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FINAL REPORT

Field Test Based Guidelines Development for the Integration of Unmanned Aerial Systems (UASs) in GDOT Operations

GDOT
Georgia Department of Transportation

OFFICE OF PERFORMANCE-BASED MANAGEMENT AND RESEARCH
15 KENNEDY DRIVE
FOREST PARK, GA 30297-2534

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16. Abstract: This project aimed at developing guidelines for the integration of Unmanned Aerial Systems (UASs) in Georgia Department of Transportation (GDOT) operations based on the experience and lessons learned from field tests with UAS technology on selected tasks performed by several groups within GDOT. The research team conducted three focus group sessions with seventeen individuals from the Construction, Bridge Maintenance, and Intermodal groups. The main purpose of the focus group sessions was to identify tasks that could benefit from the use of UAS and that could be tested in the field. A total of seven locations were selected for field tests including 2 airports, 2 rail segments, 1 road construction site, and 2 bridges. During the field tests, several UAS platforms were used to collect various data types including still images, infrared images, and videos. Flights were performed in both manual and automated modes. After data was collected, it was processed and de-briefing meetings were held with participants to collect feedback on usefulness of the process and results. After gaining insights from GDOT personnel who participated in the field tests, recommendations for integration guidelines where developed and presented in the accompanying report. The results of this study could lead implementation of UAS from GDOT tasks of the groups included and possibly at GDOT more broadly.

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GDOT Research Project No. 16-09

Final Report

Field Test Based Guidelines Development for the Integration of Unmanned Aerial Systems (UASs) in GDOT Operations

Javier Irizarry, Ph.D., P.E.
Associate Professor of Building Construction

Eric N. Johnson, Ph.D.
Professor of Aerospace Engineering

Sungjin Kim
Graduate Research Assistant

Kyuman Lee
Graduate Research Assistant

Daniel Paes
Graduate Research Assistant

Georgia Institute of Technology

Contract with

Georgia Department of Transportation

In cooperation with

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Federal Highway Administration

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Executive Summary

In April of 2016, a team from the Georgia Institute of Technology entered into a research project to develop guidelines for the use of Unmanned Aerial Systems (UASs) in Georgia Department of Transportation (GDOT) operations. These guidelines would be based on the lessons learned from field tests with personnel from the Intermodal, Bridge Maintenance and Construction groups at GDOT. Unmanned Aerial Systems are comprised of a control station for a human operator and one or more Unmanned Aerial Vehicles (UAVs). The utilized UAVs can be equipped with various sensors, such as video or still cameras, including far and near infrared, radar or laser based range finders, or specialized communication devices. The ground stations utilized by the human operators can vary from portable computer based systems to fixed installations in vehicles or dedicated control rooms. Several off-the-shelf UAS devices were employed in the research study. These included multirotor as well as fixed wing platforms.

The project lasted for a period of two-years and the research team conducted focus group sessions with seventeen individuals from the three GDOT groups included in the study. The results of these sessions allow the research team to identify the tasks that would be used for field testing with UAS integration. A total of seven locations were selected for field tests including 2 airports, 2 rail segments, 1 road construction site, and 2 bridges. During the field tests, several UAS platforms including quadcopters, hexacopters, and fixed wings were used to collect various data types including still images, infrared images, and videos. Flights were performed in both manual and automated modes with the use of mission planning applications. After data was collected, it was processed with photogrammetry software. De-briefing meetings were held with study participants from each of the three groups to collect feedback on usefulness of the process and results. After gaining insights from GDOT personnel who participated in the field tests, recommendations for integration guidelines where developed. The recommendations consider the Federal Aviation Administration's regulations as of the writing of the final report. The guidelines address UAS operations planning and execution, equipment and data management, and UAS operating personnel requirements. The results of this study could complement GDOT's plans for implementation of UAS technologies into operations that can benefit from improved safety of personnel as well as efficient use of resources.

Keywords: Unmanned Aerial Vehicles, Unmanned Aerial Systems, Integration Guidelines, Inspections.

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    - Risk Management and Legal: Robert Maguire, Annette Simelaro
    - HERO: John Sibely, Daniel Harneir
- Industry Partner - Skysight Imaging: Rick Dobbins

List of Acronyms

2D	Two Dimensions / Two-dimensional
3D	Three Dimensions / Three-dimensional
AE	Aerospace Engineering (School)
ASHT	Arkansas State Highway and Transportation Department
BC	Building Construction (School)
BMG	Bridge Maintenance Group
CAD	Computer Aided Design
CFR	Code of Federal Regulations
CG	Construction Group
COA	Certificate of Waiver or Authorization
DEM	Digital Elevation Model
DOT	Department of Transportation
DSM	Digital Surface Model
FAA	Federal Aviation Administration
FC	Facility Coordinator
FDOT	Florida Department of Transportation
FG	Focus Group
FHWA	Federal Highway Administration
FOI	Features of Interest
GCP	Ground Control Point
GCS	Ground Control Station
GDOT	Georgia Department of Transportation
GIS	Geographic Information System
GPS	Global Positioning System
GT	Georgia Tech
HERO	Highway Emergency Response Operators
IDOT	Illinois Department of Transportation
IG	Intermodal Group

KDOT	Kansas Department of Transportation
LiDAR	Light Detection and Ranging System
MDOT	Michigan Department of Transportation
MnDOT	Minnesota Department of Transportation
NAS	National Airspace System
NCDOT	North Carolina Department of Transportation
NDE	Non-Destructive Evaluation
NHDOT	New Hampshire Department of Transportation
ODOT	Ohio Department of Transportation
PE	Project Engineer
PIC	Pilot In Command
PMC	Person Manipulate Control
RABIT	Robotic Assisted Bridge Inspection Tool
TSB	Time Synchronization Board
TSP	Traveling Salesman Problem
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UDOT	Utah Department of Transportation
VDOT	Virginia Department of Transportation
VO	Visual Observer
VTOL	Vertical Take-Off and Landing
WSDOT	Washington State Department of Transportation

1. Introduction

1.1. Overview

Unmanned Aerial Systems (UASs) are increasingly being considered for government and civilian applications in the United States. In 2015, the Federal Aviation Administration (FAA) established policies and certification requirements for UAS integration into the National Airspace System (NAS). However, a number of issues impede the integration of unmanned aircraft into the manned airspace. Currently, unmanned aircraft are allowed to operate under specific conditions that comply with established regulations. Exceptions to these regulations are determined on a case-by-case basis through the FAA waiver framework. Nevertheless, the effectiveness of UASs in civil applications has not been clearly determined under these conditions, specifically in tasks such as those performed by the Georgia Department of Transportation (GDOT). Aiming at understanding and determining the advantages and limitations of UAS adoption by GDOT, as well as its legal, societal, and operational implications, this research conducted various controlled tests (i.e., structured interviews, surveys, field tests, and other activities). The results of these tests were used to develop recommendations for FAA-compatible guidelines for integrating those systems into GDOT operations.

UASs were first widely adopted in military operations and now occupy a permanent position in the military arsenals of many countries (Nisser and Westin, 2006). Current civilian applications of such systems include the following:

- border patrol
- search and rescue

- damage assessment during or after natural disasters (e.g. hurricanes, earthquakes, tsunamis)
- locating forest fires
- identifying farmland frost conditions
- monitoring criminal activities
- mining activities
- advertising
- scientific surveys
- securing pipelines and offshore oil platforms (Anand, 2007).

Several other studies have investigated the application of UASs in the agriculture, forestry, archeology, architecture, and construction industries.

A UAS consisting of a rotary wing aircraft with several sensor devices and the ability to hover for extended periods is a well-suited platform for studying UAS applications, e.g., autonomous surveillance/navigation (Krajník et al., 2011), human-machine interaction (Ng and Sharlin, 2011), and sport training assistance (Higuchi et al., 2011). In a study conducted by Irizarry et al. (2012), a UAS quadcopter was used to explore the benefits of providing safety managers with still images and real-time video from a range of locations on a construction jobsite. Another study conducted by Rosnell and Honkavaara (2012) showed how virtual point clouds can be generated from image sequences collected by small UASs. A similar study in Finland by Lin et al. (2013) proposed a novel aerial-to-ground remote sensing system for surveying land scenes of interest. The literature review section of this report presents several examples of such studies.

Continuous improvements in UAS functionality and performance create opportunities for applied research on integrating this leading-edge technology into various applications. Several departments of transportation (DOTs) across the U.S. have started to explore the use of UASs for various purposes, from tracking highway construction projects and performing structure inventories, to road maintenance and roadside environmental condition monitoring, among many other surveillance, traffic management, and safety applications. In early 2013, the Georgia DOT (GDOT) started to investigate which of its operations could be optimized with UAS adoption. Four GDOT divisions with the highest potential of benefitting from UAS technology were identified as Construction, Engineering, Intermodal, and Permits & Operation. In order to determine the operational and technical requirements for the use of a UAS by a given division, it must identify its operations/tasks and personnel needs to establish a thorough understanding of its goals, work environment, and internal decision-making processes. Each division's detailed information was processed into a set of requirements that guide the integration of UASs into its operations. As a result, five potential UAS configurations were identified (Irizarry and Johnson, 2014).

Most tasks within the GDOT divisions studied are governed by an information-sharing process focused on collecting and supplying relevant information to the involved groups. To establish a better understanding of the work dynamics and environment conditions, the research team characterized each task by attributes such as location and completion time. In summary, the analysis of GDOT tasks provides insight into the operational and technical requirements for integration of UASs into its divisions (Karan et al., 2014; Gheisari et al., 2015).

1.2. Research Objectives

This research project refers to the second phase of the 2013 GDOT study (hereinafter referred to as Phase 2). The objectives of this study are as follows: (1) to determine the technological feasibility of utilizing UASs in the operations of GDOT divisions; (2) to understand the advantages and limitations of UAS adoption (as well as its legal, safety, and privacy implications) for tasks identified from the analysis of GDOT divisions; (3) to propose FAA-compatible guidelines for integrating such systems into GDOT operations; and (4) to hold a workshop for GDOT personnel about the use of UAS technology for the investigated tasks.

1.3. Research Methodology

The research activities involved deep collaboration with GDOT personnel throughout Phase 2. Figure 1-1 presents a flowchart of the research work plan, and is followed by a description of the following related activities:

- Activity 1- Definition of tasks and selection of UAS platforms for field testing
- Activity 2 - Performance of field tests
- Activity 3 - Usability evaluation and development of UAS integration guidelines
- Activity 4 - UAS workshop (concurrent with other phases).

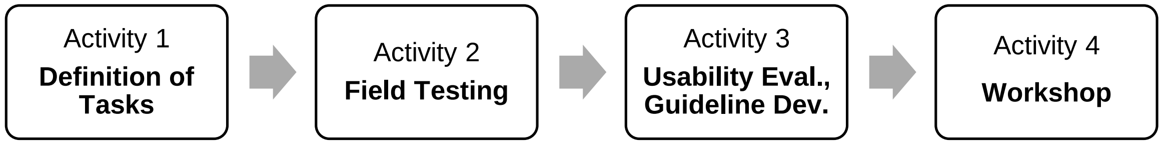


Figure 1-1: Work plan flowchart

Activity 1: Definition of Tasks and Selection of UAS Platform

In this activity, the research team performed focus group (FG) sessions with GDOT personnel in the Intermodal, Construction, and Bridge Maintenance divisions, to define the tasks to be performed during the field tests. From the focus group input, the research team generated a detailed list of procedures, resources, and processes followed by GDOT personnel to complete their respective tasks. Next, the team analyzed the tasks to determine which UAS platform and related technology is best suited for integration into each one. The last step of this activity involved the design of field tests to be conducted for selected tasks.

Activity 2: Field Testing of Selected Tasks

During this activity, the research team developed the schedule for the field tests. The estimated test period and number of tests is presented below in the work plan schedule section. Tests were to be conducted according to the field test design developed in the first activity. To understand the impact of UAS use for the selected tasks, parts of these field tests involved data collection on task performance and cost analyses. The research team compared the baseline data obtained during Activity 1 to the field test data. The field tests complied with current FAA regulations applicable to the operation of UASs in the national airspace. The results of the tests have been broadly disseminated and are being used by the FAA to develop future regulations on UAS usage by agencies such as GDOT.

Activity 3: UAS Integration Guideline Development and Use Implication Analysis

This activity involved the development of guidelines for the integration of UASs into the tasks tested in Activity 2. The guidelines were developed to observe current FAA regulations, but the research team also considered regulations that are currently under development by the FAA. In this phase, the team analyzed and reported on the legal and societal implications of UAS integration into the tasks examined in the study and performed in general GDOT operations. Data for this analysis were collected through a literature review, surveys, and interviews with various groups or stakeholders who may have concerns regarding UAS use.

Activity 4: Workshop Development and Delivery

In this activity, the research team developed and conducted a workshop for GDOT personnel. The topics of the meeting were informed by the outcomes of the field tests. The four-hour workshop was delivered at Georgia Tech facilities at the end of the first year of the research study. Selection of attendees was coordinated with personnel in the Office of Performance-Based Management and Research.

1.4. Expected Results

The expected results of the research project include the following:

- experience in the integration of UASs into GDOT operations

- knowledge about the safety and legal implications of GDOT UAS use
- knowledge about UAS performance and cost implications in selected GDOT tasks
- UAS integration guidelines for selected GDOT tasks
- increased GDOT personnel understanding of UAS technology in general.

2. Literature Review

This section presents a review of recent and relevant UAS initiatives undertaken by DOTs across the United States, as well as an overview of specific UAS efforts in key areas related to construction and bridge maintenance.

2.1. UAS Applications in State Departments of Transportation

The ***Arkansas State Highway and Transportation Department*** (Frierson, 2013) explored different UAS platforms for real-time traffic monitoring and the inspection of highways and bridges. The study did not include field experiments with the platforms, due to FAA regulations and schedule constraints.

In a ***Caltrans*** study in 2014, the primary goals were to learn more about the use of UASs in geotechnical field investigations, and to better understand the legislative issues involved (Karpowicz, R., 2014). The report developed a discussion of the role of FAA regulations, and a review of other state agencies' studies on UAS applications. The study recommends that proof-of-concept testing be conducted in advance of using UASs in transportation-related tasks and field inspections. In 2008, ***Caltrans*** designed a Vertical Takeoff and Landing (VTOL) aerial robot named "Aerobot" for inspection of bridges and elevated structures. At the time, the goal was to investigate and improve the robot's capabilities and performance. However, due to implementation issues, it was never tested in the field (Moller, 2008).

The ***Florida Department of Transportation*** developed an approach to using UASs for inspections of bridges and high mast luminaires (Otero, et al., 2015). The approach involved using a small UAS equipped with high-resolution cameras to provide real-time data. FDOT also conducted proof-of-concept tests to gain insight into the limitations of the proposed approach. The study assessed the UAS platform components and data quality under varying conditions, such as altitude, payload, and maneuverability. Major outcomes included a set of structured UAS-based maintenance procedures, as well as estimates of operator training times and of inspection, equipment, and editing costs.

The ***Georgia Department of Transportation*** looked into the economic and operational benefits of using UASs in its operations (Irizarry and Johnson, 2014). The study began with the definition of all GDOT division operations that could benefit from UAS use. Semi-structured interviews were conducted with potential GDOT UAS operators in order to identify their goals, all major decisions involved in accomplishing these goals, and the information required in the decision-making process. Several UAS platform configurations were recommended for potential application.

The ***Michigan Department of Transportation*** assessed five different UAS platforms comprising optical, thermal, and LiDAR sensors, in various applications (e.g., bridge inspection, roadway asset inspection, and traffic monitoring). The researchers performed field tests at two bridges, two pump stations, two traffic monitoring sites, and one roadway asset site (Brooks et al., 2015). The department developed an implementation action plan (IAP) encompassing bridge, roadway, and confined inspections, as well as traffic monitoring with improved LiDAR and thermal data processing. The study recommended eight UAS-related topics for future research: 1) Operations and maintenance uses and costs; 2) Data processing and analysis; 3) Slope stability assessment; 4) More formal crash scene imaging; 5) Aerial imaging to meet MDOT survey supports; 6) Optimal methods to store and share large data sets; 7) Improvements in thermal imaging; and 8) Improvements in UAS positioning.

The ***Minnesota Department of Transportation*** also investigated a UAS-based bridge inspection method (Zink and Lovelace, 2015). The researchers identified four bridges in Minnesota for field tests with various UAS platforms, to evaluate safety issues, FAA rules, and inspection methods. The three formats of the visual assets collected were as follows: 1) still images, 2) videos, and 3) infrared images. The research also involved the development of 3D models of bridge elements and site locations. The study found that UASs are indeed effective tools for providing critical information for planning cost-effective large-scale inspections.

The ***Ohio Department of Transportation*** tested UASs for the collection of aerial imagery and developing 3D models of sites (Fred, 2013). The 3D point cloud representations of surfaces improved site visualization and analysis. The researchers used the Pix4D software application to process the data into highly geospatially accurate orthorectified images. These images were then added to the ODOT Geographic Information System (GIS) database. Future ODOT plans involve exploring different UAS platforms for bridge condition assessment.

A study by the ***Utah Department of Transportation*** focused on UAS use on highway projects (Barfuss et al., 2012). The researchers employed a UAS to collect aerial images during and after the completion of a highway corridor project, allowing UDOT to develop a visual chronological record of the construction process. The high-resolution images were also used to update the department's GIS database, and to identify wetland plant species at Lake Utah. The study concluded that UASs are indeed efficient tools for the collection of real-time data and the documentation of the construction process.

West Virginia University and the ***Virginia Department of Transportation*** together developed and tested a UAS named "Foamy," which had been designed for jobsite management and traffic monitoring (Gu, 2009). Two field tests of the UAS found a significant number of positioning estimation errors. The researchers performed error analyses to identify the factors affecting positioning accuracy. To improve accuracy, a time synchronization board (TSB) was added to the UAS.

The ***Washington Department of Transportation*** conducted field tests with UASs on hills above state highways (McCormack and Trepanier, 2008). Specifically, the department's maintenance division tested a UAS for avalanche monitoring, with the aim of preventing accidents and possible highway closures. During the field tests, the UAS was able to capture useful aerial images for traffic surveillance.

A study by the ***North Carolina Department of Transportation*** explored possible UAS applications on its state highways (NCDOT, 2016). The study provided up-to-date information on FAA regulations, and developed a guide titled *Temporary Flight Restrictions and Aeronautical Charts*. The study helped ensure that UAS operators and researchers could understand and comply with UAS-related FAA rules.

