined in this report. Track inspection is discussed, followed by a discussion of disaster recovery & response. Further examination of these use cases is discussed in Section 5 under the context of ATM and human factor considerations, and an additional list of potential use case topics is presented in this section.

Track Inspection

This section briefly discusses track inspection-related use cases. Many characteristics also would apply to guideway inspection, which broadly includes rail tracks, bus guideways, bridges, and tunnels.

Current Operations

In current operations, agencies visually inspect tracks, switches, and the surrounding area, and inspectors must detect differences between inspections and assess if further actions are needed for repair. Inspectors use primarily visual methods during inspections to detect problems but may also rely on auditory or physical cues. Although dependent on the operations of the individual agency, inspections typically are carried out by a one- or two-person crew walking track segments or inspecting in conjunction with a semi-automated train on the track (NAS, 2013). The frequency of inspections is not federally-mandated, but rather is set by the agency or the State; the majority of public transit agencies conduct inspections twice a week (NAS, 2013).

Track inspections require both planning and maintenance tasks. Accounting for the schedule of operations and avoiding disruption in passenger service are ongoing challenges. Inspectors and train dispatchers must be aware of current operations and have a plan for dealing with oncoming traffic to help ensure inspector safety. Depending on the implementation, there is need for staff to “look out” for oncoming traffic, and dispatchers must provide information to inspectors (NAS, 2013). A combination of factors and safety risks is common and must be considered during track inspections, and it may be challenging for an inspector to keep track of all these factors (NAS, 2013). Additional challenges in current inspection operations include the validity of documents and reports and difficultly in conducting night inspections (France et al., 2020).

To address these challenges in track inspection, federal funding recently was granted to the Washington Metropolitan Area Transit Authority (WMATA) to develop and deploy a Location Awareness with Enhanced Transit Worker Protection system that alerts wayside workers of approaching trains while also alerting train operators to workers ahead. Additional ongoing research through the Chicago Transit Authority (CTA) is testing and deploying a "Worker Ahead" system that allows an agency to track roadway workers through the development of specialized graphics for "Worker Ahead" signals, visual display of "Worker Ahead" zones, and deployment of a database modified to link indications of "Worker Ahead" zones with developed graphics at the central control center.

Operations with UAS Technology

To offset potentially dangerous inspector/train accidents, UAS technology can assist with the process of track inspection. An operator may fly a UAS above (or adjacent to) the track and use video footage or imagery to provide an efficient visual record of the track. Inspectors can review the footage, and agencies may use automated processes to detect differences in the condition of the track. Commercial UAS operations (including those for a business or government) must follow certain regulations and will require a Part 107 certification from the FAA, as described in Section 3. More advanced operations (e.g., over people or traffic, from a moving vehicle, or beyond visual line of sight) will require waivers from the FAA, as described in Section 3.

A recent implementation of UAS technology for track inspection was at Denver's Regional Transportation District (RTD) (Nabhan, 2018). RTD, which has both light and commuter rail, uses small UAS for track inspection. The RTD program was developed internally and operates under existing Part 107 regulations—flying within visual line of sight, in daylight hours only, and under 400 feet. The program has yielded benefits and cost savings such as "faster inspections" and "less worker-hours required" (Nabhan, 2018).

Disaster Response & Recovery

After a natural disaster such as a flood, agencies must assess potential damage and determine that routes are safe and clear from debris.

Current Operations

Transportation infrastructure can be a lifeline to relief efforts and evacuations before, during, and after natural disasters. Post-disaster inspection of the transportation network is one of the most important steps in the process of recovery, ensuring that the transportation infrastructure can support relief efforts in a safe and efficient manner. The amount of infrastructure and the simultaneous efforts of recovery and inspections can lead to costly methods for completing these necessary inspections. Due to current ground conditions or highway infrastructure, transit agencies often may need to rely on fixed and rotor-wing aircraft to complete inspections, which can cost thousands of dollars per hour to operate, add significant traffic volume to an airspace possibly already in high demand, and be difficult to schedule due to shared and limited use of aircraft. It is also possible that multiple state and local agencies need to coordinate when large areas are affected.

In addition to using aircraft for inspection, response & recovery operations may also require sending individuals to walk a route or track (Carey, 2019) into potentially unsafe or inaccessible environments.

Operations with UAS Technology

Using a UAS, an agency can fly into potentially unsafe or hard-to-reach areas, which can lead to improvements in safety and reduce response time following a natural disaster. The data gathered from a UAS—video footage or imagery—can assist with response & recovery efforts, including mapping the impact of potential damage (University of Vermont UAS Team; Federal Highway Administration [FHWA], 2019). UAS also can aid in developing plans to build resiliency, for example, by mapping out changes in a body of water near a transit route to predict the likelihood of flooding. As with track inspection, commercial operations require a Part 107 certification, as described in Section 3, and more advanced operations (e.g., over people or traffic, from a moving vehicle, or beyond visual line of sight) requires additional waivers from the FAA, also described in Section 3.

Current examples of UAS technology used for disaster response & recovery are at the North Carolina DOT (NCDOT), the University of Vermont, BNSF Railway, and FHWA.[5,6,7,8] NCDOT employed UAS to assist with the planning and recovery efforts for Hurricane Florence (Karpowicz, 2018), which enabled a real-time and close-up view of infrastructure, providing more detail than that of traditional emergency response efforts. In particular, UAS was able to identify flooding in areas that were otherwise inaccessible and when coordinated with manned aircraft, enabled faster decision-making in response to the hurricane (Karpowicz, 2018).

Additional Use Case Opportunities

During stakeholder engagement, several use case applications were identified and categorized into four topic areas: 1) Data Gathering, 2) Inspection and Maintenance, 3) Emergency Management and Safety, and 4) Communication and Training. Although track inspections (categorized under Inspection and Maintenance) and disaster response & recovery (categorized under Emergency Management and Safety) are the primary focus of this report, many additional use cases apply to multiple transportation modes within these four categories. Table 2-1 presents a list of identified use cases and transportation mode applicability. Note that many, if not all, of the concepts and considerations covered in ATM and human factors sections would also apply these additional use cases.

[5] https://www.commercialuavnews.com/public-safety/ncdot-UASs-hurricane-florence.
[6] http://www.uvm.edu/~uas/.
[7] https://bnsfnorthwest.com/news/2019/10/01/bnsf-leads-the-way-in-drone-technology/; see also http://www.bnsf.com/news-media/railtalk/safety/bnsf-drone.html.
[8] https://www.fhwa.dot.gov/uas/resources/hif19019.pdf.

Table 2-1

Potential Use Case Categories and Applications by Transportation Mode

UAS Use Case Categories	Use Case	Transit Modes			
		Bus	Rail	Subway	Ferry
Data Gathering	Aerial photographs/GIS mapping	•	•		•
	Construction, traffic and crowd monitoring	•	•	•	•
	Vehicle and maintenance operations	•	•	•	•
Inspections and Maintenance	Track/rail inspection		•	•	
	Bridge and guideway inspection	•	•	•	
	Maintenance facility inspection	•	•	•	•
	Pavement inspection	•	•		
Emergency Management & Safety	Disaster response & recovery	•	•	•	•
	Resiliency planning	•	•	•	•
	Trespass monitoring		•	•	
	Traffic incident management	•	•		
Communications & Training	Development of communication and promotional videos	•	•		•
	Provision of aerial content for driver/operator training	•	•		•

SECTION

3

Air Traffic Management

Air Traffic Management (ATM) includes the regulations, policies, and recommendations for operating UAS that aim to minimize the risk of conflict with manned aircraft or other airspace users. It is important to consider ATM in planning a UAS operation to determine if the operation is feasible within the parameters defined by the FAA. It is also important to note that the regulations concerning UAS operations continue to evolve; the FAA UAS website should be consulted regularly for the most up-to-date information.