The ***Illinois Department of Transportation*** developed state regulations for UAS operations (Bryant et al., 2016). In addition to formulating these regulations, IDOT also examined UAS applications, FAA rules, insurance alternatives, and safety and privacy issues.

The ***Kansas Department of Transportation*** also explored the integration of UASs into their operations (McGuire et al., 2016). Their experience suggests that UASs are useful in bridge inspection, radio tower inspection, surveying, road mapping, high mast light tower inspection, and stockpile measurement. The study also conducted a survey and an analysis of strengths, weaknesses, opportunities, and threats, to determine how to improve the safety and efficiency of UAS operations.

The ***New Hampshire Department of Transportation*** looked into how to increase safety and efficiency while reducing the operational costs of UASs (Hunt, 2016). The study focused on integrating UASs into monitoring traffic and assessing infrastructure conditions to improve these tasks. It also aimed to educate NHDOT employees on how to use the technology. Table 2-1 lists these UAS-related studies and others conducted by state departments of transportation.

Table 2-1: UAS Applications Considered by State Departments of Transportation

DOT	Applications	References
Arkansas	Real-time traffic movement monitoring and highway, bridge, and facilities inspection	Frierson, 2013
California	Geotechnical field investigations	Moller, 2008
Florida	Bridge and high mast luminaires (HMLs) inspection Monitoring remote and rural areas in Florida	Otero, Gagliardo, Dalli, Huang, and Cosentino, 2015 Werner, 2003
Georgia	Economical and operational benefits of UAS integration into DOT operations	Irizarry and Johnson, 2014
Michigan	Bridge inspection, traffic monitoring, or roadway asset surveillance	Brooks, Dobson, Banach, Dean, Oommen, Wolf, Havens, Ahlborn, and Hart, 2015
Minnesota	Bridge inspection	Zink and Lovelace, 2015
Ohio	Three-dimensional model based on visual data collected with a UAS and Geographical Information System for project planning Data collection on freeway conditions, intersection movement, network paths, and parking lot monitoring	Fred, 2013 Coifman et al., 2004
Utah	Taking high-resolution pictures of highways to inventory their features and conditions quickly and at a very low cost	Barfuss, Jensen, and Clemens, 2012
Virginia	Transportation worksite inspection and traffic monitoring Real-time traffic surveillance, monitoring of traffic incidents and signals, and assessment of environmental conditions of roadside areas	Gu, 2009 Carroll and Rathbone, 2002
Washington	Highway maintenance and traffic surveillance Capturing aerial images for data collection and traffic surveillance on mountain slopes above state highways	McCormack and Trepanier, 2008 Coifman et al., 2004
North Carolina	UAS operator guidelines	North Carolina Department of Transportation, 2016
California	To develop a vertical takeoff and landing (VTOL) aerial robot called an Aerobot for elevated structure inspection	Moller, 2008
Illinois	To understand the UAS concept, regulatory and operational issues, and the safety and privacy concerns of implementation	Bryant et al., 2016
Kansas	To develop and provide recommendations for safer and more efficient UAS use on DOT tasks	McGuire et al., 2016
New Hampshire	To analyze the cost benefits and human factors of UAS integration on DOT tasks	Hunt, 2016

2.2. UAS for Construction Applications

Unmanned aerial systems are increasingly being considered for applications in the construction environment. This section reviews research of such applications.

Hart and Gharaibeh (2011) conducted field tests with UASs on ten roadways in Texas, to determine whether UAS use would improve the safety of roadside conditions and the accuracy of construction inventory surveys. Roadside conditions were evaluated by the examination of visual data collected with the UAS. Weather and field conditions were identified as major variables affecting overall UAS performance.

Blinn and Issa (2016) explored possible applications of UASs in active construction environments. Their study compared traditional task performance (without UASs) to UAS-supported task performance. They found that visual data provided by the UAS is indeed useful in project management and control on construction sites. In addition, the study showed that the use of a UAS for certain tasks was superior to traditional methods, since it could decrease operational costs.

Irizarry and Costa (2016) also investigated possible UAS uses in construction management. The study involved collecting qualitative and quantitative data through interviews with and surveys of construction managers. The findings indicate that construction progress monitoring and jobsite logistics could benefit from the visual assets captured and provided by the UAS.

Kim et al. (2016) identified performance factors, user requirements, and operational challenges associated with the use of UASs for construction site inspections—particularly, for safety inspections on jobsites. A survey questionnaire was distributed to safety and project managers in the field. A total of 31 factors and 17 measures were identified and used to evaluate the performance of UAS operations. Flight plans and documentation methods were determined to be the most critical user requirements, whereas FAA regulations and pilot certification were considered the most significant challenges for safe UAS operations in construction environments.

Gheisari and Esmaeili (2016) identified user and technical requirements for UAS safety applications. Safety managers indicated the following hazardous operations as the ones that would benefit the most from UAS use: 1) working around traffic or cranes; 2) working near an open area; and 3) working in the blind spot of heavy equipment. The three most critical technical requirements identified were as follows: 1) real-time communication; 2) a high-precision navigation system; and 3) a sense-and-avoid system. Table 2-2 below summarizes the studies on UAS applications in construction.

Table 2-2**:** Summary of Studies on UAS Applications in Construction

References	Objectives
Blinn and Issa, 2016	To provide the potential uses of UASs on construction environments through a survey of construction industry professionals
Gheisari and Esmaeili, 2016	To identify user and technical requirements for using UASs for safety management tasks
Kim et al., 2016	To identify user requirements, operational challenges, and performance factors of UAS use in construction
Irizarry and Costa, 2016	To identify potential applications of visual assets obtained from a UAS for construction management tasks
Rinaudo, Chiabrando, Lingua, & Spanò, 2012	To monitor daily activity of excavation work
Eisenbeiß & Zürich, 2009	To collect terrestrial images
Hudzietz & Saripalli, 2011	To create 3D models of trains
Barazzetti, Remondino, & Scaioni, 2010	To create 3D models of structures
Hart and Gharaibeh, 2011	To evaluate the effectiveness of UAS to collect condition data of roadside infrastructure.
Metni & Hamel, 2007	To inspect bridges
Irizarry et al., 2012	To improve safety management
Eschmann, Kuo, Kuo, & Boller, 2012	To detecting cracks in buildings

2.3. UAS for Bridge Maintenance Applications

Bridge maintenance activities are considered an ideal UAS application. This section reviews several research efforts to evaluate this application. Menti and Hamel (2007) studied the adoption of a UAS equipped with a computer vision sensor for bridge monitoring. This UAS deployed a novel UAS control method for quasi-stationary flights above each bridge monitored. Guerrero and Bestaoui (2013) employed the Zermelo-Traveling Salesman Problem (TSP) method to generate optimal flight routes for bridge structure inspections. The TSP method was able to improve overall flight performance, depending on weather conditions. Hallermann and Morgenthal (2014) explored autonomous and semi-autonomous flights for detecting structural damage on bridge structures. La et al. (2014) employed a robotic system for autonomous bridge deck inspections. The navigation system was designed to collect and conduct a non-destructive evaluation (NDE) of visual assets. The system aimed to reduce costs, time, and risks associated with bridge deck inspections. Khan et al. (2015) tested a UAS for inspecting bridge structures in inaccessible locations. Tests were conducted initially on a mock-up bridge model, and then on real highway bridges. The researchers found that future research could involve the development of computer vision-based UASs.

Chan et al. (2015) reviewed the current state of UAS-based bridge inspections. The study looked into the technology's historical development, inspection performance, and requirements. They conducted a case study to analyze the cost effectiveness of UAS-based inspections, and found that around US$3,000 of inspection costs could be saved from reduced traffic control and resources in general on a construction project. Gucunski et al. (2015) designed and validated the performance of the Robotic Assisted Bridge Inspection Tool (RABIT). Gillins et al. (2016) designed a protocol for UAS-based bridge inspections as a result of field tests on a bridge in Oregon. Table 2-3 summarizes these recent studies on UAS applications in bridge maintenance.

Table 2-3: Recent Studies on UAS Applications in Bridge Maintenance

References	Objectives
Hallermann and Morgenthal, 2014	To develop a method of visual bridge inspection based on aerial photos and video taken by a UAS
Laa et al., 2014	To explore how visual data collected with a UAS can be used to inspect the bridge deck conditions of common highway bridges
Metni and Hamel, 2007	To study the UAS application for monitoring bridge maintenance with a computer vision sensor
Chan et al., 2015	To provide an overview of UAS-based visual bridge inspection studies and to address the obstacles to integrating this technology into current practice
Gucunski et al., 2015	To develop and implement the RABIT system (Robotics Assisted Bridge Inspection Tool)
Gillins et al., 2016	To develop a methodology for bridge inspection in Oregon using a UAS
Guerrero and Bestaoui, 2013	To develop a methodology for developing structure inspection-based simulations
Khan et al., 2015	To evaluate bridge conditions with a UAS equipped with a set of remote sensors; to conduct a mock-up test on a small concrete bridge model and an actual small/medium bridge

2.4. Image Processing and 3D Models

UAS images can be processed to create three-dimensional models of the objects or areas captured. This section reviews research showing how these 3D images are among the most useful products of visual data collected by UASs.

Oskouie et al. (2015) developed a framework that integrated images and point cloud processing to produce high quality data for project condition assessment. A field test to validate the proposed framework deployed an off-the-shelf UAS platform to collect aerial images of an academic building at the University of Southern California. Commercial photogrammetry software applications were used to create a 3D model of the building. During data processing, geometric features of interest (FOIs) were detected, extracted, and localized within the 3D point cloud, to improve the accuracy of the features' classification. The researchers concluded that, to validate the framework, further field testing with more detailed parameters is required.

Siebert and Teizer (2014) describe the main UAS components needed to generate flight plans, including hardware and software applications. Their study demonstrates how such technology can use aerial data collection and processing to generate 3D point clouds, orthomosaic maps, and digital elevation models. The research team conducted three case studies to assess the efficiency of UAS-based construction earthwork surveys on three distinct types of jobsites: landfill, road construction, and rail construction. The UAS performance was evaluated on the basis of the error analysis results, and then compared to the conventional survey method. Findings indicated that the 3D point clouds generated from the UAS data enabled more accurate measurements of the earthworks, compared to the traditional earthwork survey process. The study also identified some technical limitations of UAS-based surveys, e.g., the UAS battery life and camera/image resolution. The research team recommended case studies of various scenarios in order to identify other possible UAS applications in construction work environments.

Rodriguez-Gonzalvez et al. (2014) proposed a methodology to reconstruct 3D models from aerial images obtained during UAS flights. The methodology involves computer vision processing and photogrammetric algorithms to extract and match key points from multiple images. The 3D model is then reconstructed through image orientation. Field tests were performed to validate this UAS-based method and assess the quality of the reconstructed 3D models. The research team found that the method was more cost effective and provided more accurate 3D models, compared to those generated from terrestrial laser scanners.

d'Oleire-Oltmanns et al. (2012) explored UAS use for more accurate and reliable 3D data for soil erosion control. A fixed-wing UAS with satellite-based remote sensors were used to collect data on different test environments. Installed ground control points (GCPs) allowed for the geo-referencing and processing of the collected images to generate the 3D models. The GCP-based workflow allowed for the development of highly accurate 3D models, and the approach proved to be very efficient for erosion assessments.

Ellenberg et al. (2014) conducted a feasibility study on potential UAS applications for infrastructure inspections. To enable a UAS to identify markers placed on an inspected structure, the research team developed an image-processing algorithm that provided distances and angles between the aerial vehicle and the markers. During the study, the researchers performed two lab tests and one field experiment to evaluate how well the system detected defects and damage on a bridge structure. The developed system was proven to more effectively generate accurate data than the traditional human-based inspection method. The study contributed to a better understanding of how UASs and image-processing algorithms can be combined and integrated into infrastructure inspection. This review of the research aims at providing context for the reader on the topic of UAS-based data. This larger view can help GDOT personnel assess the selected applications considered in this research project.

3. Focus Group Activities

This chapter presents data obtained from three focus group (FG) sessions with GDOT personnel (one session per each participating GDOT division). The sessions took place between mid-July and early August of 2016, and lasted between two and three hours each. At the beginning of each session, the general research goals and the objectives of the session were explained to all participants. The attendance sign-up sheet (with individual code numbers for identification), the demographics form, and the data collection sheet were distributed to all participants. A total of 17 management-level professionals participated in the FG sessions, distributed as follows: five from Construction, seven from Bridge Maintenance, and five from Intermodal.

3.1. FG Methodology

A FG session is a type of group interview that has proven to be an effective method for collecting qualitative data on a specific topic (Kitzinger, 1995; Sim, 1998). This method is widely used for exploring and examining the nature of participants' knowledge and experience, providing insight into how participants view a topic or process (Kitzinger, 1995), as well as how they might changes their views and what information they might require (Denning & Verschelden, 1993).

3.1.1. FG Objectives

In this study, the FG sessions provided the research team with information on the participating GDOT divisions' current tasks, resources, and decision-making processes.

This information was found to be critical to identifying the tasks that would benefit from UASs integration (Irizarry et al., 2017). The main research goals involved the following four objectives:

1) Compile a list of the participating GDOT divisions' current tasks, including detailed descriptions of their organizational structures, work processes, and required resources.
2) Define tasks that can benefit from the use of UAS.
3) Identify general UAS integration requirements, such as operational concepts, technological requirements, work environment conditions, and user characteristics.
4) Develop a field-testing protocol.

3.1.2. FG Data Collection Plan

The data collection plan was designed to achieve the objectives listed above. The FG sessions involved both unstructured and structured interviews. Before conducting the focus group, the researchers submitted a consent form (comprising the interview questions, procedures, benefits, and compensation) to the Georgia Tech Institutional Review Board (IRB) for evaluation and approval. The IRB is responsible for ensuring the physical and mental wellness of human research subjects. (See Appendix aa for the IRB approval form, Appendix bb for the consent form, and Appendix cc for the structured interview questions, and Appendix dd for the attendance sign-up sheet and the demographics questionnaire.) Figure 3-1 illustrates the FG data collection plan.

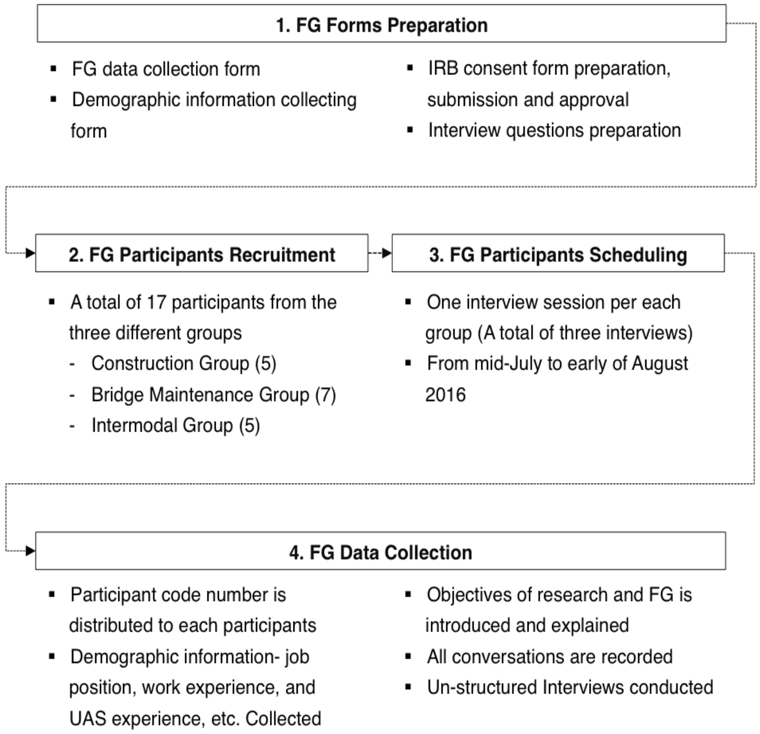


Figure 3-1: Focus Group Data Collection Process

3.1.3. FG Participants

In general, an FG session includes the coordinators (i.e., a moderator and a facilitator) and the interviewees.

FG Coordinators

In this study, the FG moderator was in charge of leading the discussions during the FG sessions, promoting participants' interest in the topic and encouraging them to engage in discussion (Kitzinger, 1995; Sim, 1998). The moderator was also in charge of introducing the participants to the research objectives, FG session goals, and general data collection procedures (e.g., the types of information that would be collected). The facilitator was in charge of recording all conversations and making annotations throughout the data collection process, to allow for accurate verbatim analysis during the data analysis phase.

FG Interviewees

The seventeen GDOT employees (see Appendix hh for list of participants) who had volunteered to participate in the study came from the Construction, Bridge Maintenance, and Intermodal groups. The FG sessions were conducted separately for each group between mid-July and early August of 2016, and lasted between two and three hours each.

The first FG session with the five participants from the GDOT District 1 Construction Group (CG) took place at their office in Gainesville, Georgia on July 12, 2016. The second FG session with the seven participants from the Bridge Maintenance Group (BMG) took place at the Georgia Transportation Management Center, on July 19, 2016. The last FG session with the five participants from the Intermodal Group (IG)—three having come from the Aviation team and two from the Railway team—took place at the GDOT office at the One Georgia Center in Atlanta, on August 1, 2016. Table 3-1 below summarizes this information on these GDOT FG sessions.

Table 3-1: FG Sessions with Personnel from Three GDOT Groups

FG Participants	**Number of Participants**	**Location**	**Date**
Construction Group (CG)	5	GDOT District 1 Gainesville Office	July 12, 2016
Bridge Maintenance Group (BMG)	7	Georgia Transportation Management Center, Atlanta	July 19, 2016
Intermodal Group (IG)	5	One Georgia Center, Atlanta	August 1, 2016

The next sections describe and elaborate on collected data, including demographic information and interview outcomes. Data collected from the FG sessions is considered and treated as qualitative data, since in this study, the groups may not provide the required degree of representativeness (Sim, 1998). A total of 17 participants were recruited for the three FG sessions. The FG participants included 14 males (82.4 percent) and three females (17.6 percent), all of whom had worked in infrastructure and construction-related fields for fewer than 10 years (35.3 percent), between 11 and 20 years (29.4 percent), or over 21 years (35.3 percent). The participants' ages varied from under 30 years of age (5.9 percent) to over 50 years of age (29.4 percent). Eight participants had high-school diplomas (47.0 percent), seven participants had bachelor's degrees (41.2 percent), and two held master's degrees (11.8 percent).

All participants (100 percent) were familiar with the basic concept of UAS and the idea of integrating this technology into their tasks. However, most of them do not have any UAS flight experience. Only three out of 17 participants (17.6 percent) had UAS flight experience, for either recreational or research purposes. Two participants from the CG had engaged in UAS flying for recreational purposes, and one person from the IG had used an UAS in urban and city planning research. Table 3-2 displays the demographic information of all FG participants.

Table 3-2: Demographic Information of FG Sample

Attribute	Participants (*N=17*)
Gender	
Male	82.4%
Female	17.6%
Age	
Under 30 years	5.9%
31-40 years	41.1%
41-50 years	23.6%
Over 51 years	29.4%
Work experience	
Less than 10 years	35.3%
11-20 years	29.4%
Over 21 years	35.3%
Educational Attainment	
High-school level	47.0%
Undergraduate level	41.2%
Graduate level	11.8%
UAS Knowledge	
Know	100%
Do not know	0.0%
UAS Flight Experience	
Yes	23.5%
No	76.5%

3.2. FG Results

This section presents the results of the interviews conducted during the FG sessions with each of the three groups, (i.e., the Construction, Bridge Maintenance, and Intermodal groups). The results include the demographic information of each group, its tasks, team structure, and associated resources, as well as the identification of the tasks that could benefit from UAS integration.

3.2.1. Construction Group (CG)

CG Demographic Information

A total of five individuals (N=5) from the CG participated in the FG session. The group included four males (80 percent) and one female (20 percent); two of them were over 50 years of age (40 percent), and the others were between 41 and 50 (60 percent) years of age. Figure 3-2 presents a photograph of the setting of the FG interview with the CG participants. All participants were responsible for managing road construction projects within the GDOT District 1 Office as project managers (20 percent) or project engineers (80 percent). Moreover, they all had significant experience in their current positions or in related fields. Three participants (60 percent) had more than 21 years of experience in their current group. Four participants had more than 21 years of experience (80 percent) in construction-related fields. In regard to educational attainment, four participants had high-school diplomas (80 percent), and one had a bachelor's degree in civil engineering. Table 3-3 summarizes the demographic information of the CG participants.

(a) FG Session Introduction (b) Data Collection from FG Participants

Figure 3-2: Focus Group Session with GDOT District 1 Construction Division

Table 3-3: CG Demographic Information

FG Member ID	C01	C02	C03	C04	C05
Gender	Male	Male	Female	Male	Male
Age	Over 50	41-50	Over 50	41-50	41-50
Job Position	Project Engineer	Project Engineer	Project Engineer	Project Manager	Project Engineer
Job Description	Management of GDOT Road Construction Projects				
Experience in Current Position	Over 21 Years	Over 21 Years	Less Than 10 Years	Less Than 10 Years	11–20 Years
Experience in Related Field	Over 21 Years	Over 21 Years	Over 21 Years	11–20 Years	Over 21 Years
Size of Department (# of Employees)	Very Large (over 100)	Small (Less than 25)	Large (50–100)	Large (50–100)	Small (Less than 25)
Educational Background	No Major	No Major	No Major	Civil Engineering	No Major
Education Attainment	High-School Diploma	High-School Diploma	High-School Diploma	Bachelor	High-School Diploma
UAS Knowledge	Yes				
UAS Experience	No	No	Yes	Yes	No
If yes, how long			Less than 1 year	Less than 1 year	
If yes, for what use			Recreational	Recreational	

CG Current Tasks

The interviewees from the CG all agreed that the main responsibility of a project engineer (PE) is to conduct field surveys, take linear and area measurements, and verify that contractually required items and construction materials are present at the construction jobsite. Usually, PEs will collect videos and photos of the jobsite to facilitate their assessment of the work environment. However, such procedures may pose risks to them. For instance, when they inspect underground pipelines and ground utilities from the roadside, they risk being struck by passing vehicles. Under such conditions, the inspector's safety is protected by safety signs placed on the road.

One of the PE's main tasks is to measure concrete and earthwork. The PE is in charge of verifying the volume of earth excavated when the GDOT Construction division processes payments to earthwork contractors. To quantify excavation volume, Construction division personnel usually use a simple calculation method involving the multiplication of the height by the square footage of the void in the ground, or the multiplication of the number of dump trucks used to remove the soil by their maximum load capacity.

Besides ensuring proper execution of excavations, PEs are also responsible for erosion control, overseeing project limits and work areas. PEs are required to wear special boots and walk around the excavation area. Using measuring devices to assess erosion. The FG participants considered this a task of special concern. They noted other responsibilities of PEs, including the inspection of pedestrian sidewalks and monitoring of traffic speed and flow, to prevent hazardous situations and accidents at the jobsite. Table 3-4 summarizes the identified CG tasks.

Table 3-4: CG Current Tasks

Group	Tasks
CG	1. Site monitoring 2. Volume measurement (earthwork) 3. Erosion control 4. Traffic and heavy equipment control 5. Pipeline and sidewalk inspection (logistic)

CG Tasks with Potential for UAS Integration

This section discusses the CG operations that could integrate UASs. In general, the integration of UASs into CG operations could lead to major improvements in construction monitoring and documentation, especially with respect to frequency, data accuracy, and safety of CG personnel, among others. Earthwork measurements and erosion control inspections are identified as CG tasks that could benefit from UAS adoption (Irizarry et al., 2017). The geo-referenced visual data captured by UASs allows for the development of 3D models through photogrammetry software applications. PEs could rely on these 3D models to quantify excavation volumes and to measure the elevation of work areas for erosion control. Due to its real-time video feed feature, a UAS could also assist in traffic control and heavy equipment displacement at/around the construction jobsite. Table 3-5 summarizes the identified CG tasks that could integrate UASs.

Table 3-5: CG Tasks with UAS Integration Potential

Group	Tasks
CG	1. UAS-based 3D model • Erosion control • Excavation measurement (quantification) 2. High-frequency site monitoring/inspection (daily or weekly inspection) 3. Traffic control and heavy equipment displacement

3.2.2. Bridge Maintenance Group (BMG)

BMG Demographic Information

Seven individuals (N=7) from the Bridge Maintenance Group (BMG) attended an FG session. All participants were male. Three of the BMG participants were 50 years of age (43 percent), and four participants were between 31 and 40 years of age (57 percent). One manager (14.3 percent) was in charge of the division, two bridge inspection supervisors (28.6 percent) were responsible for monitoring all bridge inspection jobs, three bridge inspection specialists (42.8 percent) performed bridge inspections, and one bridge inspection technician (14.3 percent) assisted the bridge inspection supervisors in the inspection and decision-making processes. Most respondents have less than 10 years of experience in their positions (85.7 percent), but one participant had between 11-20 years of experience (14.3 percent). In regard to experience in bridge maintenance, two participants had over 21 years of experience (28.6 percent), two had between 11-20 years of experience (28.6 percent), and three had less than 10 years of experience (42.8 percent). With respect to educational attainment, four participants had high-school diplomas (57.1 percent), three had bachelor's degrees (42.9 percent), two of which were in civil engineering. Table 3-6 summarizes the demographic information of the BMG interviewees. Figure 3-3 illustrates the FG session setting.

(a) FG Session Introduction (b) Data Collection from FG Participants

Figure 3-3: Focus Group Session with GDOT Bridge Maintenance Division

Table 3-6: BMG Demographic Information

	BM01	BM02	BM03	BM04	BM05	BM06	BM07
Gender	Male	Male	Male	Male	Male	Male	Male
Age	Over 50	31-40	31-40	Over 50	31-40	Over 50	31-40
Job Position	State Manager	Technician	Supervisor	Specialist	Specialist	Specialist	Supervisor
Job Description	Manage the State BMG	Assist Supervisor	Supervise Inspections	Perform Inspection	Perform Inspection	Perform Inspection	Supervise Inspections
Experience in Current Position	Less than 10 years	Less than 10 years	11-20 years	Less than 10 years	Less than 10 years	Less than 10 years	Less than 10 years
Experience in Related Field	21-25 years	Less than 10 years	11-20 years	21-25 years	Less than 10 years	Less than 10 years	11-20 years
Size of Department	50-100	50-100	Less than 25	50-100	50-100	50-100	Less than 25
Educational Background	Biology	No Major	No Major	Civil Engineering	Civil Engineering	No Major	No Major
Education Attainment	B.S.	High-School Diploma	High-School Diploma	B.S.	B.S.	High-School Diploma	High-School Diploma
UAS Knowledge	Yes						
UAS Experience	No						

BMG Work Environment

The main operations of the BMG division involve performing inspections on approximately 15,000 bridges in Georgia. The division consists of three teams with different inspection roles, depending on the bridge component to be inspected. Basically, a bridge has three main components: 1) deck, 2) superstructure and 3) substructure (includes areas of bridge located underwater). (See Figure 3-4.)

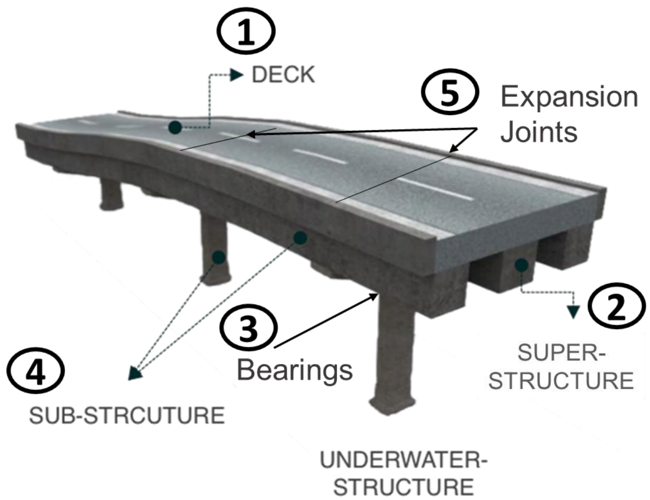


Figure 3-4: Bridge Structure Components

1. ***Deck***: Supports the roadway and traffic; also distributes “live” and “dead” loads.
2. ***Superstructure:*** Supports loads transmitted through the deck.
3. ***Bearings***: Support the transfer loads between the superstructure and the substructure.
4. ***Substructure:*** Transfers all loads from the superstructure to the ground.
5. ***Expansion Joints***: Absorb expansion and contraction of the superstructure, and protect the bearings from water and debris.

The BMG develops and adopts internal references and standard protocols for conducting its operations. An example of these materials is the Bridge Structure Maintenance and Rehabilitation Repair Manual (GDOT, 2012), which is based on the American Association of State Highway and Transportation Officials guide for bridge inspection and maintenance (AASHTO, 2010). Figure 3-5 illustrates the work structure of the BMG.

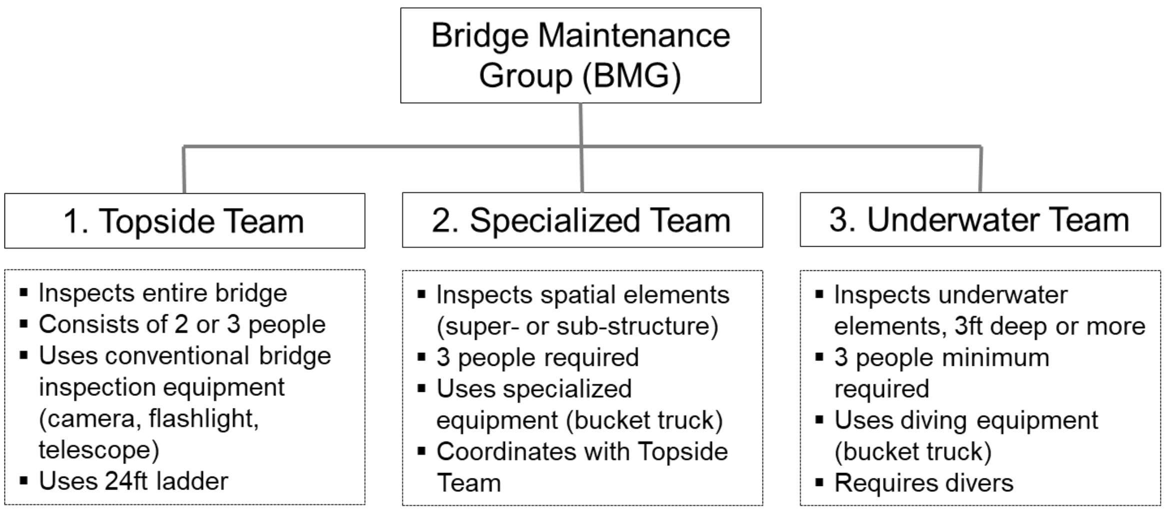


Figure 3-5: BMG Work Structure

BMG Current Tasks

The BMG performs visual observations as part of its work to inspect the various elements of a bridge. Usually, these visual inspections involve viewing bridge elements from different distances and viewpoints. Depending on the type of bridge, structural elements, size, and traffic on the bridge, the inspection task may have a different sequence and frequency. The topside teams conduct regular inspections in two-year cycles for each bridge. (See Figure 3-5.) To accommodate the variability of bridge size, location, and condition, the specialized teams operate on three-, six-, and 48-month cycles. The underwater teams work on a 60-month cycle to inspect underwater elements.

The GDOT BMG measures vertical clearances and surveys permanent capacity as scheduled. In addition, the group uses hammers to inspect connection points in hard-to-reach locations. Sometimes, an infrared camera is used to detect temperature differences to identify problems with concrete delamination in the deck or caps. A temperature profile can also be used to detect cracks on bridge elements. To ensure the safety of its personnel, the group has designed contingency plans for any unforeseen danger or accident during inspections.

To allow for an efficient and safe inspection process, the BMG coordinates with authorities with jurisdiction over the bridge (or with third parties, such as traffic control companies or Federal Highway Administration (FHWA) units in charge of a road's traffic management) to control traffic flow. A typical inspection process involves the bridge deck team and/or the specialized team. The average time required to inspect a bridge ranges from 15 minutes to three or four hours, depending on the structure, size, and type of bridge. It usually takes the team 15 to 20 minutes to set up the equipment upon arrival at the site. Table 3-7 lists the current tasks of the BMG.

Table 3-7**:** BMG Current Tasks

Group	Tasks
BMG	1. Visual observation (sequence and frequency) ▪ Depends on bridge type, structural system, size, and road traffic conditions ▪ Regular inspection (two years), specialized team (three, six, or 48 months), underwater team (60 months) 2. Vertical clearance measurement 3. Hammer used to inspect hard to access locations 4. Accident or contingency plan (procedures) ▪ Reports problem to BMG ▪ Starts traffic control (takes about 30 minutes) ▪ Starts to set up equipment (15-20 minutes) ▪ Inspect the point of interest (ranging from 15 minutes to over 4 hours)

BMG Tasks with Potential for UAS Integration

The integration of UASs into bridge maintenance operations could save a significant amount of time, particularly, on inspections of bridges with tall columns. Moreover, a UAS is capable of flying underneath bridge decks, facilitating the inspection of hard-to-reach structural elements such as bearings, connections, and column caps. However, because satellite signals may be weakened under bridge structures, it is likely that the Global Positioning System (GPS) sensors of the UAS will struggle to find and lock on to those signals. Such a technical limitation restricts the use of UASs in bridge inspections. UASs should also be equipped with special cameras with built-in flashlights capable of pointing up and illuminating hard-to-capture elements, e.g., the undersides of bridge structures. UASs that are able to generate 3D models—as described above—are ideal for assessing cracks and vertical clearances, since their use requires no interruptions of traffic on the bridge roadway. The 3D models also enable bridge maintenance teams to check the accuracy of the original bridge plans and address any significant deviations from the original design. To ensure the safety of any UAS inspection operation, the GDOT BMG should check for and avoid power lines around the inspection area.

Another task that could benefit from UAS integration is the inspection of the interior of box-beams, conducted to detect cracks on the inside walls. Since the interior of box-beams lack sufficient light for direct observation, and the detection of cracks is a visual process, performing UAS inspections in such confined spaces requires more caution and time than is required for other bridge elements. Similar to UASs for inspections underneath structures, this application would also require powerful cameras with built-in lights, besides requiring the capability for more precise manual maneuvers.

Moreover, the incorporation of sonar sensors on the unmanned vehicle would enable its use in underwater inspections. Sonar sensors can detect the vehicle's vertical position when it comes into contact with the water surface, as well as measure its distance from the bridge deck, or from the bottom of the body of water (e.g., river or lake bed). This application could assist divers when performing inspections of submerged elements by checking for debris and other possible entangling hazards. Further analysis would be needed to determine the impacts of using this technology on the time needed to conduct underwater measurements. Table 3-8 summarizes BMG operations that could incorporate UASs.

Table 3-8: BMG Tasks with UAS Integration Potential

Group	Tasks
BMG	1. Time-saving on bridges with tall columns (an upward-looking camera and strong light is required) 2. UAS-based 3D model ▪ Crack detection and assessment ▪ Vertical clearance assessment ▪ 3D steel beam model development for comparison of as-built to original designs. 3. Inspection underneath bridges and decks using various sensors (e.g., infrared camera or thermal sensor)

3.2.3. Intermodal Group (IG)

IG Demographic Information

Participants from four different departments comprise the Intermodal Group: aviation, railway, freight transport system, and public transit. However, for the FG session, only the first two departments were selected (aviation and railway), since the freight transport system and public transit departments are more involved with transportation than with construction matters. Figure 3-6 illustrates the setting of the FG session with the IG. A total of five participants volunteered for this FG session (N=5). Three were from the aviation department (60 percent), and two from the railway department (40 percent); three were male (60 percent), and two were female (40 percent); three were between 31 and 40 years of age (60 percent). Each participant had a different professional role (job position), and had less than 10 years of experience in the current position. However, two participants had 11-20 years of experience (40 percent) in airport inspection. In regard to educational attainment, three participants (60 percent) had bachelor's degrees in civil engineering or aviation management, and two (40 percent) held master's degrees in urban planning or aviation and safety management. Table 3-9 shows the demographic information of the IG.