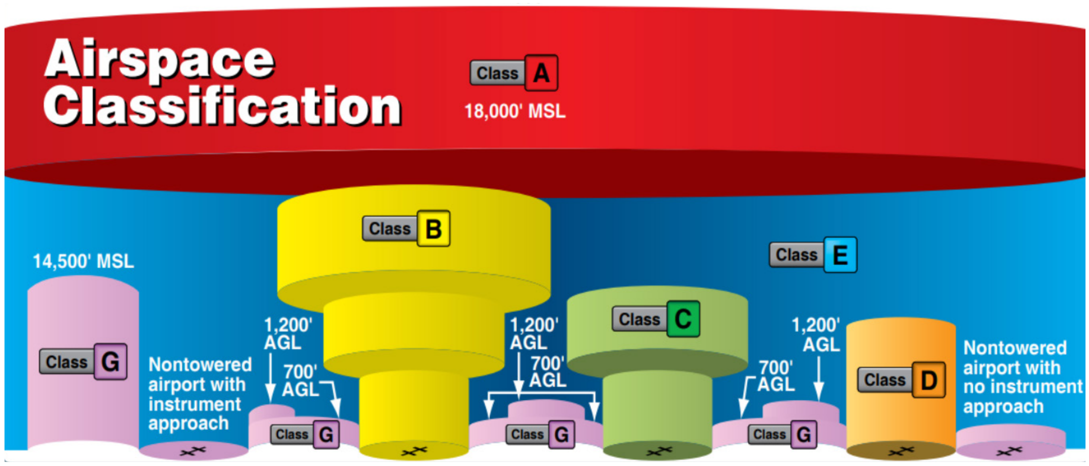
ATM considerations for UAS implementation depend on several factors: 1) intended airspace for operations, 2) time of day, 3) location of the operator in relation to UAS (within visual line of sight [VLOS] or beyond visual line of sight [BVLOS]), and 4) size of UAS. In general, similar considerations will apply to both infrastructure inspection and disaster response & recovery.

In this section, ATM considerations are described for operations permitted under current regulations that do and do not require a waiver from the FAA. A guide to the process of applying for a waiver is provided in Appendix A, as is a list of links to aid in creation and submission of a Part 107 waiver.

Operations under FAA Part 107

FAA provides requirements for commercial operations of small UAS under 14 CFR Part 107. Depending on implementation, the use of UAS for infrastructure inspection or disaster response and support can be permitted in the current regulatory environment, with few or no additional approvals required from the FAA. Specifically, if the Concept of Operations for the intended use meets the Part 107 requirements and occurs within Class G airspace, no additional authorization is needed from the FAA. Class G airspace includes all airspace below 14,500 feet MSL (Mean Sea Level) not otherwise classified as controlled and typically is airspace very close to the ground, 1,200 feet MSL or less underneath Class E and outside of B, C, and D rings around towered airports.

Figure 3-1 provides a high-level description of U.S. airspace. If the use case requires operations in Class B, C, D, or E Airspace, in addition to fulfilling the Part 107 operating requirements listed above, the operator must also obtain an airspace authorization from Air Traffic Control (ATC). This authorization enables ATC to be aware of UAS operations and determine if the operations would conflict with the path of manned aircraft. UAS Facility Maps show the maximum altitudes around airports where the FAA may authorize Part 107 operations without additional safety analysis.[9] Operators can apply for authorization through the FAA's Low Altitude Authorization and Notification Capability (LAANC). Part 107 operators seeking ATC authorization must make a request through one of the LAANC UAS Service Suppliers listed on the LAANC website; if the intended operation occurs at an airport not covered under the current LAANC authorizations, operators must submit a manual request.[10]



Source: https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/17_phak_ch15.pdf

Figure 3-1

Potential Use Case Categories and Applications by Transportation Mode

Part 107 Operating Requirements (summarized from FAA Part 107 Fact Sheet) are the following:

- UAS, including any equipment being carried, must be under 55 lbs (considered by the FAA to be a small UAS or sUAS).
- UAS operated within VLOS of the pilot or an observer.
- Pilot and/or observer operate only one UAS at a time.
- Operations occur in daylight or civil twilight (with appropriate lights on UAS).
- Operations occur in good weather (defined as 3 miles visibility).
- UAS can fly up to 400 feet above ground level or 400 feet above a structure (such as a building, tree, or a power line).
- UAS can fly up to 100 mph.
- Operations cannot occur over people (who are not involved in operation of UAS) or in a tunnel.
- No permission is required to fly in Class G airspace.

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[9] https://www.faa.gov/uas/commercial_operators/uas_facility_maps/.

[10] Request made through FAA's "DroneZone," https://faadronezone.faa.gov/#/. Additional details on this process are provided in Appendix A.

In all operations, either the UAS operator or the observer must hold a Part 107 Remote Pilot Certificate (see Section 4), and the UAS must be registered with the FAA.

Operations with a Waiver

Given the intended use cases for UAS in public transportation systems, it may be necessary to obtain a waiver from the FAA. Waivers may be required to operate:

- In extended visual line of sight (EVLOS), which occurs when one or more human observers keep the UAS in sight at all times
- Beyond visual line of sight (BVLOS), which uses "electronic means" for the operator to know the UAS position relative to all hazards and whether an avoidance maneuver is needed
- At night
- Over people
- From a moving vehicle

Given the complexity in obtaining a single waiver, it is recommended that operators pursue a single waiver only one at a time (rather than applying for operations that include more than one waiver).[11] Specific ATM considerations for each of these waivers are described below; a guide to the process of applying for a waiver is provided in Appendix A, as is a list of links to aid in development and submission of a Part 107 waiver.

Extended Visual Line of Sight (EVLOS)

To fly EVLOS operations, a waiver must be attained for Part 107.31, Visual Line of Sight Aircraft Operations. This type of waiver allows the operator to strategically place adjacent observers within VLOS with each other (all must be Part 107 certified) to extend the VLOS operation. This could be used to inspect larger volumes of roadway, bridges, or railway without the need to make shorter, more frequent flights.

Beyond Visual Line of Sight (BVLOS)

There are several considerations for BVLOS for small UAS.[12] As described above with EVLOS operations, BVLOS operations also require a waiver for Part 107.31. This process is more stringent than EVLOS, as the operator will be relying solely on electronic means to be alerted to other manned aircraft in the area. Other potential hazards to BVLOS operations include ground infrastructure such as power lines and radio antennas, which must be known or mapped carefully to avoid collisions.

[11] A list of Part 107 waivers approved by FAA is available at https://www.faa.gov/uas/commercial_operators/part_107_waivers/waivers_issued/.

[12] The FAA-sponsored Alliance for System Safety of UAS through Research Excellence (ASSURE), sUAS Detect and Avoid (DAA) Requirements for Limited BVLOS Operations, §2.3.6.1-2 contain general recommendations that are most suitable for FTA use cases, including recommendations gathered from literature review, forecasts of upcoming regulations, and experimental data.

When applying for a waiver in BVLOS, it is important to consider the altitude of the intended operation. If the operation is planned to occur at very-low level altitude, typically ranging between 400 and 1,200 feet above ground level (AGL), it is unlikely that the UAS will encounter another aircraft, as these altitudes are below manned aircraft flight paths and procedures. Understanding collision risks at both air and ground level and quantifying those risks with structured, repeatable processes will greatly enhance the safety case/proof-of-concept of use cases. Air and ground risk will change often over lengths of infrastructure.[13]

Detect and Avoid (DAA) technologies are generally the electronic means used to enable BVLOS flight. If an operator decides to use DAA technologies, he/she should consider functionalities addressed and/or achieved, the guidance provided by the technology, and if functionalities address the risk inherent in the operations. Comparable examples for FTA use case development are found in several FAA UAS Integration Pilot Program operations.[14] A BVLOS waiver may be necessary for extended track inspection or bridge inspection when the operator does not maintain visual contact with the UAS due to distances covered.

Operations at Night

To fly operations at night when pedestrian, vehicular, and/or rail traffic is generally infrequent, a waiver is required for Part 107.29, Daylight Operations. This is needed for flight operations between the end of evening civil twilight (one hour after sunset) and the beginning of morning civil twilight (one hour before sunrise). For example, if track inspections occur at night, a waiver for operations at night would be required.

Operations over People

Should operations require inspection of an active roadway, rail, or bridge, a waiver is required for Part 107.39, Operation Over People. For example, highway or rail inspections with active traffic will most likely require a waiver to operate over people (CFR 107.39).[15]

Operations from a Moving Vehicle

Should operations deem use from a moving vehicle necessary, a waiver can be obtained for Part 107.25, Operation from a Moving Vehicle or Aircraft. For example, given the volume of rail tracks and the necessity to remain clear of the tracks if possible, rail inspection may require a waiver for Operations from a Moving Vehicle (CFR 107.25) to complete operations/inspections in less time, allowing for a faster return to service.

[13]The JARUS SORA Process provides example sets of parameters to determine air and ground risk; see http://jarus-rpas.org/content/jar-doc-06-sora-package.
[14]https://www.faa.gov/uas/programs_partnerships/integration_pilot_program/.
[15]For additional information on waivers, see https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/afx/afs/afs800/afs820/part107_oper/.

SECTION 4

Human Factors Considerations

It is important to consider human factors issues in the design, planning, and implementation of UAS operations. This can help to ensure that procedures are in place for a seamless operation, plan for unexpected events, and clarify roles and responsibilities. For the operation to be successful, the tasks should be clear and feasible from a user perspective. Human factors considerations for the use of UAS technology for both infrastructure inspection and disaster response & recovery will depend on the specific operations of the transit agency and the implementation of the UAS. In general, this will require clear operating procedures for all individuals involved in the UAS flight, including procedures for planning, en-route operations, and unexpected scenarios (Ni & Plotnikov, 2016). The following provides general human factors considerations for UAS operations with a focus on VLOS operations.