(a) FG Session Introduction

(b) Data Collection from FG Participants

Figure 3-6: Focus Group Session with GDOT Intermodal Division

Table 3-9: IG Demographic Information

Participant ID	I01	I02	I03	I04	I05
Gender	Male	Female	Male	Female	Male
Age	41-50	31-40	Less than 30	31-40	31-40
Job Position	Railway Engineer	Railway Planner	Airport Project Engineer	Airport Program Manager	Airport Inspection Manager
Job Description	Railway Inspection	Railway Planning	Airport Construction Management	Airport Department Management	Airport Inspection
Experience in Current Position	Less than 10 years	Less than 10 years	Less than 10 years	Less than 10 years	Less than 10 years
Experience in Related Field	Less than 10 years	Less than 10 years	Less than 10 years	11-20 years	11-20 years
Size of Department	Small (fewer than 25)	Medium (25-50)	Small (fewer than 25)	Small (fewer than 25)	Small (fewer than 25)
Educational Background	Civil Engineering	Urban Planning	Aviation Management	Aviation and Safety Management	Aviation Management
Education Attainment	Bachelor	Master	Bachelor	Master	Bachelor
UAS Knowledge	Yes				
UAS Experience	No	Yes	No	No	No
If yes, how long	-	1-2 years	-	-	-
If yes, for what use	-	Research	-	-	-

IG Work Structure

Figure 3-7 presents the organizational structure of the four departments of the GDOT Intermodal Group: 1) aviation, 2) railway, 3) freight transport, and 4) public transit. As mentioned previously, only the aviation and railway departments participated in the FG sessions.

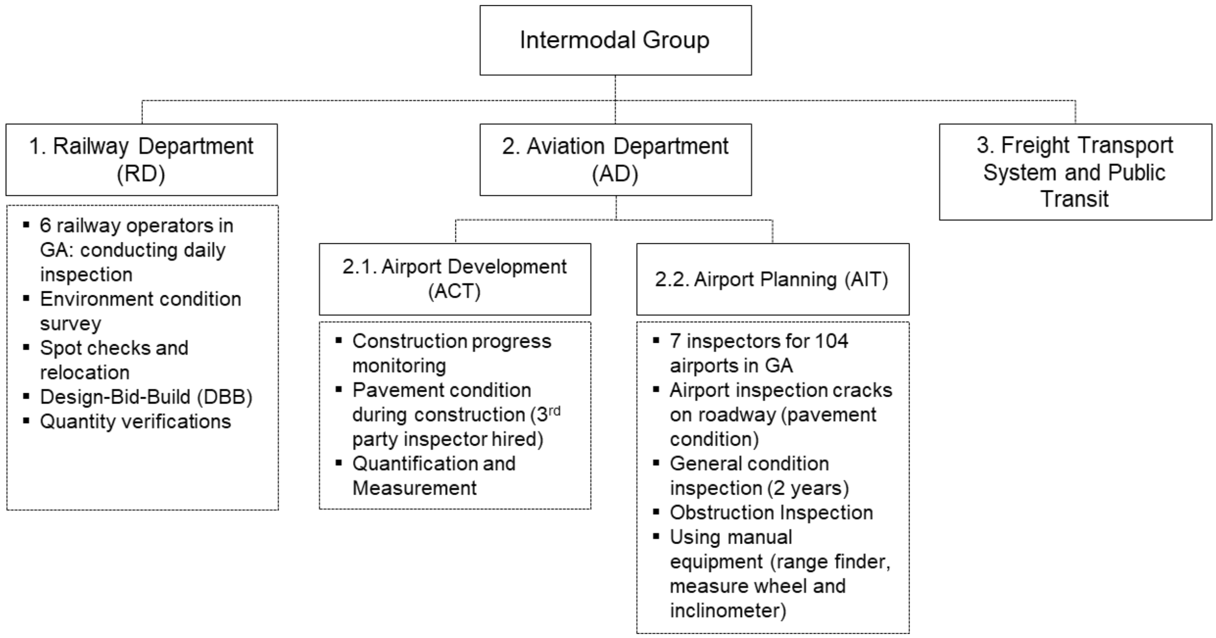


Figure 3-7: Work Organizational Structure (IG)

The railway department has contracts with six consultants that conduct daily inspections on the railways and their surroundings. The aviation department performs its own inspections, dividing itself into two subgroups: 1) the airport planning team and 2) the airport development team. The airport planning team is mainly in charge of inspecting the pavement conditions of airport runways, as well as conducting visual assessments of the general conditions around the airport and its runways. Planning also conducts reviews of airport master plans and layout plans. The aviation department sometimes hires third-party inspectors. The aviation department's other subgroup, the airport development team, is charged with monitoring the progress of construction at airport facilities. Seven project managers in this group are assigned to the 104 airports in Georgia.

Current Tasks of IG

The general railway inspection process involves four steps: 1) walk through the railway line; 2) check its general conditions; 3) take pictures of points of interest; and 4) document and address issues, and document solutions. The railway department has been using a truck equipped with a camera to facilitate such tasks. The truck is used to record videos of the rails and its surroundings at an average speed of five miles per hour, 30 to 50 miles per day.

Inspectors and managers in the aviation department drive onto the airport runways and taxiways to perform visual inspections. This task usually requires the use of special equipment such as a range finder, an inclinometer, and a measuring wheel. The time required to inspect a runway is a function of the size of the airport. Runway inspections involve verifying that the runway markings are visible and signs are intact, the height of trees around and in the airport environment meets FAA standards, and the conditions of the airfield pavements are maintained. To ensure the safe operation of aircraft, obstacles and cracks on the runway should be carefully inspected. The aviation department occasionally hires external inspectors to help its internal personnel perform pavement inspections. All data collected from the inspections is processed and reported to the airport manager, who compares it to the data from previous inspections and requests any necessary corrective measures. Table 3-10 summarizes the current tasks of each of the three IG departments.

Table 3-10: Current IG Tasks

Department of IG	Tasks
Railway department	1. Monthly manual visual observation ▪ Walking through the railway—checking conditions, taking pictures, documenting issues ▪ Inspecting railway tracks, including wood ties and the conditions of the surrounding environment 2. Use of special truck equipped with camera (30-50 miles per day at an average speed of five mph)
Aviation department	1. Visual inspection (performed manually) ▪ Inspecting runway markings and signs (general condition) and condition of pavement ▪ Inspection of tree heights and approach angle around runway ▪ Equipment: range finder, inclinometer, and measuring wheel 2. Pavement condition inspection: external or internal inspector 3. Data-processing and reporting to airport manager: pre-/post-visual data comparison

IG Tasks with UAS Integration Potential

The railway department could integrate a UAS with low altitude and long-distance flight capabilities into its inspections of track elements. If equipped with a thermal camera, a UAS could also provide a temperature profile of the railway and facilitate the assessment of cracks, expansion and contraction of the rails, and other issues. UASs could also be used to monitor railway crossings from various perspectives.

With respect to the aviation department's operations, a UAS could provide enhanced images of obstacles and cracks on airport runways. It could also be used to verify the accuracy of the approach path, providing more accurate and reliable information on the height of the tree line surrounding the airport. In addition, a UAS could collect topographic data of runways and/or of airport construction areas with acceptable precision for management applications. This aerial data collection would decrease the work hours required for this task. Aerial photography can also facilitate pre- and post-survey comparisons, optimizing progress monitoring of construction work at airports. During the FG session, an aviation manager stated that UAS adoption could help solve cost issues associated with inspecting the large number of airports in the department's charge. Table 3-11 presents IG operations that could incorporate UASs.

Table 3-11: IG Tasks with UAS Integration Potential

Departments in IG	**Tasks**
Railway department	1. Low-altitude and long-distance flight with low speed for UAS inspection 2. Temperature profile development ▪ Thermal camera-based ▪ Railway condition: railway expansion, contraction, and cracking ▪ Railway crossing area inspection with UAS
Aviation department	1. UAS-based 3D model through photogrammetry ▪ Inspect/assess runway pavement conditions (i.e., detect and measure cracks) and obstructions ▪ Airport area topography (reduced work-hours and increased accuracy) 2. Different perspectives (aerial photography) ▪ Construction progress monitoring ▪ Pre/post-survey comparisons of runway 3. More cost-effective airport inspection with reduced reliance on outdated equipment

3.2.4. Summary of FG sessions and tasks with UAS integration potential

In general, UASs can be integrated into the progress measurement, site monitoring, and inspection tasks of all GDOT's divisions addressed in this study, providing 3D-engineered data such as point clouds, digital elevation models (DEMs), and orthomosaic maps. Table 3-12 summarizes the results of the data analysis developed in this chapter, and lists the tasks with potential for UAS integration in all groups.

Table 3-12: Potential UAS-assisted Tasks in all Groups

Group	Potential Operations with UAS Integration
Construction	1. Generating 3D models with photogrammetry ▪ Erosion control ▪ Earthwork measurement (quantification) 2. High-frequency site condition inspection (daily or weekly inspection)
Bridge Maintenance	1. Time saving on bridges with tall columns (an upward-looking camera and illumination is required) 2. 3D modeling with photogrammetry ▪ Detect and measure cracks, conduct vertical clearance assessment ▪ Develop 3D steel beam model for precision comparison of as-built structures 3. Inspection underneath bridge and on underside of deck, using various sensors (e.g. IR or thermal sensors)
Intermodal (Railway)	1. Low-altitude and long-distance flight at low speeds for corridor inspection 2. Temperature profile ▪ Thermal camera-based ▪ Inspect railway condition – expansion, contraction, and cracking 3. Railway crossing inspection with UAS
Intermodal (Aviation)	1. 3D modeling with photogrammetry ▪ Inspect and observe obstructions ▪ Inspect/assess runway pavement conditions (i.e., detect and measure cracks) ▪ Airport area topography (reduced work-hours and increased accuracy) 2. Different perspectives (aerial photography) ▪ Construction progress monitoring ▪ Pre-/post-construction survey comparisons of runways 3. More cost-effective airport inspection with reduced reliance on outdated equipment

4. Field Tests of UAS-Assisted Tasks

As discussed in the previous chapter, a series of UAS-assisted tasks were derived from the data collected in the FG sessions. (See Table 3-12.)

4.1. Field Test Design

The proposed field test protocol was developed based on the findings from the FG sessions with the participating GDOT personnel. The proposal included three different types of UAS platforms for use in the field tests: 1) an off-the-shelf quad-copter (first platform); 2) a developer-grade UAS (second platform); and 3) a fixed-wing UAS provided by a third-party service (third platform). In keeping with the proposed experiment design presented in Figure 4-1, the field tests were developed to employ different platforms for various tasks and work environments.

The construction inspection test performed by the CG would involve all platforms for collecting images and generating 3D models through the photogrammetry process. Since the CG had never used laser scanners in their operations due to costs involved, the use of a laser scanner-equipped platform (second platform) was of special interest. This same platform could be used in the BMG's bridge inspection tests. Three main bridge elements were selected as points of interest for the bridge inspection experiments: 1) top-deck, 2) under-deck, and 3) bridge foundation.

All three UAS platforms would be used for the IG's airport inspection tests, which involved monitoring the progress of airport facility construction and performing inspections of airport runway conditions and obstructions. Lastly, the off-the-shelf quad-copter and the developer-grade UAS were considered for railway alignment and crossing inspections, as suggested by the railway team.

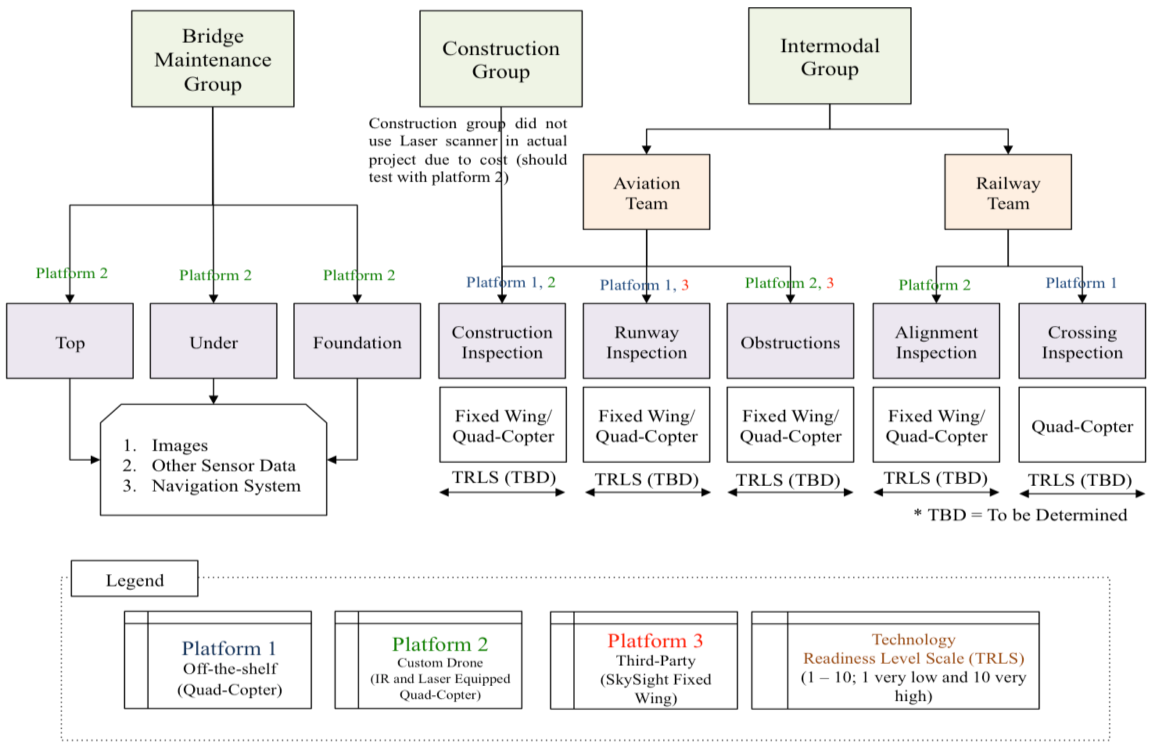


Figure 4-1: Proposed Field Test Design

4.2. Field Tests - Aviation Group

4.2.1. Test Site Selection

The aviation group within the GDOT IG provided three possible test locations. Table 4-1 presents details about these options, including airport name, location, stage of construction project (if applicable), expected travel time, and distance to locations from the Georgia Tech Campus.

Table 4-1: Aviation Group Potential Test Sites

Site (Name)	Code	Location	Start Date	Work Description	Expected Distance to Location (Time)
Habersham County Airport (Cornelia)	IA01	Hwy 441 Bypass, Cornelia, GA 30531	March 2017	Earthwork	75 miles (1H45M)
Monroe-Walton County Airport	IA02	111 Spring Street, Monroe, GA 30655	Feb 8 2017	Airport runway inspection and obstruction evaluation	56 miles (1H25M)
Roosevelt Memorial Airport	IA03	5A9, Woodbury, GA 30293	March 2017	Earthwork	70 miles

4.2.2. Site Selection Visits Results

The research team visited the three possible locations to evaluate existing site conditions at the sites. Table 4-2 provides information from each site visit. The team also visited a fourth airport on the way to one of the three suggested locations. Based on the site visits, the research team selected two test sites (IA01 and IA03). Figure 4-2 shows the locations and provides characteristics of the airports visited during the selection process.

Table 4-2: Site Visit Summary

Site (Name)	Code	Person in Charge	Operational Controls	Scheduling
Habersham County Airport (Cornelia)	IA01	▪ Ray Reed – Airport Manager (FBO, 706-778-0198) ▪ Brenda Reed – FBO ▪ Austin Hulsey – Line Manager	▪ Handheld radio control – advisory frequency (no air traffic control tower) ▪ Operation depends on weather conditions (strong winds)	Need to schedule in advance (heavy traffic on weekends)
Monroe-Walton County Airport	IA02	▪ Cris Baily – City Manager (770-266-5406) ▪ Cy Nuually – Airport Manager (678-725-3542)	▪ Handheld radio control – advisory frequency (no air traffic control tower) ▪ Flight school and sky diving club	Need to schedule in advance
Roosevelt Memorial Airport	IA03	▪ Wallace Berry (334-740-1994) ▪ Mark Blace (770-783-0645) ▪ Time McGowin (334-703-3984)	▪ Handheld radio control – advisory frequency (No Air Traffic Control Tower)	Need to schedule in advance
Newnan-Coweta County Airport	IA04	▪ John D. Carroll – Airport Manager (FBO, 770-254-8102)	▪ Handheld radio control – advisory frequency)	Need to schedule in advance

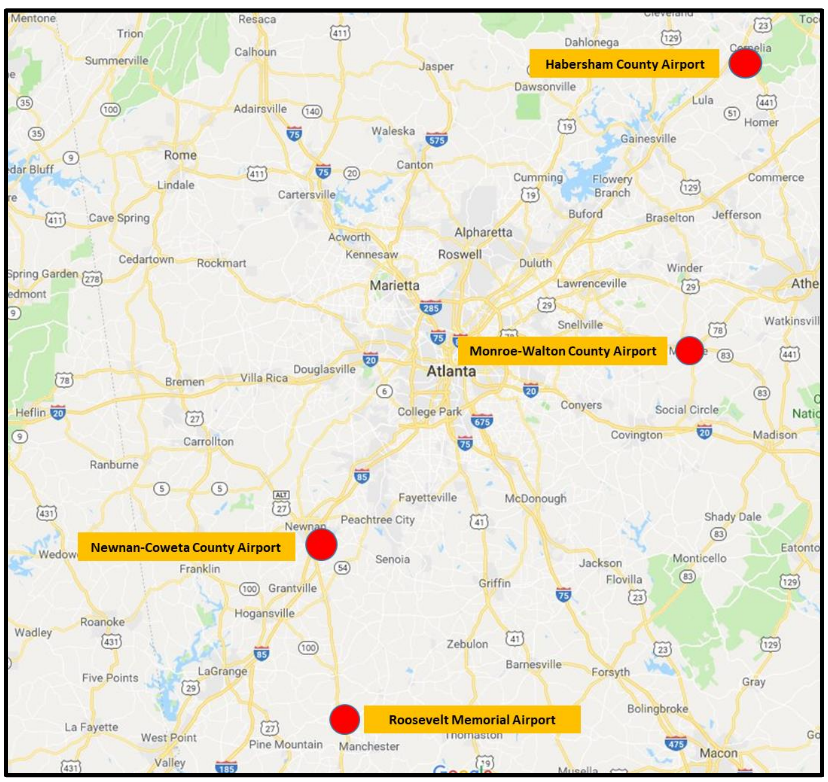


Figure 4-2: Location of the Potential Test Sites

Figure 4-3 shows logistical features at each airport, e.g., the location of construction projects, offices, and taxiways. Figures 4-4, 4-5, and 4-6 provide additional images of each airport, for reference.

(a) Habersham County Airport

(b) Monroe-Walton County Airport

(c) Roosevelt Memorial Airport

(d) Newnan-Coweta County Airport

Figure 4-3: Logistics features at Each Airport

(a) Project Location (Earthwork around taxiway)

(b) Taxiway

(c) Airport Office

Figure 4-4: Images from Visit to Habersham County Airport

(a) Taxiway

(b) Potential Obstructions

(c) Airport Office

(d) Airport Overview

Figure 4-5: Images from Visit to Monroe-Walton County Airport

(a) Taxiway

(b) Airport Office

Figure 4-6: Images from Visit to Newnan-Coweta County Airport

4.2.3. Selected Test Sites and Field Tests Schedule

Two sites were selected for the field tests: 1) the Habersham County Airport, and 2) the Roosevelt Memorial Airport. Both airports were undertaking earthwork activities in March 2017. Table 4-3 summarizes information on the selected sites. Based on the feedback from involved staff, the dates of field tests were as follows:

1. Habersham County Airport: Thursday May 18, 2017 9AM to 1PM. (The back-up plan in case of inclement weather was Friday, May 19, 2017.)
2. Roosevelt Memorial Airport: Tuesday May 16, 2017 9AM to 1PM. (The back-up plan in case of inclement weather was Wednesday, May 17, 2017.)

Table 4-3: Selected Test Sites

<table>
<tr><th>Site (Name)</th><th>Code</th><th>Personnel performing tasks</th><th>Field Test Work Descriptions</th><th>Field Test Schedule</th></tr>
<tr><td>Habersham County Airport (Cornelia)</td><td>IA01</td><td rowspan="2">• Georgia Tech Building Construction – Dr. Irizarry and Sungjin Kim
• Georgia Tech Aerospace Engineering – Dr. Johnson, Kyuman Lee and an UAS Operator (with Control System equipped truck)
• GDOT Aviation Division Inspection Personnel (Alan and Joseph)
• Aerial Photographer (Rick Dobbins)
• Airport Facility Managers</td><td rowspan="2">(1) Earthwork monitoring

(2) Airport inspections</td><td>Tuesday May 16,2017 (9:00 a.m. to 1:00 p.m)</td></tr>
<tr><td>Roosevelt Memorial Airport</td><td>IA03</td><td>Thursday May 18,2017 (9:00 a.m. to 1:00 p.m.)</td></tr>
</table>

4.2.4. Field Test Protocol – Aviation Group

The research team developed a protocol for airport inspection tests. (See Figure 4-7.) A total of six distinct UAS platforms were used for three different inspection tasks. The platforms used included the following:

- DJI Mavic Pro (quad-copter);
- DJI Phantom 4 (quad-copter);
- Yuneec Typhoon H (hexa-copter);
- Parrot Disco FPV (fixed-wing),
- Topcon Sirius (fixed-wing provided by the industry partner);
- DJI Matrice (developer-customized platform).

The inspection tasks tested included the following:

- Runway inspection;
- Construction inspection;
- Obstruction inspection.

Each participant in the field tests was assigned a combination of code numbers reflecting the team to which they belonged, the task they participated in, and the platform they were testing. This coding system facilitated the subsequent data analysis. Table 4-4 shows the code numbers used in the field tests.

Table 4-4**:** Field Test Code Designation

Resource	Description	Code Number	Note
Task	Runway Inspection	AV01	AV (Aviation)
	Construction Inspection	AV02	
	Obstruction Inspection	AV03	
Platform	DJI Mavic Pro	P01_1	P01: Off-the-shelf P02: Customized P03: Fixed-wing
	DJI Phantom 4	P01_2	
	Yuneec Typhoon	P01_3	
	DJI Matrice	P02_1	
	TOPCON Sirius	P03_1	
	Parrot Disco	P03_2	
Team	GT Research Team (PIC and VO)	T01	T01: GT T02: GDOT T03: Industry Partner
	GDOT Airport Inspector	T02_1	
	GDOT Airport Project Engineer	T02_2	
	Industry Partner (Skysight)	T03	

As the participants arrived at the test locations, they took part in a pre-flight meeting and then set up the ground control station (GCS) for each set of tests. Flights were performed for each inspection task tested (AV01, AV02, and AV03). The GT research team and the representative from Skysight (the industry partner) operated the platforms while the GDOT team inspected the points of interest at the GCS (e.g., runway pavement, earthwork, and surrounding vegetation, among others). All UAS pilots from the GT research team and from the industry partner were Part 107-certified. Four platforms were used in the runway inspection test (AV01) to collect still pictures (including pictures for 3D model development) and infrared imagery. In the construction inspection test (AV02), two platforms were used to collect still images (including pictures for 3D model development). Lastly, both quad-copter and fixed-wing platforms were tested for the obstruction inspection (AV03), which checks for visual or physical obstructions in the approach path at the ends of a runway. The fixed-wing platforms were particularly useful for simulating a pilot's point of view when approaching the runway during landing. The industry partner was also involved in the runway and obstruction inspection tests (AV01 and AV03). At the end of each test flight, the teams would decide collaboratively whether additional flights and/or changes to the takeoff location would be required. Figure 4-7 presents the field test protocol and Figure 4-8 illustrates the platforms used in the field tests. Table 4-5 provides the main technical specifications and other information on the equipment used.

A total of three types of data were collected: 1) still pictures (including pictures for 3D model development); 2) infrared imagery; and 3) videos. Quad-copter and fixed-wing platforms were used to collect still pictures, some of which were processed into orthomosaic maps, digital elevation models, and 3D point cloud-based models. In fully autonomous flights (enabled by a flight mission planning software application), a fixed-wing platform recorded videos of the runway approach paths. Infrared imagery was collected and processed to facilitate inspection of a number of elements of airport infrastructure. Data were collected based on the data collection plans developed for each test site. (See Figure 4-9.)

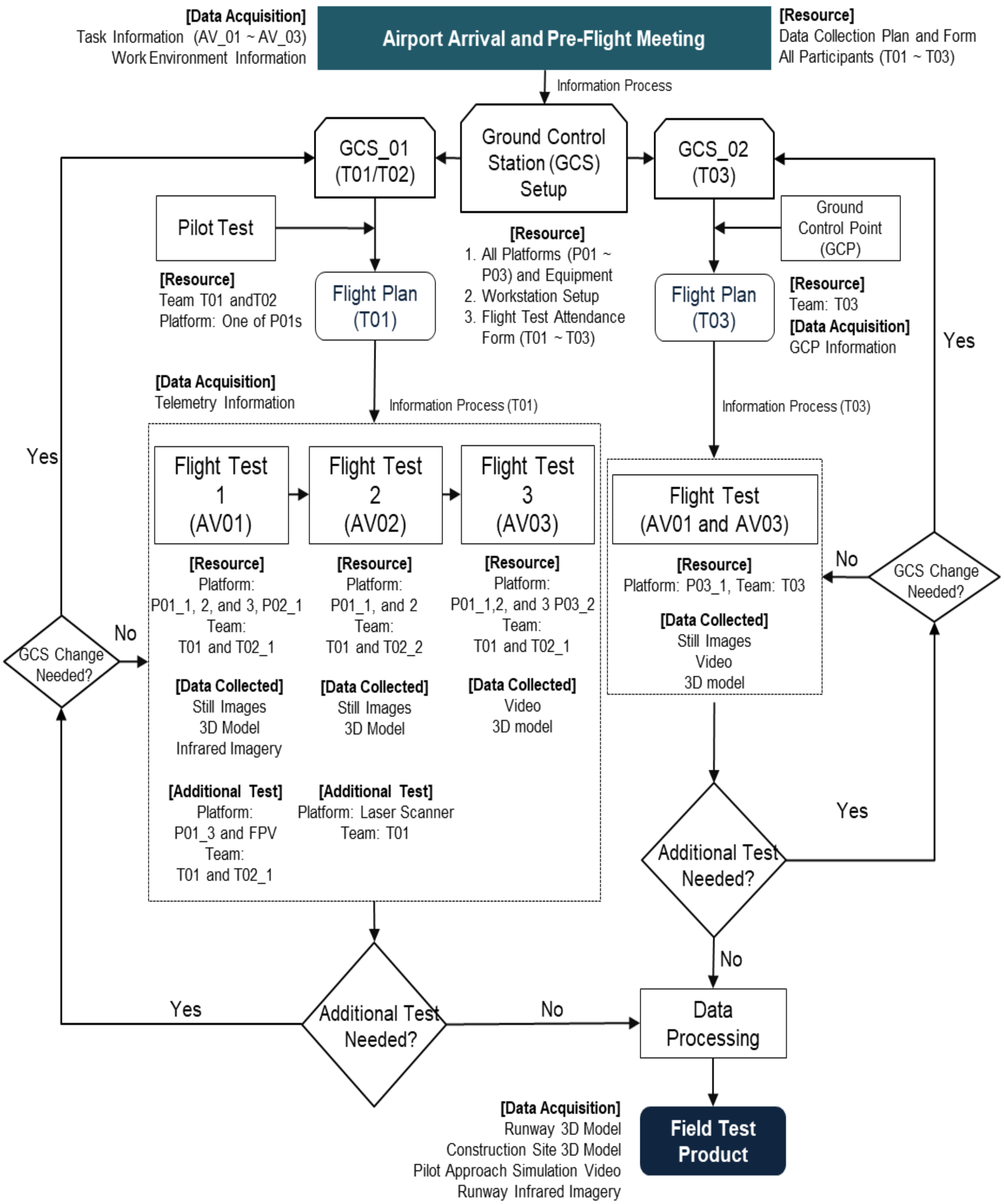


Figure 4-7: Field Test Protocol – Aviation Group

(a) DJI Mavic Pro and DJI Phantom 4 (Quad-copters)

(b) Yuneec Typhoon H (Hexa-copter)

(c) DJI Matrice (Customized Platform)

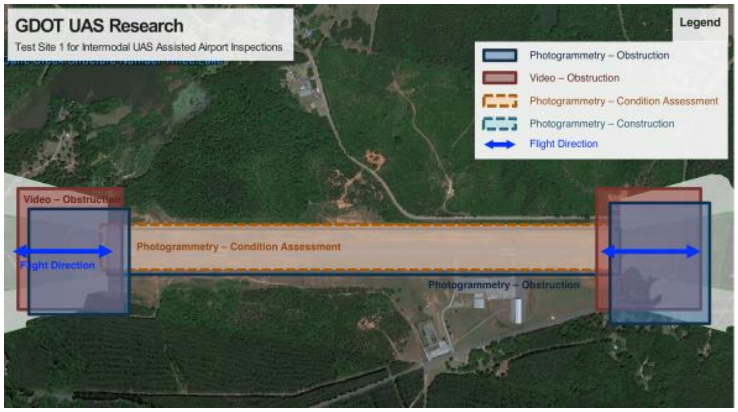
(d) Topcon Sirius (Fixed-wing)

(e) Parrot Disco FPV (Fixed-wing)

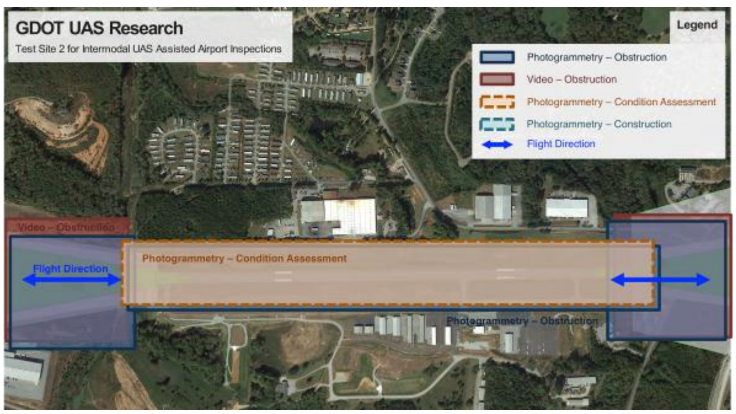
Figure 4-8: UAS platforms used in field tests

Table 4-5: UAS Platforms Specifications

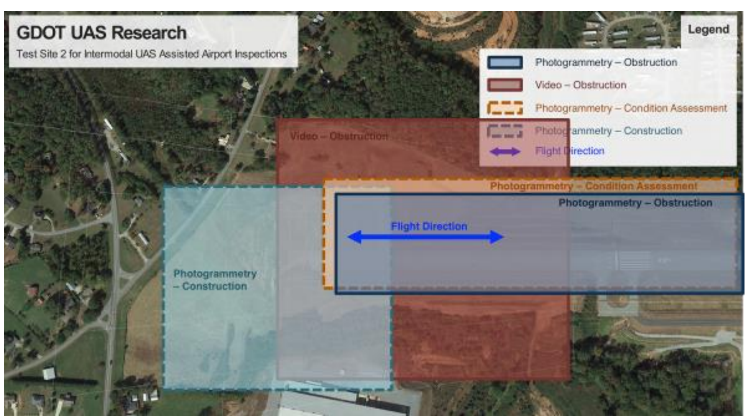
UAS Platform	Weight (g)	Flight Time (min)	Photo (MP)	Video	Mission Planning Software	Cost
DJI Mavic Pro  https://www.dji.com/mavic/info	734	27	12.35	C4K	Pix4Dmapper DJIFlightPlanner	$999
DJI Phantom 4  https://www.dji.com/phantom-4/info	1,380	28	12.4	C4K	Pix4Dmapper DJIFlightPlanner	$799
Yuneec Typhoon H  http://us.yuneec.com/typhoon-h-overview	1,695	25	12.4	4K UHD	None used	$1,199
DJI Matrice 100  https://www.dji.com/matrice100/info	2,431 + 247 (camera)	23	12	4K UHD	Pix4Dmapper DJIFlightPlanner	$3,299 + $899 (camera)
TOPCON Sirius  https://www.topconpositioning.com/mass-data-collection/aerial-mapping/sirius-pro	2,700	50	16	1080p FHD	MAVinci	$20,000
Parrot Disco FPV  https://www.parrot.com/us/drones/parrot-disco-fpv	750	45	14	1080p FHD	FreeFlgiht	$399
SenseFly Albris  https://www.sensefly.com/drone/ albris	1,800	22	38	720p HD	eMotion 3 Pix4Dmapper	$10,500



(a) Roosevelt Memorial Airport



(b) Habersham County Airport



(c) Habersham County Airport

Figure 4-9: Data Collection Plans

4.2.5 Data Collection - Airport Group

4.2.5.1. Roosevelt Memorial Airport

The field test at the Roosevelt Memorial Airport was conducted on May 16, 2017. The site is located at 9620 Roosevelt Highway in Warm Springs, Georgia, approximately 70 miles from the Georgia Tech campus. (See Figure 4-10.)

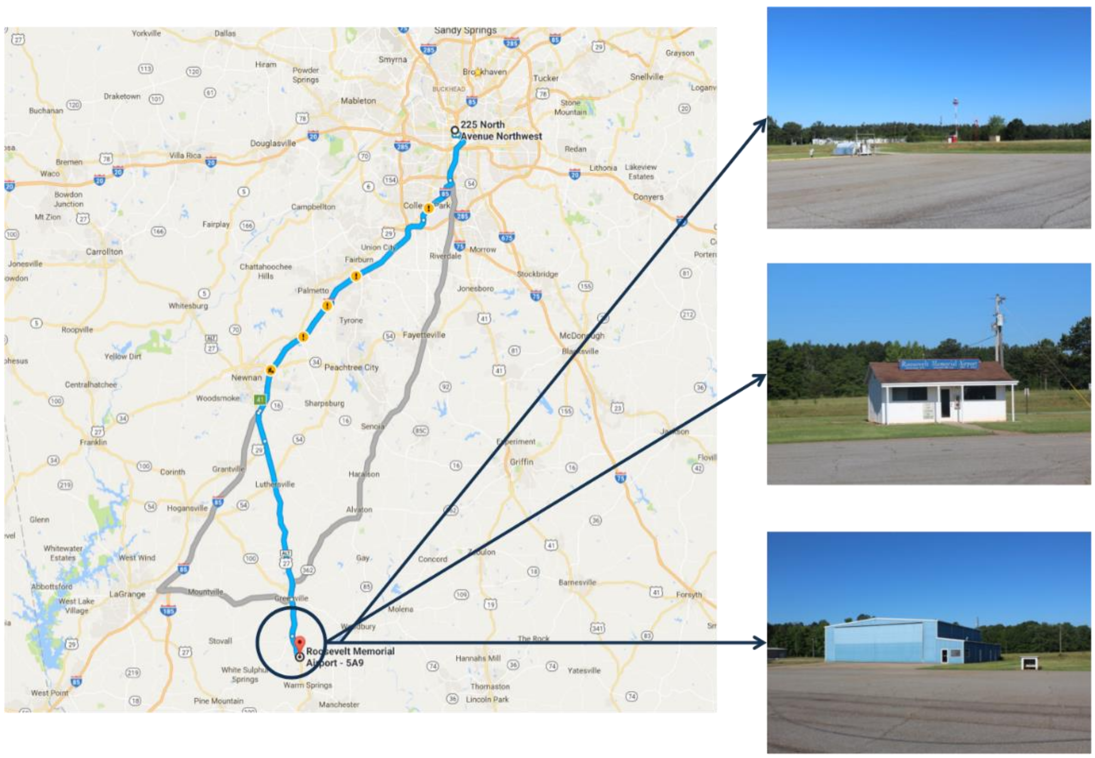


Figure 4-10: Roosevelt Memorial Airport Location and Views

The GT research team, GDOT personnel in charge of airport inspections, one airport facility manager, and four Skysight representatives were present at the test. (See Table 4-6.) Five platforms were used to collect still images, infrared images, and videos. Photogrammetric processing was used to develop 3D models from the geo-referenced still pictures. Table 4-7 lists the platforms used and the data collected during the field test.