Flight Planning

General

Careful consideration should be given to the planning of each UAS flight. It is recommended that operations start small in scope and are redundant with existing procedures (e.g., if using a UAS for track inspection, consider collecting data from the UAS and an inspector walking the tracks initially). The extent to which an organizational structure and planning documents and procedures are required would be based on size of the operation, number of UAS, number of operators, areas of deployment, and frequency of operations. In general, flight planning should consider the flight path and altitude, duration of flight, weather conditions, privacy or noise issues, and information-sharing. These considerations are discussed in the following subsections.

Flight Path and Altitude

Flight planning should consider the lateral and vertical route of the UAS. The location of the UAS relative to the terrain, tree line, and nearby buildings and roads should also be considered. It is important to include a buffer between the altitude of flight and the highest allowable altitude (which, in most cases, is the highest allowable altitude is 400 feet). This buffer will reduce the chance and severity of flying above the intended altitude (i.e., an "altitude bust") should the UAS accidentally fly too high. Note that Part 107 regulations will specify how information about UAS operations should be communicated to other airspace users, such as air traffic control and manned aircraft flying in the vicinity.

Duration of Flight

The duration of a UAS flight will be impacted by several factors including how long the UAS will need to complete its operation and how long it can reasonably fly over/near the track given the transit agency's scheduled operations and the battery life of the UAS. The planned start and stop times for an operation should be defined during flight planning.

Weather Conditions

It is likely that the flight must occur in good weather (defined as a visibility of three miles) and within the wind parameters defined by the UAS. Wind can impact the ability of the UAS to fly by reducing the length of battery life and can impact the quality of data collected from on-board sensors.

Privacy or Noise Issues

It is important to consider whether the UAS operation will raise any privacy or noise issues. For example, will the UAS be operating near any residential areas? Will it be necessary to communicate to the public about the planned UAS operations? Who can the public contact in case of questions? The transit agency should consider these questions during flight planning and may need to coordinate operations and communications about operations with the local community or local government organization. The agency may want to establish a point of contact for the community in to address questions or concerns about the sUAS operation.

Access to Relevant Information and Information-Sharing

Given the planning and coordination required, UAS flight paths (for example, over a specific area of track) may be planned far in advance of the operation. Depending on the location of the flight and if authorization or a waiver is needed from the FAA, some parameters of the operation must be shared with the FAA (such as the time of operation, intended altitude, flight path, type of UAS, and UAS operator contact information). It is important that individuals at the transit agency involved in the operation have access to this information, including the start and stop times of the operation, the intended altitude(s) of flight, and the duration of each flight. This allows them to address any questions that may come up during flight, for example, from ATC or other individuals at the transit agency. This flight planning information should be in a standard format and shared with all individuals in the sUAS operation.

Additional Considerations

Additional considerations will be necessary if the transit agency is using BVLOS operations, especially if an operator is controlling more than one UAS at a time. This raises additional considerations on the need for a detailed communication protocol, the ability to use an interface to control the UAS, and the ability to safely monitor more than one UAS. BVLOS will require a more in-depth flight plan than operations that occur within line of sight.

It is also important to consider whether the UAS will be in communication with ATC, for example, through a transponder visible on an ATC display. This is likely not necessary given the small size and intended flight plan of the UAS, but it should be considered if implementing an aircraft over 55 lbs. In this case, contact information (and back-up contact information) should be provided to ATC in case ATC needs to contact the operator during flight.

Pre-Flight Checklist

There can be much to remember before a UAS flight. Consequently, developing a pre-flight checklist that includes, at minimum, the following items is recommended; each operator/team should review such a checklist prior to flight:

- Review flight plan with team; note current airspace and any potential airspace boundaries.
- Test communications, including range of communications on, for example, hand-held radios and between all individuals involved; test control and communications digital link with the UAS.
- Review local weather; determine if weather is OK for flight.
- Check for any "Notice to Airmen" (NOTAMS) or flight restrictions in the planned area of flight.[16]
- Check UAS display (e.g., tablet display).
- Check battery life of UAS and tablet display.
- Determine if the UAS NOTAMS are in place for flight and if agency has appropriately alerted other airspace users of the planned operation.
- Inspect suitability of UAS for flight.
- Review contingency procedures for unexpected events, or ensure that all team members have access to this information during the flight operation.
- Consider additional checklist items for extra batteries, field equipment, or items specific to the operation.

Post-Flight

Following a flight, a post-flight debrief is recommended. The team can review the operation and discuss whether anything unexpected occurred, and, if so, how the situation was handled. The team also can discuss any lessons learned that could be applicable to future operations. Agencies should also have a plan in place for data organization, analysis, and storage for footage or images taken during flight.

[16]https://www.skybrary.aero/index.php/Notice_To_Airmen_(NOTAM).

Training Guidelines

Training for UAS operations should be specific to the planned implementation of the public transportation system. A best practice identified by a scan of UAS applications across states (NCHRP, 2018) is to incorporate both the required Part 107 training and training/experience that comes from specific operations. To the extent possible, training should also be standardized across operators within an agency. UAS operators should be familiar with the inspection task; in some implementations, the UAS operator may also be familiar with the data analyses (NCHRP, 2018).

Additional considerations for an agency's training program include:

- Potential to include both initial and recurrent training
- Using "scenario-based training" that includes both routine and non-routine situations that could be encountered in flight
- Familiarizing UAS operators with the site of operations, terrain, flight path, and perspective of terrain on the UAS display.

Remote Pilot Training Requirements

Before Part 107 operations can take place, either the UAS operator or a visual observer must hold a Remote Pilot Certificate from the FAA.

First-Time Pilots

To obtain a Remote Pilot Certificate, first-time pilots must be at least age 16; be able to read, speak, write, and understand English; be in a physical and mental condition to safely fly a drone; and pass an initial aeronautical knowledge exam.[17] A knowledge test must be scheduled at an FAA-designated Knowledge Testing Center;[18] it is recommended that first-time pilots complete a ground study course before taking the aeronautical knowledge test to become familiar with FAA rules and regulations. Once obtained, a remote pilot certificate is valid for two years.

Existing Part 61 Certificate Holders

Existing pilots with a current FAA Pilot License can obtain a Remote Pilot Certificate in an expedited manner. Part 61 holders must create an account on FAASTeam website and complete the online training course "Part 107 Small Unmanned Aircraft Systems ALC-451."[19] Once completed, an Integrated Airman Certification and Rating Application (IACRA) form must be completed

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[17] https://www.faa.gov/uas/commercial_operators/become_a_drone_pilot/.
[18] http://candidate.catstest.com/sitesearch.php.
[19] https://www.faasafety.gov/.

and validated by an FAA Flight Standards District Office, Designated Pilot Examiner, Airman Certification Representative, or FAA-Certified Flight Instructor.[20] This certificate must be renewed every two years.

Roles and Responsibilities

For all UAS operations, it is imperative to have clear roles and responsibilities for all individuals involved. At a minimum, the team will consist of one or more UAS operators (the pilots in control of operating the UAS) and potentially one or more visual observers to assist the operator by monitoring the flight path of the UAS during operations. Under FAA Part 107 (without a waiver), a 107.31 visual observer is usually in close proximity to the operator and is in communication with him/her at all times.

In situations in which there may be multiple UAS operating concurrently for a single organization, it is recommended to include a "flight coordinator" on the team who will know the "big picture" and oversee the UAS operations. This individual should know the location of each concurrent UAS flight, be in communication with each UAS operator, and able to share information about operations as necessary between UAS operators (NCHRP, 2018), including if/when operations should be halted. Clear roles and responsibilities will facilitate an understanding of procedures and expectations and an increase the predictability of operations and may allow the team to manage unexpected events (Cardosi & Lennertz, 2017).

User Interface

"Ease of the user interface for UAS operations" was identified as a top factor in the adoption of UAS technology for construction and facility management (Kim, Irizarry & Costa, 2016). There are several human factors considerations for the interface used by an operator to control a UAS and visually monitor the flying environment. The operator typically controls the UAS through a tablet; how actions on the tablet translate to actions of the UAS may vary between implementations. For example, depending on the implementation, a physical action on the interface to the right may actually move the UAS to the left or an action backward may translate into the UAS flying forward. In addition, operators should be aware that the image displayed on the tablet is not the full view; birds or other nearby aircraft are visible on the display only when they are in close proximity. Thus, it is important not to rely completely on the display when keeping the UAS in visual line of sight.