Table 4-6: Roosevelt Memorial Airport Field Test Attendees

Name	Team	Role
Irizarry, Javier	GT-BC (PI)	Pilot in Command (PIC)
Kim, Sungjin	GT-BC	Visual Observer (VO)
Lee, Kyuman	GT-AE	Visual Observer (VO)
Hur, Jeong	GT-AE	Visual Observer (VO), Extra PIC
Haviland, Stephen	GT-AE	Visual Observer (VO)
Hood, Alan	GDOT-Aviation	Airport Inspector
Edmisten, Colette	GDOT-Aviation	Airport Inspector
Harper, Bill	Skysight	Pilot in Command (PIC)
Dobbins, Rick	Skysight	Person Manipulate Control (PMC)
Not provided	Skysight	Visual Observer (VO)
Not provided	Skysight	Visual Observer (VO)
Pynenburg, Alfons	Meriwether County FD	Attendee
Pnoullen, Gam	Airport Facility Management	Facility Coordinator

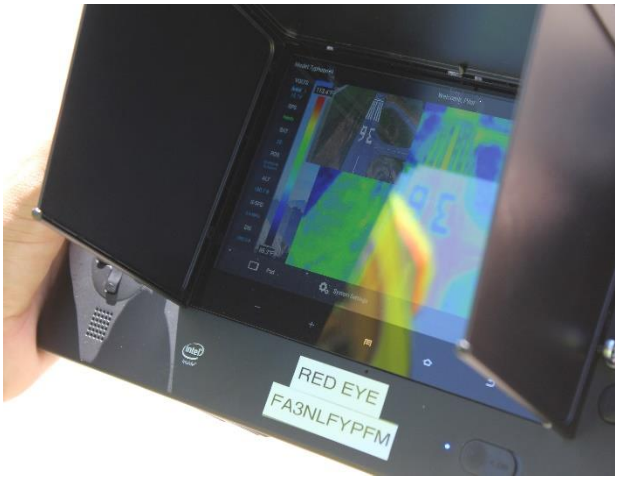
Table 4-7: Dataset from Field Test

Used Platform	Collected Data	Amount of Data
DJI Mavic Pro	Still Images Video	82 photos 1 video (2 mins, 44 secs)
Yuneec Typhoon H	Still Images Infrared Image	29 photos 29 photos
DJI Matrice	Still Images	143 photos
TOPCON Sirius	Sill Images	1233 photos
Parrot Disco	Video	2 videos (15 mins, 12 secs)

Figure 4-11 shows the field test setup, including GCS components and the personnel involved. Figure 4-12 shows sample products of the field test conducted at the Roosevelt Memorial Airport. The data collected will be described and assessed in more detail below.

(a) Hexa-copter Flight

(b) GCS Setup



(c) Ground Control Unit at GCS (Typhoon UAS)

(d) Ground Control Unit at GCS (SYrius UAS)

(e) GT Research Team's Setup

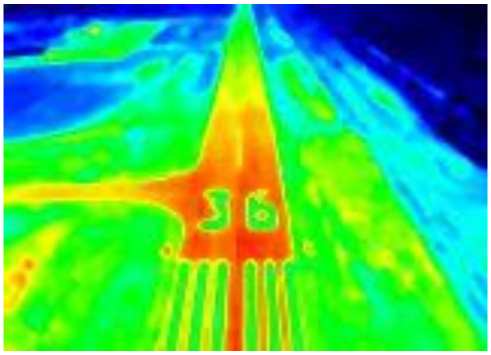
(f) Industry Partner's Setup

Figure 4-11: Field Test Setup

(a) Orthomosaic of Runway Section

(b) Approach Simulation Video and Mission Plan

(c) Still Image



(d) Infrared Image

Figure 4-12: Field Test Product Samples

4.2.5.2. Habersham County Airport

The field test at the Habersham County Airport was conducted on May 18, 2017. The airport is located at Hwy 441 Bypass in Cornelia, Georgia, approximately 70 miles from the Georgia Tech campus. (See Figure 4-13.) Table 4-8 lists the field test attendees. Table 4-9 lists the platforms used and the data collected during the field tests.

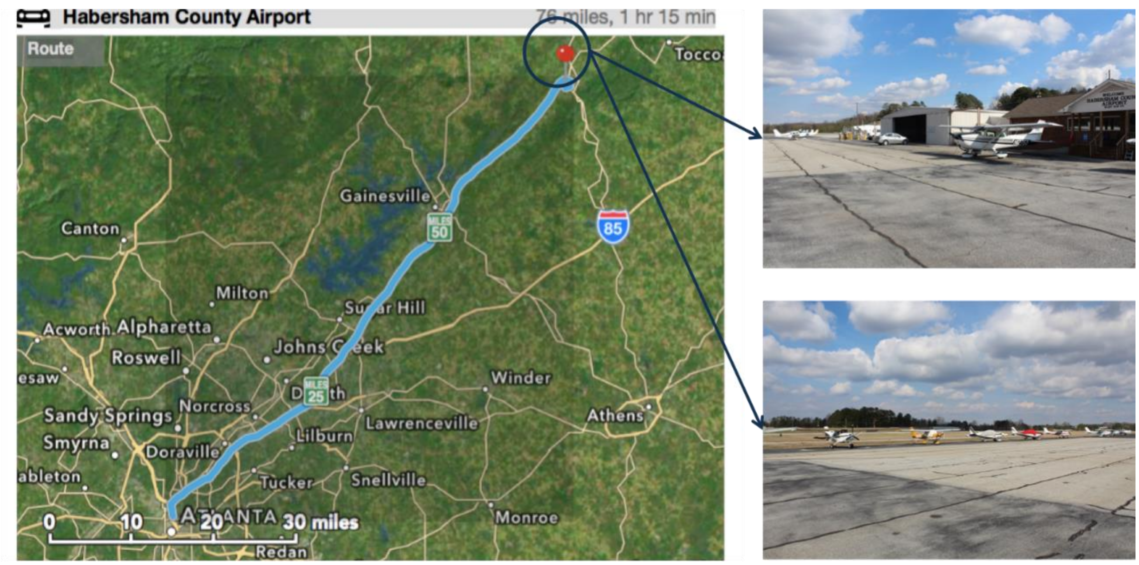


Figure 4-13: Habersham County Airport Location

Table 4-8**:** Field Test Attendees

Name	**Team**	**Role**
Irizarry, Javier	GT-BC (PI)	Pilot in Command (PIC)
Kim, Sungjin	GT-BC	Visual Observer (VO)
Lee, Kyuman	GT-AE	Visual Observer (VO)
Hur, Jeong	GT-AE	Visual Observer (VO), Extra PIC
Haviland, Stephen	GT-AE	Visual Observer (VO)
Hood, Alan	GDOT-Aviation	Airport Inspector
Robinson, Joseph	GDOT-Aviation	Airport Inspector
Harper, Bill	Skysight	Pilot in Command (PIC)
Dobbins, Rick	Skysight	Person Manipulate Control (PMC)
Not provided	Skysight	Visual Observer (VO)
Not provided	Skysight	Visual Observer (VO)

Table 4-9: Dataset from Field Test

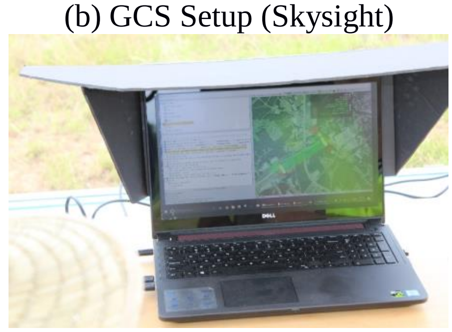
Used Platform	**Collected Data**	**Amount of Data**
DJI Phantom 4	Still Image Video	101 photos 2 videos (4 mins, 54 secs)
Yuneec Typhoon H	Still Image Infrared Image	29 photos 29 photos
DJI Matrice	Still Image	660 photos
TOPCON Sirius	Sill Image	1533 photos
Parrot Disco	Video	1 video (5 mins, 8 secs)

Figure 4-14 shows the field test setup, GCS operation and components, and the involved personnel. Figure 4-15 shows sample products from the field test conducted at the Habersham County Airport. The data collected will be described and assessed in more details below.

(a) Hexa-copter Flight

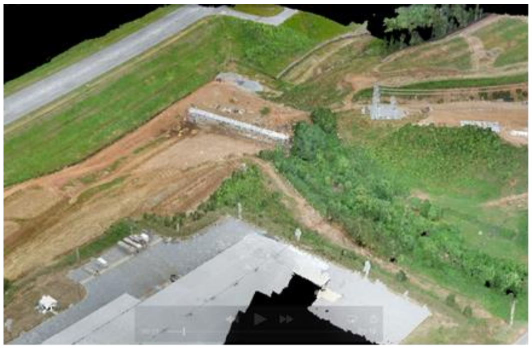
(b) GCS Setup (Skysight)

(c) Airport Inspector wearing FPV device



(d) Ground Control Unit at GCS

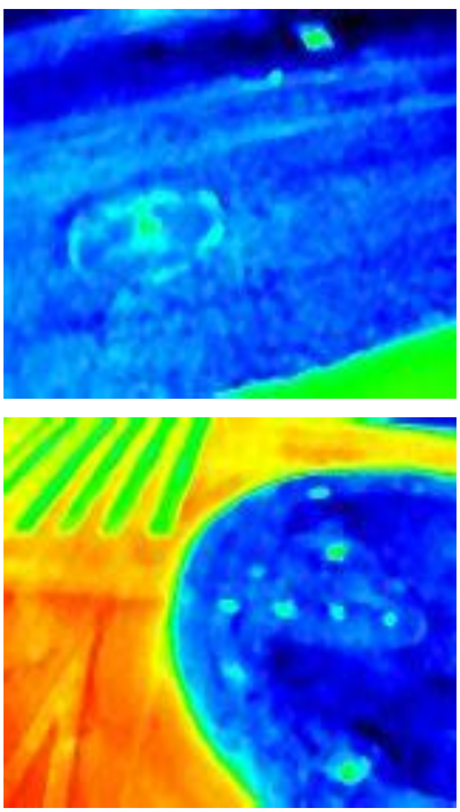
Figure 4-14: Field Test Setup



(a) 3D Model of Construction Site

(c) Approach Simulation Video and Mission Plan

(b) Orthomosaic of Facility (by Skysight)

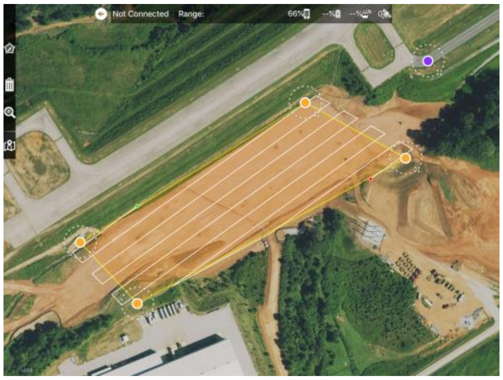


(d) Infrared Image

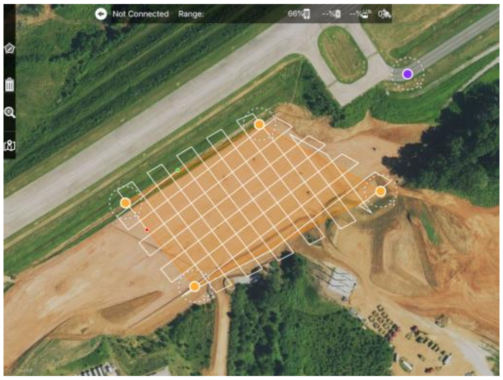
(e) Still Image

Figure 4-15: Field Test Initial Products

The last field data collection activity at Habersham Airport took place on July 11, 2018. For this last data collection session at an airport facility, GDOT personnel had the opportunity of piloting the UAS under the guidance of a research team member, who performed the role of PIC. As shown in Figure 4-16, GDOT personnel piloted a DJI Phantom 4 UAS and a Mavic Pro UAS to collect progress photos. The test also involved pre-programmed autonomous flights using the Maps Made Easy application.



(a) Linear flight pattern



(b) Grid flight pattern

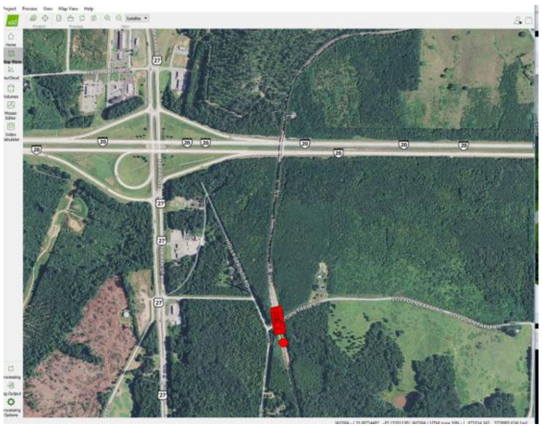
(c) GDOT Personnel at UAS controls

(d) GDOT Personnel monitoring autonomous flight mission

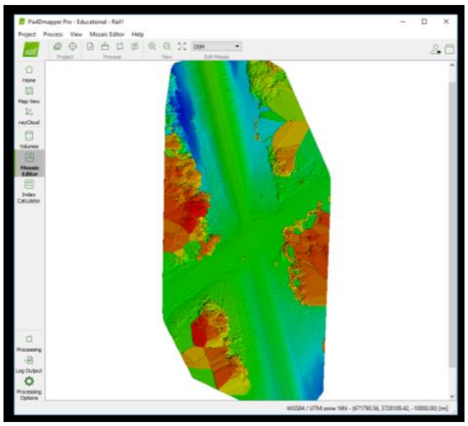
Figure 4-16 Data collection session at Habersham Airport with GDOT personnel operating UAS.

4.3. Field Test – Rail Group

Two field tests were performed in rail infrastructure environments. The first was at a section of rail located at Lovvorn Farm Road in Carrolton, Georgia and took place on August 7, 2017. The research team performed the data collection flights and used the Pix4D Capture application to perform autonomous flights. Sample products of the first of these field test are shown in Figure 4-17.

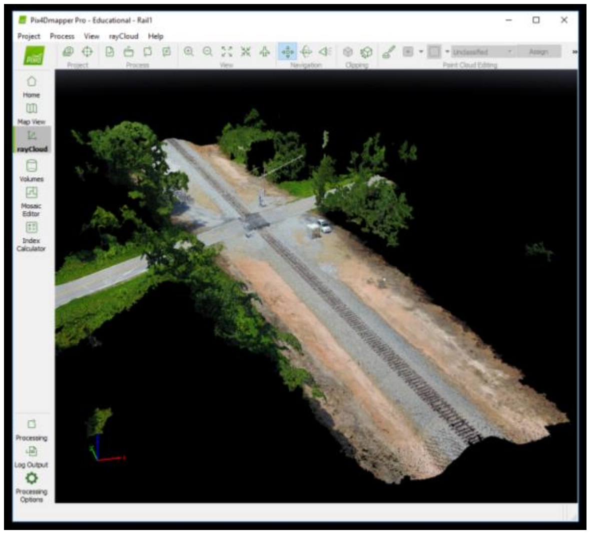


(a) Location of test site



(b) DSM of test site

(c) Orthomosaic



(d) Point cloud of site

Figure 4-17 Sample products of first rail location test

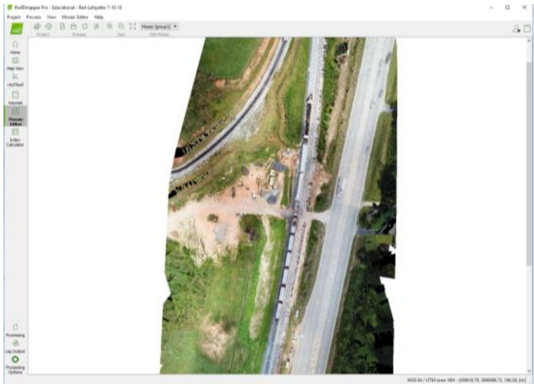
The second field test took place at sections of rail infrastructure in Lafayette, Georgia on July 10, 2018. GDOT personnel performed data collection flights under the supervision of a research team member PIC. As shown in Figure 4-18, GDOT personnel piloted the DJI Phantom 4 UAS to collect progress photos. The test also involved pre-programmed autonomous flight using the Pix4D Capture application.

(a) GDOT Personnel piloting UAS

(b) Rail Test Site Location 2 overview

(c) Rail Test Site Location 2 detail

(d) Rail Test Site Location 2 point cloud



(e) Rail Test Site Location 2 orthomosaic

Figure 4-18 Sample products of second rail location test

4.4. Field Test - Bridge Maintenance Group

4.4.1. Data collection at 17th Street Bridge

Three different UAS platforms were used to collect still images and videos during a bridge inspection field test. The platforms were tested for two different inspection tasks: deck inspection and super-/sub-structure inspection. Each participant was assigned a combination of code numbers reflecting the team to which they belonged, the task they participated in, and the platform they were testing. Figure 4-19 shows an aerial image of the location of the test environment. Table 4-10 shows the code numbers used in the field test. In addition to the GT research team, five GDOT personnel from the BMG attended the field test. (See Table 4-11.)

Figure 4-19: 17th Street Bridge Test Location

Table 4-10: Field Test Designation Codes

Resource	Description	Code Number	Note
Task	Deck Inspection	BR01	BMG (Bridge Maintenance Group)
	Super/Substructure Inspection	BR03	
Platform	DJI Mavic Pro	P01_1	P01: Off-the-shelf P02: Customized
	DJI Spark	P01_2	
	DJI Matrice	P02	
Team	GT Research Team (PIC and VO)	T01	T01: GT T02: GDOT
	GDOT BMG	T02	

Table 4-11: Field Test Attendees

Name	Team	Role
Irizarry, Javier	GT-BC (PI)	Pilot in Command (PIC)
Kim, Sungjin	GT-BC	Visual Observer (VO)
Lee, Kyuman	GT-AE	Visual Observer (VO)
Haviland, Stephen	GT-AE	Visual Observer (VO), Person Manipulating Control (PMC)
Joshua Cofer	GDOT-BMG	Bridge Inspector
Ryan Beasley	GDOT-BMG	Bridge Inspector
Charles Blue	GDOT-BMG	Bridge Inspector
Dana Mccrary	GDOT-BMG	Bridge Inspector
Bob O'Daniels	GDOT-BMG	Bridge Inspector

During the deck inspection test (BR01), multi-rotors (P01 and 02) were used to collect still images of the top- and under-deck for subsequent development of 3D models of the deck. These images allowed for the inspection of minor scaling, transverse cracks, core holes, and joint failures. For the super- and sub-structure inspections (BR02), platforms P01 and P02 were used to check for hairline cracks, large voids, and scrapes or spalls. After finishing the data collection process, the researchers used photogrammetric processing to develop 3D models. Table 4-12 summarizes the platforms used and the data collected with each UAS platform. Figure 4-20 shows the field test environment, involved personnel, and sample products (e.g., high-resolution still images). The data collected will be described and assessed in more detail below.