[20] https://iacra.faa.gov/IACRA/Default.aspx.

Contingency Plans

The agency should develop contingency plans in case of an unexpected scenario, such as a lost link, a "fly away," or altitude "bust."

Lost Link Procedures

During operations, the Command and Control link between the UAS and the operator can sometimes be temporarily lost. Most UAS will have a built-in procedure in the case of a lost link. For example, some UAS will go into a holding pattern at a pre-determined location and others will "return to base" or land at another pre-determined location. All individuals involved in the UAS operation should know the procedures for a lost link situation.

"Fly Away"

It is possible that the Command and Control link between the UAS and the operator can be lost and the operator cannot resume control. In this case, the UAS may fly in an altitude or direction that the operator cannot control. If this occurs, there should be a list of contacts to be notified, depending on the location of the flight (e.g., nearby airports).

Altitude "Bust"

In some cases, the UAS may inadvertently fly above its intended altitude (i.e., an "altitude bust"). One way to mitigate this risk is to define a buffer zone between the UAS altitude for operations (e.g., 300 feet) and the highest altitude allowable (e.g., 400 feet per Part 107). Thus, if the UAS unintentionally flies above its intended altitude, it remains in airspace in which UAS operations are permitted and is unlikely to come in proximity to a manned aircraft.

Other Aircraft

If flying under Part 107 rules, a manned aircraft would not fly in close proximity to the UAS. Given that the UAS must remain below 400 feet or within 400 feet of a structure, this airspace will not be used by a manned aircraft (one exception could be a low-flying helicopter). In the case that another aircraft is in close proximity to the UAS, there should be a procedure for halting or modifying UAS operations and a plan to communicate this information to all individuals involved in the UAS operations.

Incident/Accident Reporting

Incident/accident reporting regulations for Part 107 UAS operations are provided under 14 CFR 107.9.[21] From a human factors perspective, each agency should have

[21]See FAA UAS FAQs for questions regarding accident and incident reporting at https://www.faa.gov/uas/resources/faqs/.

a plan in place for reporting incidents and accidents to share experiences and lessons among operators, develop recommendations to avoid common "errors," and potentially to understand the factors that contributed to the "errors." Depending on the size of an agency's operation, this information may be shared informally or anonymously.

One established location for reporting, although not specific to an agency's internal operations, is the Aviation Safety Reporting System maintained by NASA[22] to which anyone can anonymously report safety information (e.g., pilots, observers, or the public); these data can be used for further analysis or to glean lessons learned. Although the data on the site cannot be used to determine the frequency of an event (as not all events are reported), they can provide useful information into the types and causes of errors that would be expected.

[22] https://asrs.arc.nasa.gov/.

SECTION 5

Use-Case Specific Considerations

Considerations specific to infrastructure inspection and disaster response & recovery are provided below through two example use cases. These cases combine the information presented in the previous sections to provide a well-rounded analysis of the regulatory and operational aspects of these two use case scenarios. It should be noted that this is not an exhaustive list of possible ATM and human factor considerations, but it provides, at a minimum, what prospective public transportation systems need to consider.

Infrastructure Inspection

As an example, consider a rail inspection operation with a small UAS at an urban public transportation system. The operation will take place in Class B airspace between 0900 and 1100 hours in good weather conditions. The UAS has a planned altitude of 50–100 feet above the track. During inspections, rail operations over this portion of the track will be suspended. The UAS will be a small quadcopter (under 55 lbs) equipped with a camera. An operator will control the UAS with a handheld tablet and will be accompanied by a visual observer. The operator and visual observer will keep the UAS in visual line of sight at all times.

In terms of ATM, in this scenario, the operation will fall under FAA Part 107 but will require authorization from the FAA given that it occurs in Class B airspace. If the UAS operator is Part 107 certified, a visual observer is not required as long as the operator maintains visual contact with the UAS at all times. However, should operations (i.e., rail inspection) require the UAS operator to focus on the tablet for imaging purposes, a visual observer must be used to track the UAS, and the visual observer must also be Part 107 certified. The agency would need to notify the FAA of the planned flight and seek authorization under FAA's Low Altitude Authorization and Notification Capability (LAANC).[23] Under LAANC, the following parameters must be met to be authorized to operate:

- Since a UAS must fly under 400 feet AGL per FAA Part 107, the intended altitude is well within that range.
- A UAS id considered small, as it is under 55 lbs, including any added camera or hardware.
- The UAS operator or visual observer must have a Remote Pilot certificate, and the UAS must be registered with the FAA. [24,25]

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[23]https://www.faa.gov/uas/programs_partnerships/data_exchange/.
[24]https://www.faa.gov/uas/commercial_operators/become_a_drone_pilot/.
[25]https://www.faa.gov/uas/getting_started/register_drone/.

Given the length of the flight, the operation will likely require additional batteries.

Most of the human factors considerations described in Section 4 will apply; however, the impact may vary depending on the specific implementation. In this scenario, the agency should consider the location and path of the UAS operation, the number of operators/individuals involved to ensure that the UAS remains in visual line of sight and within the allowable parameters, and that the UAS operator has the necessary training. The UAS operator should be familiar with the terrain of the planned UAS flight, including proximity to any hazards or obstructions (e.g., tree line, active roadways, neighborhoods). The operator should plan for any unexpected events and communicate the plan to address unexpected events to all individuals involved; for example, where is the UAS planned to fly in the case of a lost link? If operations need to be suspended, how will this be communicated, and to whom should it be communicated? What conditions would lead to the suspension of operations, even if unlikely? This may include a low-flying helicopter, oncoming traffic, or time to change the UAS battery.

Information about the UAS flight plan, including duration, time of day, and relevant contact information for the UAS pilot, should be distributed to all involved individuals. Prior to the flight, the operator should document the weather, check for airspace restrictions or NOTAMs, and review tasks to be completed during flight. Roles and responsibilities should be considered; for example, will the UAS operator work in conjunction with an inspector? Will the inspector review the data in real time with the UAS operator or post-flight? How will dispatch know the location of the UAS operator at all times? How will the UAS operator know that the data collected is sufficient for inspection?

Disaster Response & Recovery

The second example use case is a disaster response & recovery effort after a hurricane. A storm system resulted in flood waters covering major roads/highways and bridges, and conventional search and rescue vehicles cannot be used. Due to compromised ground infrastructure, high-wheeled vehicles, amphibious vehicles, and watercraft need to be used. Due to damage at the nearest airports, manned aircraft cannot be used to aid in the rescue efforts.

With proper coordination between transit agency assets and search and rescue groups, the transit agency is providing all its UAS assets and operators for search and rescue effort. Operations are taking place while moving through floodwaters on a small boat/watercraft and in uncontrolled airspace and will be conducted under 400 feet AGL. The UAS will be a small quadcopter (under 55 lbs) equipped with a camera. An operator will control the UAS with a handheld tablet and will be accompanied by a visual observer. The operator and visual observer will keep the UAS in VLOS at all times. Proper lines of communications will be established to allow for notification of locations in need of rescue.

In terms of Air Traffic Management, in this scenario, the operation will fall under FAA Part 107; however, because the operations are taking place in uncontrolled airspace, no prior notification needs to be provided to Air Traffic Control. Due to operations taking place from a moving vehicle, a Part 107 waiver will be required. Because this is a natural disaster, an expedited waiver can be requested through FAA's Special Governmental Interest (SGI) process. (See Appendix A for a link to the form.) There are limitations to the Part 107 operations that must be adhered to:

- UAS must fly under 400 feet.
- UAS are considered small, as they are under 55 lbs, including any added camera or hardware.
- UAS operator or visual observer must have a Remote Pilot certificate.[26]
- UAS must be registered with the FAA.[27]

Most of the human factors considerations described in Section 4 will apply. Given that there are many unknowns, it is important to develop plans ahead of time. One example is identifying hotspots for potential flooding prior to a natural disaster.

In this scenario, the operators of the UAS should consider the location and search area of the UAS operation, the number of operators/individuals involved to ensure that the UAS remains in visual line of sight and within the allowable parameters, the appropriate notification/communication procedures for recuse notification, and the training necessary for the UAS operator. If more than one UAS will be in operation at a given time, it will be important to ensure that all operations are coordinated (e.g., through a flight coordinator in communication with each UAS operator). This example will also require contingency plans for unexpected events such as knowing the course of action in the case of a lost link (if the UAS is swept up in the wind or sustains water damage). There may be a need to communicate with the public about planned operations in case of questions or concerns. Operations will also need to be carefully planned to account for the battery life of the UAS. As with all operations, information about the UAS flight plan, including duration, time of day, and relevant contact information for the UAS pilot, should be distributed to all involved individuals.

[26] https://www.faa.gov/uas/commercial_operators/become_a_drone_pilot/).
[27] https://www.faa.gov/uas/getting_started/register_drone/.

SECTION

6

Cost-Effectiveness Analysis

This section provides a framework for evaluating the potential efficiency gains from using UAS in public transportation applications. To accomplish this, a cost-effectiveness analysis was conducted, whereby the baseline costs of an application, such as track inspection, is compared directly to a scenario applying UAS technology. This allows for both a direct cost comparison between the baseline and scenario applications and a straightforward means to estimate returns on investment under the UAS scenario. Additionally, a key feature from the cost-effectiveness analysis is the ability to present outcomes in easily-interpretable metrics such as cost per labor hour or per lane- and track-mile.

A cost-effectiveness approach was selected over a more formal benefit cost analysis given the current lack of publicly-available data on the benefits side of the UAS scenario. As discussed in previous sections, there is ample and well-documented qualitative evidence of expected efficiency gains from using UAS in the form of safety, time, and other related costs savings. However, direct benefits cannot be computed without quantitative results from thorough evaluations of applying UAS technology with specific use cases in mind.

Defining the case study to apply the cost-effectiveness framework requires data on the labor and equipment cost under the baseline case in addition to cost associated with UAS technology. This case study focused on standard rail track inspections using Massachusetts Bay Transportation Authority (MBTA) data as an example, but the methodology is easily applied to a range of other potential use cases as well. Track inspections were the preferred case study due to both data availability for estimating baseline costs for routine inspections and the relative ease of applying UAS technology. It also was expected that both track and other related infrastructure inspections are common use cases in the near term, and deriving the potential costs and efficiency gains provides prospective agencies with valuable information to apply to their own systems.

The cost-effectiveness analysis is detailed in the following sections. An accounting of the capital and operating costs of standard UAS technology is followed by details the baseline labor cost estimates for routine track inspections, and a comparison of costs between the baseline and UAS scenario approaches and plausible ranges for the return on investment is presented, concluding with a discussion on the cost-effectiveness application for emergency response & recovery.

Cost of Standard UAS Technology

The unit cost for a typical commercial UAS is generally inexpensive, ranging between $1,000–2,000. However, it is important that an agency consider all cost components associated with UAS, including hardware, data collection and storage, software, training, and other additional equipment needs. Also, although the overall focus of this analysis was on track inspections, these cost estimates also provide a reasonable benchmark for expected costs under most standard applications and use cases.

Hardware

A commercial UAS can vary in price depending on its features and specifications, ranging from less than $1,000 to more than $10,000. However, a standard sUAS costs roughly $2,000. It can be used to take high-quality video and photos for asset inspection and disaster response, the standard use cases presented in this report. The $2,000 cost includes a remote control to fly the UAS, a battery, a charger, a power cable, and other supplementary parts.

However, other hardware accessories are necessary for an asset inspection operation. Standard UAS support micro SD cards up to 128 gigabytes (GB), used to store photos and videos, and photo and video resolution plays a key role in storage needs. If 4k video, the highest quality possible, is used during flights, three 128 GB SD cards are required to store all data captured by the UAS in a day. Each SD card costs about $20, and this analysis assumed that agencies would need five SD cards in case of defects, resulting in an extra $100 in costs. If lower-quality video or photos are taken, agencies may need fewer SD cards, so the $100 figure represents an upper bound. The agency can upload its data into the cloud so it can reuse the SD cards each day. Additionally, since the UAS battery lasts for only 30 minutes, UAS teams will need multiple batteries that can charge in a vehicle when not being used. Most commercial UAS take roughly 70–80 minutes to fully charge, so this analysis assumed each inspection team would need two extra batteries at $200 each for a total of $400. Finally, the inspection team would need a mobile device or tablet compatible with the UAS. Numerous devices are compatible, including cost-effective options of around $165.[29] Table 6-1 summarizes the hardware and associated costs necessary for a daily UAS operation.

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[28]Gettinger & Michael, Analysis of Part 107 UAS Registrations, 2017.

[29]Many UAS can come packaged with controllers that included displays, which are similar in price to acquiring a separate mobile tablet.

Table 6-1

Hardware Inputs and Costs

Hardware	Quantity	Cost per Item	Total Cost
UAS	1	$2,000	$2,000
128 Gb micro SD card	5	$20	$100
Extra battery	2	$200	$400
Mobile tablet	1	$165	$165
Total hardware cost per UAS	–	–	$2,665

Data Storage

Data usage varies based on the video resolution quality the UAS is using. The highest resolution setting on most standard commercial UAS is 4K, which uses approximately 22.5 GB of data per 30-minute flight; the lowest resolution setting is high-definition, which only uses 5.6 GB of data per 30-minute flight.[30] Multiplying these figures over a full 8-hour workday leads to a daily data usage rate of 90–360 GB. Alternatively, some agencies may choose to take photos instead of using video. Standard UAS take 20 megapixel (MP) images. A total of 20 MP photos taken 1 second apart for 30 minutes would use roughly 10 GB of data, which is between the data usage for the lowest and highest video resolutions.

Agencies need to store the videos and photos they are using to analyze how infrastructure changes over time. Data storage costs $0.023 per GB if using a standard cloud service.[31] Multiplying this by UAS data usage results in a daily cost of $2.90–$8.30 and an annual cost of $1,075–$3,022. Table 6-2 summarizes the inputs and costs of a standard UAS asset inspection operation.

Table 6-2

Data Storage Inputs and Costs

Input	Lowest Resolution	Highest Resolution
GB used per flight	5.6	22.5
GB used per day	90	360
Cost of cloud storage per Gb	$0.023	$0.023
Daily cost of cloud storage	$2.90	$8.30
Annual cost of cloud storage	$1,075	$3,022

Software

In addition to hardware and data storage costs, agencies using UAS will need to purchase software to analyze the collected data. Software costs vary based on the complexity and type of analysis agencies want to perform, but software currently on the market that performs 3D mapping for infrastructure management and construction costs $416 a month or close to $5,000 for an annual license. Agencies with multiple UAS will be able to reduce the average cost of software per UAS, as they can incorporate data from several UAS into the program.[32] Agencies may also choose to design their own software, but this

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[30] Note that typical UAS battery life roughly equates to 22–30 minutes of flight time. Further information on battery needs are discussed in the hardware section.

[31] https://aws.amazon.com/s3/pricing/

[32] https://cloud.pix4d.com/store/?=&solution=fields#solution_fields

would be an expensive undertaking given the staffing expertise required to build software capable of UAS data analysis. Table 6-3 shows the lower and upper bounds for monthly and annual costs of using UAS infrastructure management software.

Table 6-3

Software Inputs and Costs

Input	Lower-Bound Cost	Upper-Bound Cost
Infrastructure management software/month	$0	$416
Infrastructure management software/year	$0	$5,000

Training

All staff who operate UAS are federally-required to have a Part 107 license, which has both a direct cost and an opportunity cost (in the form of the employee's hourly wage). To obtain the license, operators are required to pass a written examination, which costs $150 to take, and there are numerous inexpensive online courses that cost around $250 that cover content on the test.[33] The FAA recommends 20 hours of studying before taking the test. When multiplied by the average wage rate for track maintenance inspectors (roughly $25 per hour), this adds $500 in training costs, totaling $900 per operator.[34] Pilots need to renew their license every two years by passing a recurrent knowledge test, which is free of charge. Depending on the scope of operations, public transportation systems may need to apply for additional waivers, such as Part 107.25, Operation from a Moving Vehicle, which would add further administrative/labor costs. Table 6-4 breaks down the costs associated with training UAS operators.

Table 6-4

Training Inputs and Costs

Input	Quantity	Cost
Part 107 license training course	1	$250
Hours of training	20	$500
Part 107 examination	1	$150
Total cost of training per operator	–	$900

Total Cost per UAS

The total cost of procuring and using a UAS for a public transportation system is the summation of costs for hardware, data storage, software, and training.[35] Because storage and software costs have lower- and upper-bound estimates, this analysis provided estimates for both for total UAS costs. Table 6-5 summarizes these calculations.

[33]https://pilotinstitute.com/course/part-107-remote-pilot/?gclid=CjwKCAiAIO7uBRANEiwA_vXQ-1Q1L8fMZZl5qB8WSojXuv4BxkYKf3F_GqeM1bStCYsm60NQVby8lBoCD2wQAvD_BwE
[34]https://www.bls.gov/oes/current/naics4_485100.htm
[35]Training costs are not annual. This analysis assumed one person per UAS would need to be trained each year, but that would not always be the case.