Table 4-12: Dataset from Field Test

Used Platform	Collected Data	Amount of Data
DJI Mavic Pro	Still Image Video	99 photos 4 videos
DJI Spark	Still Image	22 photos
DJI Matrice	Still Image	41 photos

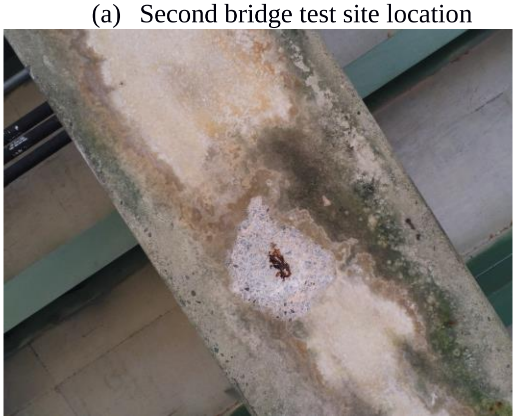
Figure 4-20: Image-based Bridge Inspection

A second bridge inspection field test was conducted on July 18, 2018 at a location under a bridge over the Chattahoochee River on GA 400. In this field test, GDOT Bridge

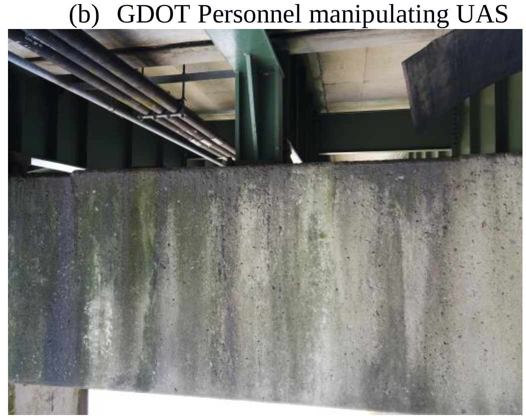
Maintenance personnel manipulated two platforms: the DJI Mavic Pro; and the Parrot ANAFI, which was one of the newer platforms available. During this test, elements similar to those observed during the first field test were also inspected, including the under-deck area and beam supports. The Parrot ANAFI platform was selected for testing because it has a camera that can face upward, a feature that no other UAS platform in the consumer-grade market possesses, and one that is particularly useful for under-bridge inspection. Figure 4-21 shows sample products from the field test.

(a) Second bridge test site location

(b) GDOT Personnel manipulating UAS



(c) Under beam support spalling observed with ANAFI UAS facing up.



(d) Under deck observation with Mavic Pro UAS

Figure 4-21 Sample products of second bridge inspection test site

4.5. Field Test – Construction Group

4.5.1. Data Collection at SR11 US-129 Project

In the field tests conducted on August 16 and September 8, 2017, four different UAS platforms were used to collect still images, infrared images, and videos, to monitor road construction. Again, each participant was assigned a combination of code numbers reflecting the team to which they belonged, the task they had participated in, and the platform they were testing. Figure 4-22 shows the location of the test site. Table 4-13 shows the code number for each task, platform, and team involved in the field test.

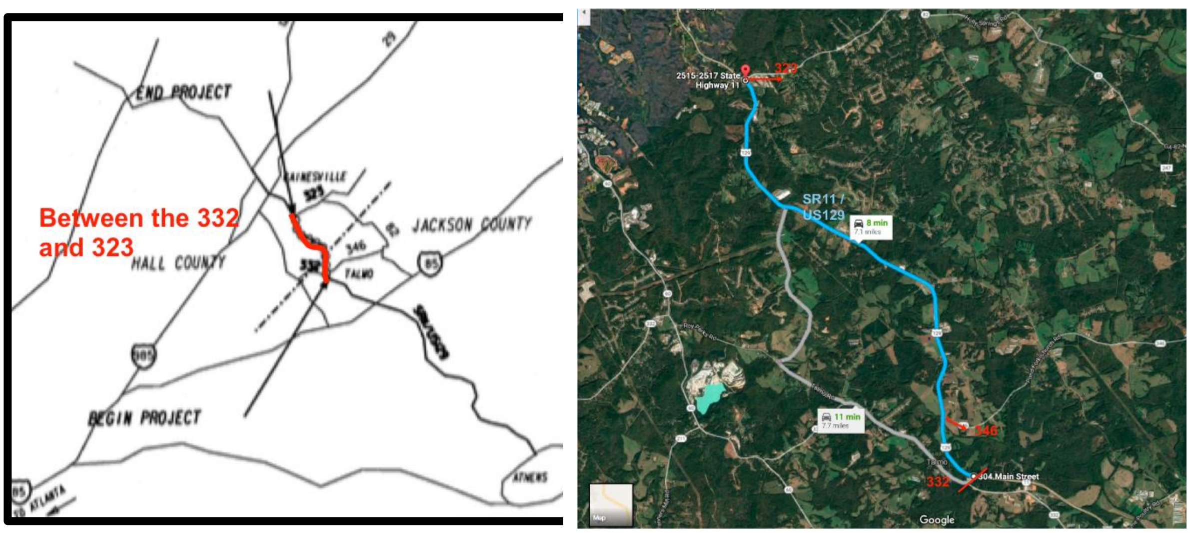


Figure 4-22: US129 Project Location

Table 4-13: Field Test Designation Codes

Resource	Description	Code Number	Note
Task	Construction Progress Monitoring	CG01	CG (Construction Group)
Platform	DJI Mavic Pro	P01_1	P01: Off-the-shelf P02: Fixed-wing
	DJI Phantom 3 Professional	P01_2	
	Yuneec Typhoon	P01_3	
	Parrot Disco	P02	
Team	GT Research Team (PIC and VO)	T01	T01: GT T02: GDOT
	GDOT CG	T02	

The GDOT PE was in charge of performing the construction progress monitoring while the GT team operated the platforms. (See Table 4-14 for a list of field test participants.)

Table 4-14: Field Test Attendees

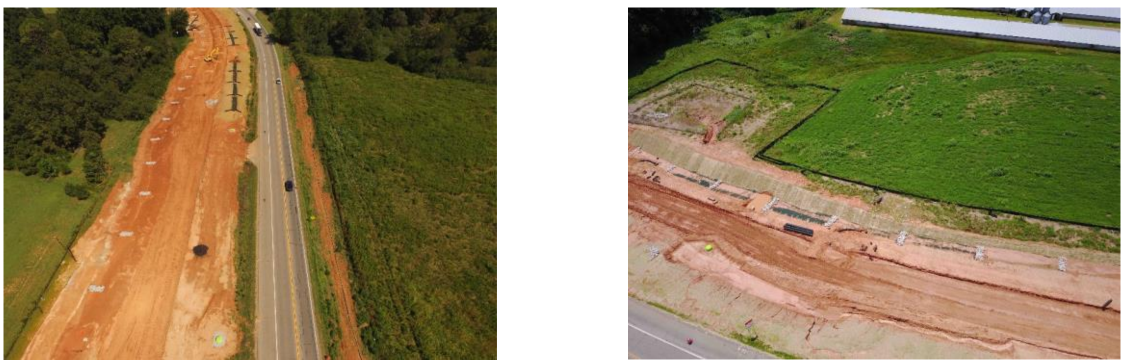
Name	Group Involved	Responsibility during test
Irizarry, Javier	GT-BC (PI)	Pilot in Command (PIC)
Kim, Sungjin	GT-BC	Visual Observer (VO)
Beaudry, Jeana	GDOT-CG	Project Engineer/Manager

Multi-rotors (P01_1 and P01_2) were used to collect still images for the subsequent development of 3D models of the road construction site, whereas the fixed-wing Parrot Disco (P02) was used to collect videos and still images. After finishing the data collection process, the research team used photogrammetric processing to develop 3D models of the site. Table 4-16 summarizes the platforms used and the data collected with each platform. Figure 4-23 shows the road construction environment, and Figure 4-24 provides examples of products from the field tests. The data collected will be described and assessed in more detail below.

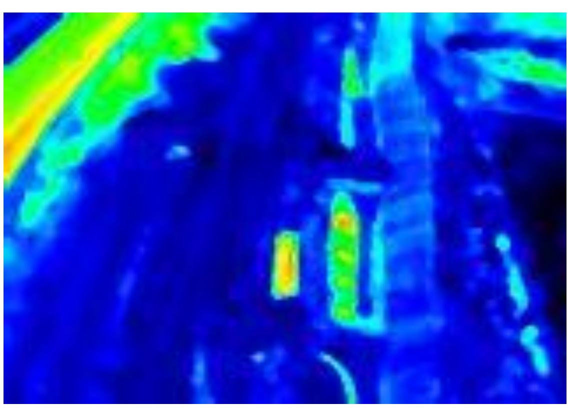
Table 4-15: Dataset from Field Test

Used Platform	Collected Data	Amount of Data
DJI Mavic Pro	Still Image	32 photos (09/08/17) 160 photos (08/16/17)
DJI Phantom 3	Still Image	387 photos (08/16/17 - Road) 680 photos (09/08/17 - Road) 49 photos (09/08/17 - Bridge)
Yuneec Typhoon (08/16/17)	Still Image Infrared Image	21 photos 21 photos
Parrot Disco (09/08/17)	Still Image Video	11 photos 3 videos

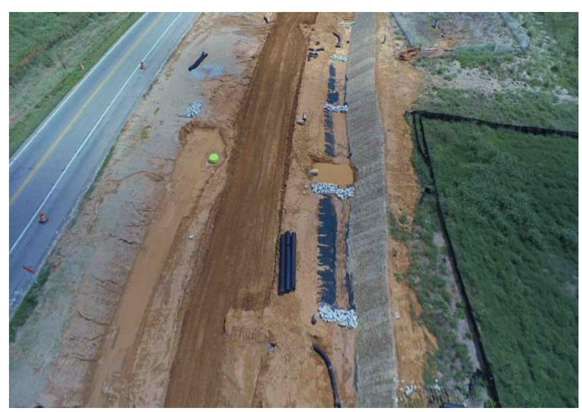
Figure 4-23: Road Construction Environment



(a) Still Images of Road Construction Project (Phantom 3)



(b) Infrared Image (Yuneec Typhoon)

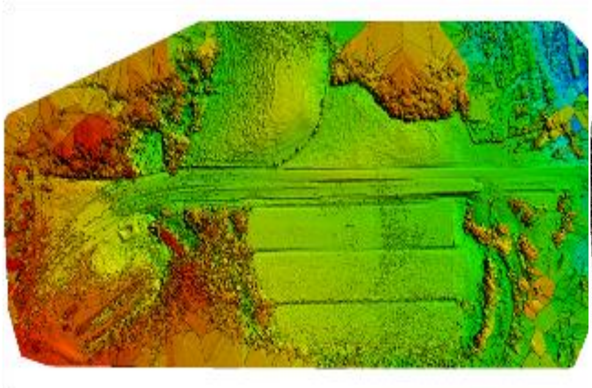


(c) Still Image (Yuneec Typhoon)

Figure 4-24: Field Test Sample Products

A total of 547 geo-referenced images collected from this test were processed into 3D models. Figure 4-25 and 4-26 shows samples of 3D models and orthomosaic maps of the road construction project.

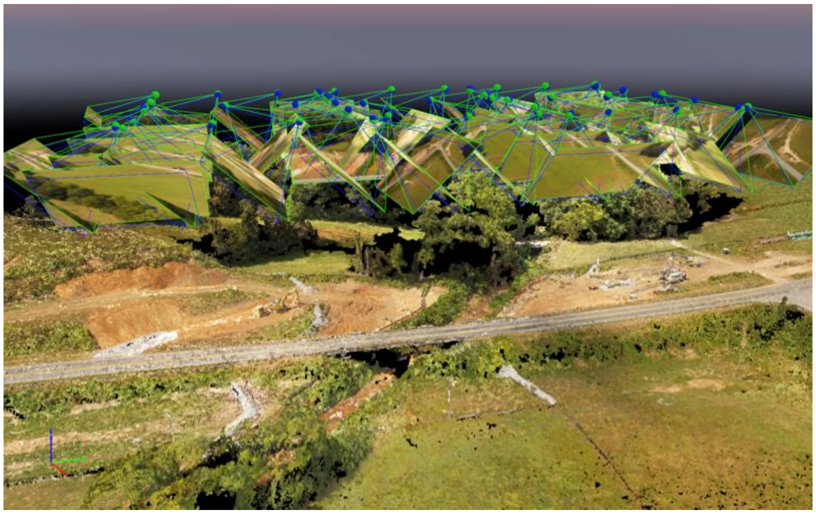
(a) Road Construction 3D Point Cloud



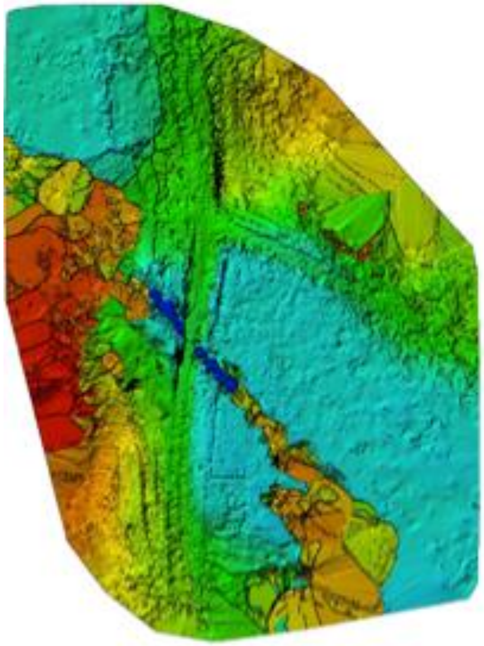
(b) Road Construction Digital Elevation Model

(c) Road Construction Orthomosaic Map

Figure 4-25: Field Test Sample Products



(a) Bridge Construction Point Cloud



(b) Bridge Construction Digital Elevation Model

(c) Bridge Construction Orthomosaic Map

Figure 4-26: Field Test Sample Products

The last field data collection activity at the US-129 project took place on July 23, 2018. During this last data collection session at a construction site, GDOT personnel had the opportunity to pilot the UAS under the guidance of the research team member acting as PIC. As shown in Figure 4-27, GDOT personnel piloted the DJI Phantom 4 UAS to collect progress photos. This test also involved pre-programmed autonomous flight through the use of the Pix4D Capture application.

(a) GDOT personnel at UAS controls

(b) progress photo capture by GDOT personnel

Figure 4-27 Data collection session at US-129 project with GDOT personnel operating UAS.

5. UAS Workshop

In order to disseminate preliminary results from initial field tests and introduce GDOT personnel to UAS technology, the research team held a workshop in the Caddell Building on the Georgia Tech Campus on July 18, 2017.

5.1 Workshop Attendees

Personnel from the Construction, Bridge Maintenance, and Intermodal Groups, as well as from the HERO, public safety, and legal departments attended the workshop. The industry partner, Skysight Imaging, and the project's research implementation manager also attended.

5.2 Workshop Sessions and Topics

The workshop included an overview of the research project, an introduction to UAS technology, an overview of applicable FAA regulations, preliminary findings from the first year of the research project, and a UAS hand-on activity. The preliminary research findings include a thorough review of UAS-related research by other State DOTs, as well as the results from the FG sessions and initial field tests with the aviation department.

The workshop was structured in three sections: 1) presentation of UAS-related information; 2) brainstorming session and survey questionnaire completion; and 3) a hands-on activity and structured group interview session. In the presentation portion, the research team provided a description of the results from the FG sessions and field tests with the aviation department. During this section, the researchers also performed a Pix4D use demonstration, and presented 3D models obtained from UAS-collected data. Lastly, samples of visual data collected from the I-85 bridge re-construction project were also presented and discussed. Figure 5-1 shows the setting of the workshop.

Figure 5-1: Workshop setting

After completing the presentation portion of the workshop, participants engaged in a brainstorming session on how UAS technology could be integrated into their tasks. The discussions covered several topics related to the technological, procedural, and legal requirements for UAS integration. A survey form with open-ended questions was provided to workshop participants to collect their feedback on the following topics:

- equipment needs
- equipment and software capabilities
- internal operational changes
- FAA regulation compliance
- internal usage policies, procedures, and permissions

- flight documentation/report needs
- training and licensing requirements
- insurance and privacy issues
- damage liability.

Figure 5-2 shows the setting of this brainstorming session.

Figure 5-2: Brainstorming Session Setting

The final session of the workshop was a hands-on activity conducted outdoors in front of the Caddell Building on the Georgia Tech campus. This activity was followed by a structured group interview. During the hands-on activity, participants had the opportunity to fly a UAS platform under close supervision of the GT research team. Two pilots with Part 107 certification supervised the activity, demonstrating the tasks involved before participants took part in the activity. Participants were able to launch the aircraft from the grassy area in front of the Caddell Building—where the research team had set up the GCS—and fly it over the Van-Leer Building construction site adjacent to Tech Green. (See

Figure 9-4.) Participants were asked to perform the following six tasks: 1) taking off and climbing to altitude (100 feet); 2) hovering in place; 3) performing flight patterns; 4) flying to the construction jobsite (point of interest); 5) taking still pictures; and 6) returning to and landing at the home location. To comply with FAA regulations, all tasks were conducted below 400 feet above ground level (AGL). A total of 10 attendees participated in this activity. Figure 5-3 shows the setting of the hands-on activity session. Figure 5-4 shows the DJI Phantom 4 UAS that was the platform used for the hands-on activity.

Figure 5-3: Hands-on Activity Session

Figure 5-4: UAS platform used for the hands-on activity

Following the hand-on activity, a structured group interview was conducted with workshop participants to collect their perceptions about additional technological, operational, and human factors involved in UAS integration into GDOT tasks. A total of 13 GDOT professionals participated in the group interview (including the 10 participants in the hands-on activity). The entire interview session was recorded, and all questions were previously evaluated and approved by the Georgia Tech Institutional Review Board (IRB).

5.3 Results of Group Interview

UAS Platform Type

The interviewees were asked to indicate which UAS platform was most suitable for their tasks (e.g., multi-rotor or fixed-wing). Construction managers and airport inspectors stated that both platforms could be used in their tasks (for airport runway as well as road construction inspections). However, since road construction environments usually involve large jobsites—often extending over two miles—a fixed-wing platform could be of more benefit to construction progress monitoring tasks than multi-rotor UASs.