Table 6-5

Total Cost of Using a UAS

Input	Lower-Bound Cost	Upper-Bound Cost
Hardware cost	$2,625	$2,625
Annual data storage cost	$1,075	$3,020
Annual software cost	$0	$5,000
Training cost per person	$900	$900
Total cost of using a UAS	$4,600	$11,545

Baseline Track Inspection

To compare the scale of UAS costs vs. baseline operations, this analysis estimated the labor and equipment cost of standard track inspection without the use of UAS. Public transportation systems do not report annual track inspection costs, so the analysis used three different methods to estimate an average annual cost; all three methods use the MBTA's track inspection scope.[36] The MBTA has 28 total inspectors, working in pairs of 2, who work an average of 9 hours per day, 3 times per week to inspect MBTA's commuter rail tracks. There are 699 miles of track, all almost entirely outdoors except for some small tunnels.[37]

Method 1 – Wage Labor Estimate

This method uses the number of track inspectors, number of hours they work, average wage rate of track inspectors, and a Bureau of Labor Statistics (BLS) benefits multiplier as inputs to estimate annual track inspection costs.[38] First, the number of hours track inspectors work per year was calculated—9 hours per day for 5 days per week and 52 weeks per year—multiplied by 28 workers for a total of 65,520 hours. This was multiplied by the average wage rate and the BLS benefits multiplier, resulting in a cost of almost $2.4 million. Notably, this method does not account for equipment costs, making it a lower-bound estimate.[39] This cost breakdown is summarized in 6-6.

[36]Information on the scope was provided via a phone interview with the MBTA and from MBTA's 2018 Transit Asset Management Plan.

[37]MBTA 2018 Transit Asset Management Plan, https://www.ctps.org/data/calendar/pdfs/2019/MPO_0321_MBTA_TAM_Plan_2018.pdf

[38]This wage rate is based on an average for all urban public transportation systems and does not reflect a specific locality adjustment for the MBTA. The BLS benefits multiplier is a coefficient that reflects the employer costs of benefits such as insurance, paid leave, and disability compensation. The multiplier is necessary to estimate a "fully-loaded wage" or the true cost of an employee to the employer.

[39]The most significant piece of equipment is a Hi-rail, which is attached to a pick-up truck and allows the truck to ride on top of the tracks. This gives inspectors an ideal view to look for defects. Attaining an estimate for Hi-rail equipment is challenging because it can be purchased with the truck or attached separately. Additionally, the equipment is considered a durable good lasting several years, so estimating an accurate annual cost for a public transportation system is difficult without reliable estimates of the equipment cost and finance and discount rates to amortize over the life of capital.

Table 6-6

Method 1 Baseline Track Inspection Cost Estimate

Input	Value
Number of inspectors	28
Hours worked per day per inspector	9
Hours worked per year per inspector	2,340
Total hours worked	65,520
Average wage rate	$25.03
BLS benefits multiplier	1.46
Fully-loaded wage rate	$36.63
Total labor cost for track inspection (total hours * fully-loaded wage rate)	$2,399,998

Method 2 – Labor and Equipment Estimate

Method 2 uses numbers cited by Minnesota DOT's Freight and Rail Planning Director in a *Star Tribune* article, in which he said a rail inspector in Minnesota costs about $120,000 a year in compensation and equipment.[40] Multiplying this by MBTA's 28 rail inspectors results in an estimated cost of $3.36 million.

The first caveat for this estimate assumes that the wage rate of a track inspector in Minnesota is similar to the national average calculated in Method 1 (roughly $87,000 annually). The second caveat is although this method includes the equipment cost associated with rail inspections, it might be an overestimation because it assumes no equipment sharing between pairs of inspectors. Unfortunately, as labor compensation and equipment were bundled into a single estimate, equipment costs cannot be isolated from the MNDOT estimate. Therefore, Method 2 is considered to be an upper-bound cost estimate.

Table 6-7

Method 2 Baseline Track Inspection Cost Estimate

Input	Estimate
Rail inspector cost (includes labor and equipment)	$120,000
Number of rail inspectors	28
Total cost for track inspection	$3,360,000

Method 3 – Rail Inspection Formula Estimate

Method 3 uses an equation to estimate rail inspection cost, where cost of inspection = (track length/inspection vehicle speed) × inspection cost per hour per vehicle, as developed by Liu, Dick, and Saat (2014). The authors communicated with track engineers from a major railroad to determine an average inspection cost per hour per vehicle of $300 and an average inspection vehicle speed of 15–20 mph. The *Star Tribune* article cited an average inspection vehicle speed of 15 mph, which was used in this analysis as an input for Method 3. To calculate annual cost of inspection, the cost of a full track inspection was calculated. Using MBTA commuter rail's 699 miles of track as the track length in the equation resulted in a daily inspection cost of $13,980; MBTA inspects its

[40] http://www.startribune.com/march-30-4-500-miles-of-railroad-worry/253060741/.

tracks 3 times per week, resulting in a weekly cost of $41,940 and an annual cost of $2.2 million. As the study considered only the variable cost of labor, the capital costs associated with the Hi-rail vehicle was similar to Method 1; therefore, the total annual costs derived from Methods 1 and 3 were within 10% of each other. A breakdown of the cost estimate using Method 3 is summarized in Table 6-8.

Table 6-8

Method 3 Baseline Track Inspection Cost Estimate

Input	Value
Track length (mi)	699
Average inspection vehicle speed (mph)	15
Inspection cost per hour per vehicle	$300
Daily inspection cost (track length x speed x inspection cost/hr)	$13,980
Weekly inspection cost	$41,940
Annual inspection cost	$2,180,880

Average Annual Track Inspection Cost Estimate

This analysis triangulated the results of the three methods to get an estimate for MBTA's annual cost for track inspection. The estimate of each method and the resulting average, approximately $2.65 million, are summarized in Table 6-9.

Table 6-9

Average Annual Track Maintenance across Three Estimation Methods

Method	Cost Estimate
Method 1: Wage Labor	$2,399,998
Method 2: Labor and Equipment	$3,360,000
Method 3: Rail Inspection Formula	$2,180,880
Average across three methods	$2,646,959

Comparing UAS Costs to Baseline Track Inspection Costs

Using MBTA as an example, the analysis estimated the percentage increase in cost of incorporating UAS into routine track inspection. If each of MBTA's 14 inspection crews used one UAS, the cost would be $64,400–$161,630 annually, depending on software and data storage used by the agency. This analysis assumed that MBTA would use 3D mapping software, which represents the upper bound for software cost, and would require an average amount of data storage, estimated as the midpoint for the data storage cost range. Therefore, each UAS would cost $10,416, or $145,825 annually. However, there are reasons this cost could be higher or lower for different agencies, depending on the agency's staffing and scope of operations. UAS adoption may require some on-the-job training and experience, which this analysis did not measure. For agencies with less experience using UAS, it will take more time to get operations up and running, and this analysis assumed a seamless adoption rate. Agencies that have not used UAS will likely be using UAS for basic operations to begin with and fall on the lower side of the cost estimate range. However, the cost range may overestimate the annual price of UAS operations as well, as it assumes MBTA would procure new UAS each year.[41]

Furthermore, agencies likely would not fly during the entire course of daily routine inspections. UAS will take additional time to set up and swap out batteries and may experience some technical issues. As a result, this analysis likely overestimated data storage costs and efficiency gains from using UAS. The $145,825 annual cost estimate for MBTA's operations is conservative, especially given high software costs, but agencies with smaller operations can use the lower bounds from individual cost components if these costs would be more applicable.

Ultimately, the annual UAS cost estimate of $145,825 for MBTA is 5.5% of its estimated total annual track inspection cost of $2.65 million, suggesting that if MBTA had a combination of safety, performance, and efficiency gains of 5.5% by using UAS in its track inspection, investing in UAS would be cost-effective.

Safety benefits, performance improvements, and exact travel time savings are difficult to measure without data such as the decrease in inspection-related injuries or the increase in switch deficiencies identified that UAS can provide in track inspections. Without these data, this analysis estimated efficiency gains three ways—increases in equipment inspection speed, decrease in cost of a full track inspection, and increases in inspection time savings.

Currently, Hi-rail trucks that drive on top of tracks travel at 15 mph, where UAS can travel up to 40 mph, and trucks can ride alongside the track rather than on top of it, following the UAS. There may be instances in which a rail line moves away from the road, and trucks would need to take a detour to continue following the UAS. However, UAS would need to travel an average of only 0.83 mph faster to increase efficiency gains by 5.5%, and the gains have the potential to be much larger. A 1.5-mph average increase would lead to a 10% efficiency gain, and a 2.25-mph average increase would lead to a 15% efficiency gain. Therefore, even if a truck must take a small detour, the increased speed would likely still result in efficiency gains.

Using Liu, Dick, and Saat's equation, equipment inspection speed increases would also increase track miles covered per day, which could, in turn, decrease the cost of a full inspection. Using MBTA as an example and keeping its 699 track miles constant, a full inspection cycle would cost $733 less with a 5.5% efficiency gain, $1,270 less with a 10% efficiency gain, and $1,820 less with a 15% efficiency gain.

An alternative way to measure efficiency is through time savings rather than equipment speed increase. For current track inspections, inspectors need to stop, exit their trucks, and write notes if they see a track flaw. UAS allow

[41]Comparing UAS Costs to Baseline Track Inspection Costs

inspectors to ride continuously, as even if the inspectors see a problem, the UAS captures a visual record that can be analyzed later or sent directly to an operations center. If UAS save inspectors 26 minutes on an 8-hour track inspection route, it would lead to a 5.5% efficiency gain, making it a cost-effective investment; a 48-minute decrease would lead to a 10% efficiency gain, and a 72-minute decrease would lead to a 15% efficiency gain.

The three methods for measuring efficiency gains are summarized in Table 6-10.

Table 6-10

Different Measures of Efficiency Gains

Efficiency Gain	Increase in Equipment Speed	Decrease in Cost of Full Track Inspection	Time Savings per 8-Hour Inspection Route
5.5% (breakeven point)	0.83 mph	$733	26 min
10%	1.5 mph	$1,270	48 min
15%	2.25 mph	$1,820	72 min

UAS also provide benefits to public transportation systems beyond efficiency gains by capturing information that the human eye might miss and providing a permanent visual record that can be compared over time. UAS, therefore, has the potential to lead to safety benefits such as fewer train derailments, and other accidents that may be caused by repeated human error, such as a missed visual inspection.

However, although UAS can improve safety, performance, and efficiency for track inspections, it may not be a direct substitute for inspections in all scenarios. MBTA conducts two types of track inspections—visual and mechanized. Visual inspections check for switch, turnout, and track crossing issues, and mechanized inspections look for internal rail defects, track geometry, and other structural issues.[42] Mechanized inspections are less routine than visual inspections and are required to be conducted only once per year. Due to current technology and regulatory restrictions, UAS cannot replace Hi-rail for these inspections, as mechanized inspections require a vehicle to weigh down on the track to detect internal rail defects and track geometry.

UAS may encounter some issues during visual detections as well; it may flag rain, snow, and other natural elements that do not need to be reviewed, leading to false positives and false negatives that could reduce some of the other efficiency gains UAS offer.

[42]MBTA Transit Asset Management Plan." September 2018. Massachusetts Bay Transportation Authority, https://www.ctps.org/data/calendar/pdfs/2019/MPO_0321_MBTA_TAM_Plan_2018.pdf

Therefore, the values illustrated in Table 6-10 still reflect the potential efficiency gains UAS can bring to track inspections; however, to reach those levels of efficiency gains, public transportation systems will need to account for the gradual implementation of UAS into their routine inspections and the possible limitations of UAS technology in its current state.

Disaster Response & Recovery Use Case Cost Estimate

A full cost-effectiveness analysis for disaster response & recovery was not attempted, as there are very little cost data on transit disaster response operations and the scope of operations varies considerably based on the type of disaster. However, there are certain steps a public transportation system should take in determining if UAS could save costs in disaster response.

First, an agency should determine the baseline cost for current disaster response & recovery operations. This can include labor, vehicles such as boats and helicopters, and other important equipment such as cameras and tools to measure the impact of a disaster.[43] Second, agencies should determine the frequency of these responses. If it is a significant cost to procure and use UAS, then it may not be worth the additional cost for agencies that would use them infrequently.

There is precedent for UAS being used to help disaster response. For example, the University of Vermont uses UAS to map ice jams, flood conditions, and storm damage, which helps transportation officers in determining the resources necessary to repair roads and other infrastructure.[44] This can save time in evaluating damage and can help agencies budget for repairs.

When evaluating cost savings for disaster response & recovery, agencies should assess the equipment and labor costs UAS could save. Agencies that need to use helicopters and other expensive vehicles may benefit the most from adding UAS to their operations. Additionally, the ability for UAS to easily map infrastructure and geographic areas can improve resiliency, so agencies can better prepare contingency plans in the case of disasters, reducing the cost of the disaster response.

Smaller and more rural public transportation systems could also consider splitting the cost of a UAS with other nearby agencies for disaster response. This could be particularly helpful for agencies that experience similar types of disasters.

[43]A standard helicopters costs $1,600/hr. https://www.seeker.com/rescued-at-sea-who-foots-the-bill-1768448609.html

[44]http://www.uvm.edu/~uas/?Page=CaseStudies.php

SECTION

7

Evaluating Future UAS Applications

Although the results from the cost-effectiveness analysis are encouraging, they are preliminary estimates only. Similarly, although aspects from ATM and human factors considerations will apply across applications, some aspects will be dependent on the specific UAS application in public transit. Therefore, if FTA is to consider funding opportunities to support the development of UAS applications, conducting formal evaluations of potential use cases will ensure that Federal funding is allocated in the most informed and cost-effective manner. Before conducting an evaluation, however, criteria and related parameters should be established to assist FTA in determining the types of agencies to support and the method of evaluation for a given use case.

Demonstration and Evaluation Approaches

Whereas some public transportation systems have begun to use UAS, their use is not yet widespread, so FTA-sponsored demonstrations and evaluations could provide useful information both for public transportation systems considering using UAS and for FTA staff identifying ways to support their use in appropriate applications.

This section focuses on the necessary criteria for demonstrations and operational evaluations with the goal of strengthening the business model for transit UAS use cases.:

- Likelihood of attracting agencies that sufficiently represent the overall potential market
- Addressing data and knowledge gaps
- Data collection and estimating benefits and costs of the UAS application
- Measuring the uncertainty of private sector outsourcing

Sufficiently Representing the Overall Market

Future research and use case considerations could take multiple directions depending on an agency's goals and needs. It will be important for FTA to balance common themes across use cases, attracting prospective agencies that sufficiently represent the potential market. For example, nearly every public transportation system would benefit from additional emergency response and resiliency planning; however, if it is determined that most public transportation systems would lack the expertise or resources to carry out these use cases successfully, then it would be more appropriate to start with a narrower focus. Given the likelihood that most public transportation systems will have generally little to no experience in adopting UAS technology, starting small and building up a UAS program should capture a more accurate representation of the market. For instance, FTA could consider framing demonstrations and accompanying evaluations to:

- Start infrastructure inspections limited to certain segments of road, track, or specific bridges; these could be designed as pilot programs within an agency to base and design more sophisticated future operations.
- Assist in targeting the correct aspect of operations that could use UAS and use an evaluation to assess possible limitations; for example, UAS cannot replace all components of a bridge inspection but it can cover many aspects that would be considered routine.
- Test a waiver process that allows for growth in institutional knowledge of the process.
- Develop standard training practices for new inspectors and UAS operators.
- Test cooperative cost-sharing or asset-sharing across small metro or rural agencies to assess if these arrangements could enable successful, cost-effective application of UAS by smaller agencies.

These options lay the groundwork for further expansion and, ultimately, a successful, cost-effective adoption of the use case.

Addressing Data and Knowledge Gaps

A central goal for the evaluation of UAS use cases is to determine the current knowledge gaps for local public transportation systems seeking to apply UAS technologies and FTA knowledge gaps at the funding level. This report has outlined some important steps to be considered for lawful and safe UAS operations. These steps, however, do not address specific demands and unique situations at the local transit level or the possible resource allocations and funding decisions at the Federal level. Agencies may have more success when applying for certain types of Part 107 waivers (e.g., operations from a moving vehicle vs. nighttime operations) or have lessons learned that could lead to additional human factors considerations. Also, the cost-effectiveness section provides data only on the direct capital and training costs associated with adoption, leaving uncertainty around the actual cost specific to on-the-job training and how it relates to operational learning curves.

These knowledge gaps can be addressed through comprehensive data collection in cooperation with agencies participating in a demonstration and help inform whether UAS adoption is more cost-effective than current operations. Additionally, addressing knowledge gaps will contribute to a more efficient and swift adoption of successful use cases.

Data Collection and Estimating Benefits and Costs

Evaluating the success from a funding perspective will require data collection from a number of different sources. First, a detailed analysis of the current baseline approach that documents current operations, associated costs, and levels of performance is needed. The agency should then define key metrics of interest that can be compared across the baseline and UAS scenario. These metrics will also be dependent on the type of application considered. Examples could include the following:

- Benefit-cost analysis of rail inspections using the time per inspection under the baseline case compared to the alternative using UAS
- Analysis of waiver application best practices for common waiver requests
- Metrics of safety, such as number of risks identified (e.g., as part of track inspection) and the time/actions required to mitigate the risk
- Amount of training required per inspector in terms of time and cost
- Impact of inspections on schedule of operations (e.g., delays or impact to passengers before and after technology adoption)

Assessing Likely Private Sector Service Provision

In some cases, it may be more cost-effective or efficient if certain UAS applications are outsourced to private contractors as opposed to full-scale implementation by the local public transportation system. Based on the analysis in this report, this situation would likely apply primarily to agencies that either lack the routine tasks that make UAS adoption cost-effective or those that are labor- and/or financially-constrained. A demonstration could be structured to assess the cost-effectiveness of in-house adoption of UAS compared to outsourcing by including a range of sizes and types of agencies and business models. Comparing cost-effectiveness evaluations across these different situations could enable FTA to provide information to public transportation systems about what would be the best approach for their situations and assess how quickly UAS use might be adopted by different types of agencies, based on likely cost savings.

SECTION

8

Summary and Conclusion

This study sought to extend the use of UAS technology to public transportation systems, with a focus on two envisioned use cases, infrastructure inspection and disaster response & recovery. The implementation of UAS for public transit was considered from ATM, human factors, and cost-effectiveness perspectives. Commercial UAS operations are permitted under Title 14 of the Code of Federal Regulations, Part 107. Some UAS operations within VLOS may be permitted with no additional approvals from the FAA; however, operations that extend BVLOS, occur at night, from a moving vehicle, or over people will require a waiver to Part 107. This report outlines the high-level process to develop and submit a request for a waiver and guidance on where to find additional information from the FAA.

It is important to consider human factors in the development and implementation of a UAS operation to ensure that procedures are clear, roles and responsibilities are understood, and plans are in place for unexpected events. Training should focus on both Part 107 operations and the task specific to the agency. Specific considerations, at a minimum, for pre-flight, during flight, and after flight are provided. It is important to share lessons learned among operators to understand and develop mitigations for common errors. These ATM and human factors considerations are applied to each of the notional use cases.

To examine the cost-effectiveness of a UAS implementation for infrastructure inspection or disaster response & recovery, it is important to consider baseline costs and compare them with what is necessary to develop and implement UAS technology. This comparison includes labor and wages as well as hardware, software, training, and data storage costs.

Based on these three perspectives—ATM, human factors, and cost-effectiveness—the use of UAS technology for infrastructure inspection and disaster response & recovery is permitted under current regulations, is operationally feasible, and may offer some cost-savings.

Future evaluations should consider how best to deploy Federal funds and leverage lessons learned in UAS implementations across agencies. Other specific criteria for an evaluation may include the size and location of the market for applying UAS technology to public transit, capturing and addressing knowledge gaps through data collection, assessing improvements in safety and efficiency, and the anticipated costs of developing and implementing a UAS program.

ACRONYMS AND ABBREVIATIONS

AGL	Above Ground Level
ATC	Air Traffic Control
ATM	Air Traffic Management
BLS	Bureau of Labor Statistics
BVLOS	Beyond Visual Line of Sight
CFR	Code of Federal Regulations
DAA	Detect and Avoid
DOT	Department of Transportation
EVLOS	Extended Visual Line of Sight
FAA	Federal Aviation Administration
FTA	Federal Transit Administration
GB	Gigabyte
LAANC	Low Altitude Authorization and Notification Capability
MBTA	Massachusetts Bay Transportation Authority
MP	Megapixel
MSL	Mean Sea Level
NCHRP	National Cooperative Highway Research Program
NOTAM	Notice to Airman
SGI	Special Governmental Interest
sUAS	Small Unmanned Aircraft System
UAS	Unmanned Aircraft System
VLOS	Visual Line of Sight

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APPENDIX

A

Requesting a Part 107 Waiver

Where to Apply

All waivers are processed through FAA's DroneZone. To file for a waiver, you must create a DroneZone account. The sections below outline the process and what information is needed in sections before applying for a Part 107 waiver.

FAA will review and approve or disapprove waiver requests within 90 days of submission.

Waiver Application

The following are required for completing a Part 107 Waiver in DroneZone:

- Determine the operation in which a waiver is needed. Waivers must be obtained for any operation that falls outside Part 107 rules.
  - Request a waiver for only what is needed to complete intended operation
    - Operations from a Moving Vehicle or Aircraft – § 107.25
    - Operations other than Daylight Operations – § 107.29
    - Operations Beyond Visual Line of Sight – § 107.31
    - Operations With Limited visual Observers – § 107.33
    - Operations of Multiple Small UAS – § 107.35
    - Operations Yielding Right of Way – § 107.37(a)
    - Operations Over People – § 107.39
    - Operations Over sUAS 107 Limitations – § 107.51
- Follow FAA Part 107 Operational Waiver Application instructions
  - Document explains sections requiring details in the waiver application process:
    - Acknowledgement
      - o Operation Title
      - o Responsible Party Information
      - o Pilot
    - Waiver Application
      - o Which regulation waiver being sought (refer to 1.a above)
      - o Waiver Safety Explanation
      - o Operation Parameters
    - sUAS Details

Guidelines for Waiver Safety Explanation

Each waiver requires a Waiver Safety Explanation field from the list below. More details can be found on the Waiver Safety Explanation Guidelines website.

- Operational Details
- sUAS Details
- Pilot/Personnel Details
- Describe Operational Risks and Mitigations

Additional Operational Risks and Mitigations questions to be answered in the Waiver Safety Explanation can be found at Operational Risks and Mitigations Questions, which provides questions to answer when applying for any 107 waiver.

Emergency Operations Request Form

This Emergency Operations Request Form is used by first responders and other organizations to request an emergency Part 107 waiver in the case of a natural disaster or emergency.

Part 107 Waiver Helpful Links

- Part 107 Waivers – Detailed information on waivers, choosing which waiver is needed and how to fill out a Part 107 Waiver
- How To Identify, Assess & Mitigate Risks Posed to Your Drone Operation – Information on how to properly identify, assess and mitigate risks related to a proposed drone operation
- Waiver Safety Explanation Guidelines for Part 107 Waiver Applications – A guide to help fill out the Waiver Safety Explanation field in the DroneZone operational waiver application
- Part 107 Operational Waiver Application Instructions – Further details of what information is needed in 107 waiver sections
- Operational Risks and Mitigations Questions – Detailed questions associated with each waivable section of Part 107.
- Sample Safety Justifications for Small Unmanned Aircraft System (UAS) or Drone Waivers – A representative sample of the safety justifications for UAS waivers and airspace authorizations; provides PDFs of sample waiver authorizations

- How-To Apply for a Drone Waiver – Webinar on how to apply for a 107 waiver.
- How-To Properly Prepare a Drone Safety Case – Webinar on how to properly prepare a drone safety case.
- Emergency Operations Request Form – First responders and other organizations responding to natural disasters or other emergency situations may be eligible for expedited approval through the FAA's SGI process.

APPENDIX

B

U.S. Airspace VFR Visibility Requirements

Basic VFR Weather Minimums				
Airspace			Flight Visibility	Distance from Clouds
Class A			Not applicable	Not applicable
Class B			3 statute miles	Clear of clouds
Class C			3 statute miles	1,000 feet above 500 feet below 2,000 feet horizontal
Class D			3 statute miles	1,000 feet above 500 feet below 2,000 feet horizontal
Class E	At or above 10,000 feet MSL		5 statute miles	1,000 feet above 1,000 feet below 1 statute mile horizontal
	Less than 10,000 feet MSL		3 statute miles	1,000 feet above 500 feet below 2,000 feet horizontal
Class G	1,200 feet or less above the surface (regardless of MSL altitude).	Day, except as provided in section 91.155(b)	1 statute mile	Clear of clouds
		Night, except as provided in section 91.155(b)	3 statute miles	1,000 feet above 500 feet below 2,000 feet horizontal
	More than 1,200 feet above the surface but less than 10,000 feet MSL.	Day	1 statute mile	1,000 feet above 500 feet below 2,000 feet horizontal
		Night	3 statute miles	1,000 feet above 500 feet below 2,000 feet horizontal
	More than 1,200 feet above the surface and at or above 10,000 feet MSL.		5 statute miles	1,000 feet above 1,000 feet below 1 statute mile horizontal

Note: Basic VFR Weather Minimums are for manned aircraft. UAS operations must follow Part 107 Visibility Regulations.

Figure B-1

Airspace VFR Visibility Requirements

U.S. Department of Transportation
Federal Transit Administration

U.S. Department of Transportation
Federal Transit Administration
East Building
1200 New Jersey Avenue, SE
Washington, DC 20590
https://www.transit.dot.gov/about/research-innovation