Conversely, multi-rotors were seen as more suitable for bridge and culvert construction inspections, bridge inspections, highway emergency operations, and traffic monitoring. Such tasks cannot rely on fixed-wing platforms, since they require significant room for takeoff and landing. In addition, some of these tasks (e.g., bridge inspections) require the platform to collect close-up images, which a fixed-wing platform cannot do since it cannot approach structures in the way needed to collect detailed images.

UAS Sensors

Participants indicated that infrared cameras and light detection and ranging (LiDAR) sensors could be beneficial to their tasks. They also indicated that a UAS platform equipped with a thermal camera could be used at airports to check airport runway marking conditions and monitor runway lighting operation. Nevertheless, the interviewees agreed that the most useful resources could be the 3D models developed from geo-referenced 2D images, even given that the accuracy of these 3D models is subject to the capabilities of the platform's camera and GPS sensor.

Data Process and Management System

Participants also discussed the need for a data processing and management system to support UAS operations, as outlined in Table 5-1. Most groups concurred that all data should be properly stored in a secure server, including flight log files. They also agreed on the need for a defined process for performing 3D mapping.

Table 5-1: Data Process and Management System Requirements

Task Environment	Requirements
Construction	• Requires cloud-based software and employee training on software • Defined 3D data-mapping process • Automated earthwork measurement from UAS data • UAS would monitor many construction processes • Capability to continuously map project progress in 3D • System ability to provide data access depending on the organizational or staffing level
Bridge	• Defined 3D data-mapping process • Be able to handle/share large volume of data • Needs to consider different types of bridges, sizes, and surrounding environments • Needs UAS-based work procedure
Airport	• Liability, insurance, data retention, and flight planning • Inspection could take longer because the UAS cannot accomplish all tasks. • Requires new operational team; requires a certified pilot and visual observer • Cloud-based software able to handle large volume of data
HERO	• Cloud-based software • Defined 3D data-mapping process
Others	• Needs further study about developing software for infrastructure domain • Considers insurance, liability, documentation process, and federal law (14 CFR Part 107)

Team Composition

Participants agreed on four essential roles for UAS operation teams: 1) the pilot-in-command (PIC); 2) the person manipulating control (PMC); 3) the visual observer (VO); and 4) project specialists. (See Table 5-2.) Nonetheless, team members could perform multiple roles depending on their capabilities, training, and experience. The PIC must be an FAA-certified pilot—that is, he or she must hold a Part 107 Remote Pilot Certificate), and must have knowledge of flight controls and airspace. The PIC can operate the UAS during missions or directly supervise others flying missions. The project specialist, who is primarily in charge of project management or inspection, could eventually take the place of the PIC, if he or she has been trained and certified. According to FAA regulations, the PMC is the team member in charge of handling the sensors, platforms, and missions during the entire operation (FAA 2016). The visual observer is responsible for making sure the aircraft is at a safe distance from surrounding objects by maintaining a line of sight on it. In addition, the VO should be familiar with the work environment and sequence of UAS flights. During the aircraft's flight, team members should use two-way radios and hand signals for remote, continuous communication. Table 5-2 presents the UAS team roles and their respective duties.

Table 5-2: Team Composition Requirements

Roles	Requirements
PIC	• Holds the highest level of operational training • Needs certification (FAA Part 107 Remote Pilot Certificate) • Needs continuous communication with others
PMC	• Assists the PIC in operating UAS hardware and software • Crew resource management, UAS operation, air traffic, and flight mission planning • Not required under the FAA Part 107
VO	• Maintains sight of the aircraft • Is familiar with GDOT's field tasks, equipment, and safety procedures • The roles of VO and PMC could be held by one person.
PE	• With proper training and certification, PE may take PIC role. • Should be involved in all flight operations with the PIC

Privacy, Safety, and Legal Issues

All operations should consider private property, pedestrians, and traffic near the flight area. Moreover, an emergency response plan must be implemented in case of accident or loss of communication between the operator and the aircraft. Insurance for UAS damage liability should be required. The GDOT UAS operation policy should comply with FAA regulations. Privacy protection measures, emergency response plans, and insurance requirements should be clearly described in the policy as well. Table 5-3 presents the legal issues in terms of privacy, emergency response, and insurance.

Table 5-3: Privacy, Safety and Legal Requirements

Attribute	Requirements
Privacy	• Do not fly over people. • Follow current FAA guidelines. • Apply existing data management policy to ensure privacy.
Emergency Response	• `Emergency response plans • Classification of emergency situations and corresponding response measures
Insurance	• Provide insurance for GDOT operators as well as third party liability insurance (GDOT requires contractors and consultants to provide their own insurance). • A state equipment coverage system could be used.

Other Relevant Issues

Interviewees also emphasized the importance of conducting pre-flight inspections and of an adequate GCS setup. Another point raised related to the involvement of third-party UAS operators, who should provide certified pilots, equipment, and insurance. They also suggested that employers have a legal agreement with GDOT regarding data access and management. Table 5-4 summarizes the group interview results.

Table 5-4: Summary of Group Interview Results

	UAS Platform	UAS Sensors	Data Management System	Team	Legal Issues
Construction	Fixed-wing & Multi-rotor	High-accuracy telemetry sensors	3D data processing system, automated earthwork measurement and payment calculation system, and cloud-based documentation system	PIC, PE, and VO	Certified PIC, privacy issues, emergency response plan, insurance.
Bridge	Multi-rotor	Infrared camera, LiDAR	3D data processing and documentation system	PIC, Bridge Inspector, and/or VO	
Airport	Fixed-wing & Multi-rotor	Infrared camera, LiDAR, and high-accuracy telemetry sensors	Cloud-based documentation system	PIC, Airport Inspector, and/or VO	
HERO	Multi-rotor	Infrared camera, conventional camera	3D data processing and cloud-based documentation system	PIC and VO	
Others	Fixed-wing & Multi-rotor	Infrared camera, LiDAR, and high-accuracy telemetry sensors	Documentation system compatible with current system	PIC and VO	

6. Data Processing

This chapter describes the processing of the visual data collected from the various field test sites. Photogrammetry had been the method deployed to obtain several products for use in the GDOT tasks selected for study. The process is described in detail in this chapter through an example. Lastly, samples of products from the various tests are presented.

6.1 Photogrammetry Software Selection

A number of software applications can be used to enable the UAS-assisted tasks tested in this research. In short, data collected with the UAS platforms can be processed into graphical representations such as 3D models and orthomosaic maps, which, in turn, allow for the inspection, surveying, mapping, and monitoring of infrastructure, among other tasks. Some applications available include the following: Pix4Dmapper, DroneDeploy, Agisoft Photoscan, Autodesk Recap, and PhotoModeler UAS. Table 6-1 provides information on each application referenced.

Table 6-1: Sample of Photogrammetry Software Available

Application	Measurement features	Processing mode	Cost (per licensed user)	Product website
Pix4Dmapper	Polylines, distance, surface, volume	Cloud & Local	$1,900 Educational Version, $3,500/year Professional Version	https://pix4d.com/wp-content/uploads/2017/10/Pix4Dmapper-V4.0-Feature-List_NEW_version-m.pdf
DroneDeploy	Volume, crop health, roof	Local	$399 per user/month	https://prismic-io.s3.amazonaws.com/dronedeploy-www%2Fd25e2331-b928-471d-9c6b-fbbc4f7e456b_dronedeploy-pricing-comparison.pdf
Agisoft Photoscan	Coordinate, distance, area, volume	Local	$179 Standard Edition, one computer	http://www.agisoft.com/pdf/photoscan_presentation.pdf
Autodesk Recap	Ortho distances, pipe diameters, angles, snap to objects	Cloud	$300 annually	https://www.autodesk.com/products/recap/overview
PhotoModeler UAS	Volume, terrain contour	Local	$3,995 permanent license, $2,075 annually, $199 monthly	http://www.photomodeler.com/products/UAS/default.html

Pix4Dmapper was selected as the primary data processing software tool for this research project due to a number of advantages it has over its peers. This application is highly compatible with the DJI equipment used on the project. It provides the option to process data locally or in the cloud (as shown in Table 6-1). It can also automatically separate a dense point cloud into five groups: ground, road surfaces, buildings, high vegetation, and human-made objects. The application interacts with a companion mobile application that facilitates the planning of autonomous data collection missions. Lastly, Pix4Dmapper also has a “floating license” feature that allows for the activation/deactivation of a license tied to a certain computer at any time in case a new computer is required. This provides flexibility to users since the license can be shared by several users.

6.2 Photogrammetry Process with Pix4D

The first step in the application of photogrammetry to images collected with a UAS is to design an efficient image acquisition plan, taking into account the following factors: project purpose and type (aerial, terrestrial, mixed); type of camera; the rate, distance, and angle at which images are taken; and the flight path(s). On aerial projects, for instance, paths can be of different types: corridor; regular grid; or circular grid. Deciding on whether more than one flight is needed to cover the full area is also critical. In such cases, it is important to determine the area to cover on each flight. The second step before starting a project is to configure the camera settings. Wrong configuration can result in images with unwanted blur, noise, and distortions. (For specific details on camera configuration, refer to the software developer's documentation.)

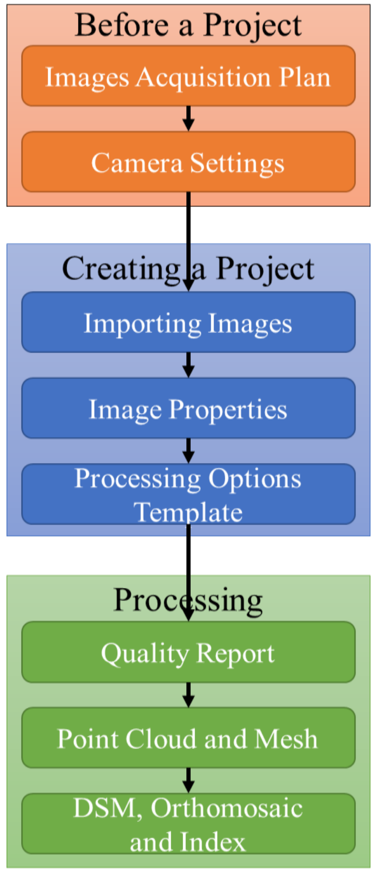


Figure 6-1: Data Processing Workflow

Creating a new project on Pix4D involves the following five steps: 1) starting and saving a new project; 2) importing the images; 3) setting up the image properties; 4) selecting the output/ground control point (GCP) coordinate system; 5) and selecting the processing options template. Because images carry internal geo-location information, it is important to define the coordinate system on Pix4D in order to import the geo-location information along with the images. This is especially important when using GCPs.

Lastly, when processing a new project, the following steps are recommended: initial processing; analyzing the quality report; point cloud and mesh development; and Digital

Surface Model (DSM), orthomosaic and index processing. Figure 6.1 shows the photogrammetry workflow with Pix4Dmapper, and the following sections briefly describe the process steps.

Creating a New Project

To create a new project, start Pix4Dmapper and then click **Project, New Project**, on the menu bar. Then, type a name for the project and keep the default option **New Project** selected in **Project Type**, as shown in Figure 6-2.

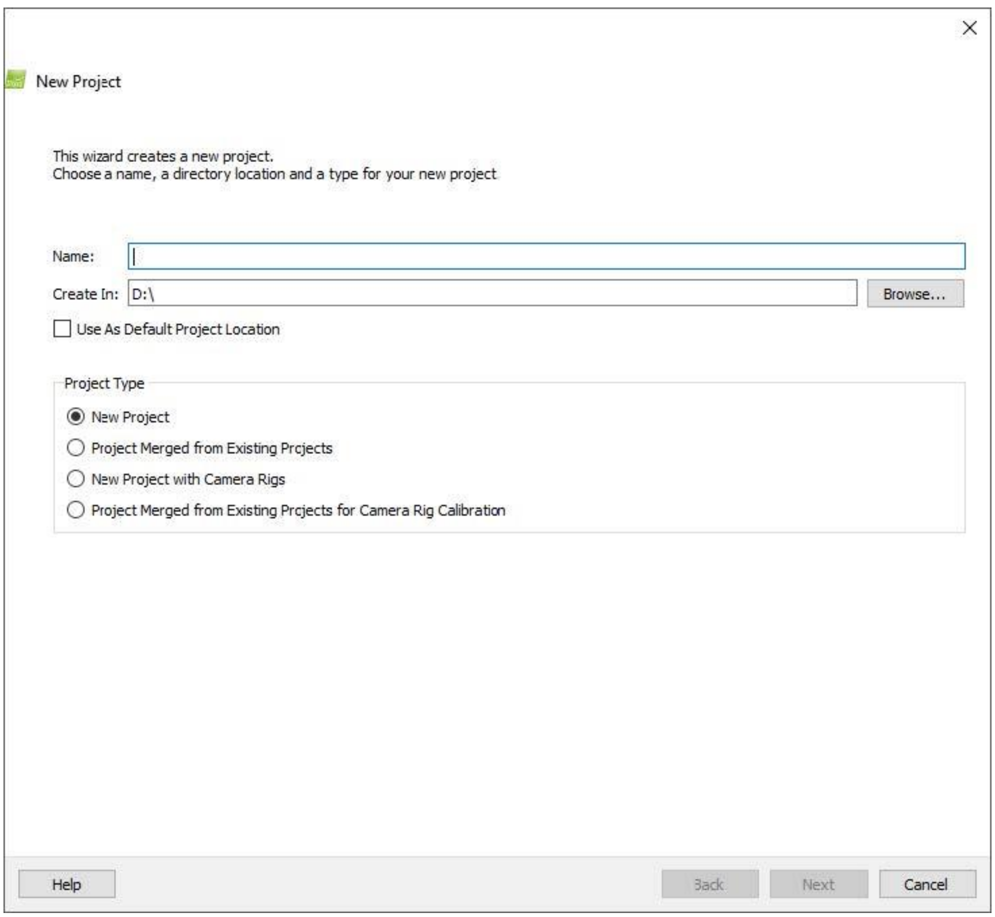


Figure 6-2: New Project Window

Next, to import the images, click **Add Images** in the **Select Images** window. On the **Select Images** pop-up, navigate to select the folder in which the images are stored, select the images to be imported (it is possible to select multiple images), and then click **Open**. As shown in Figure 6-3, the **New Project** wizard displays the **Image Properties** window, which contains three separate sections for image geolocation, the selected camera model, and a table of images.

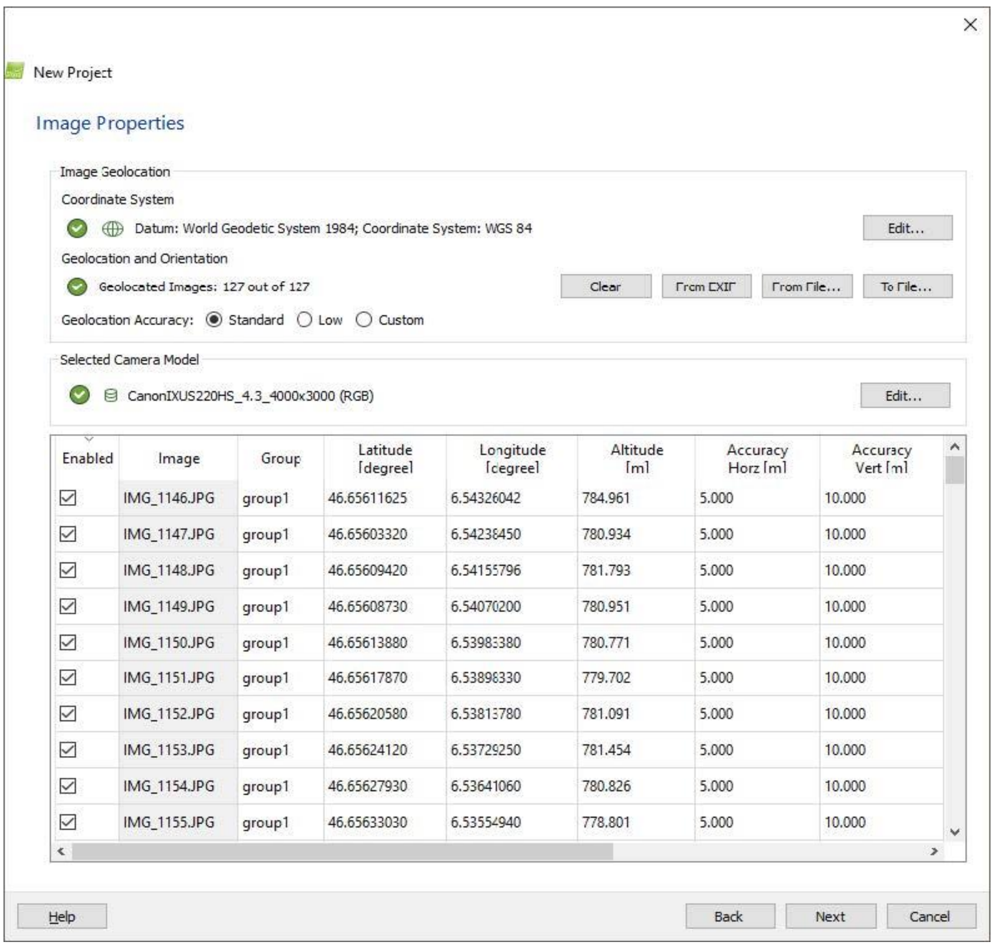


Figure 6-3: Image Properties Window

- **Image Geolocation**: This function sets the coordinate system to which the image geo-location data refers. It imports or exports coordinates and, if needed, it registers the orientation of the images and/or the accuracy of the coordinates. It also sets the accuracy of the image geo-location. If the image geo-location information is stored in the EXIF of the images, it will be loaded automatically.
- **Selected Camera Model**: This function sets and configures the camera model associated with the images. If the software cannot recognize the camera model, different camera parameters can be submitted by editing the camera model.
- **Images Table**: This section of the **Image Properties** window displays the selected images, and provides the group, position, position accuracy, and orientation of each image. It also registers whether the image is enabled or not. (Only enabled images can be processed.)

In the **Processing Options Template** window, select the desired template (it can be edited or changed before processing). The **3D Maps** option is selected by default, but many others templates are available. (See Figure 6-4 and Table 6-2.)

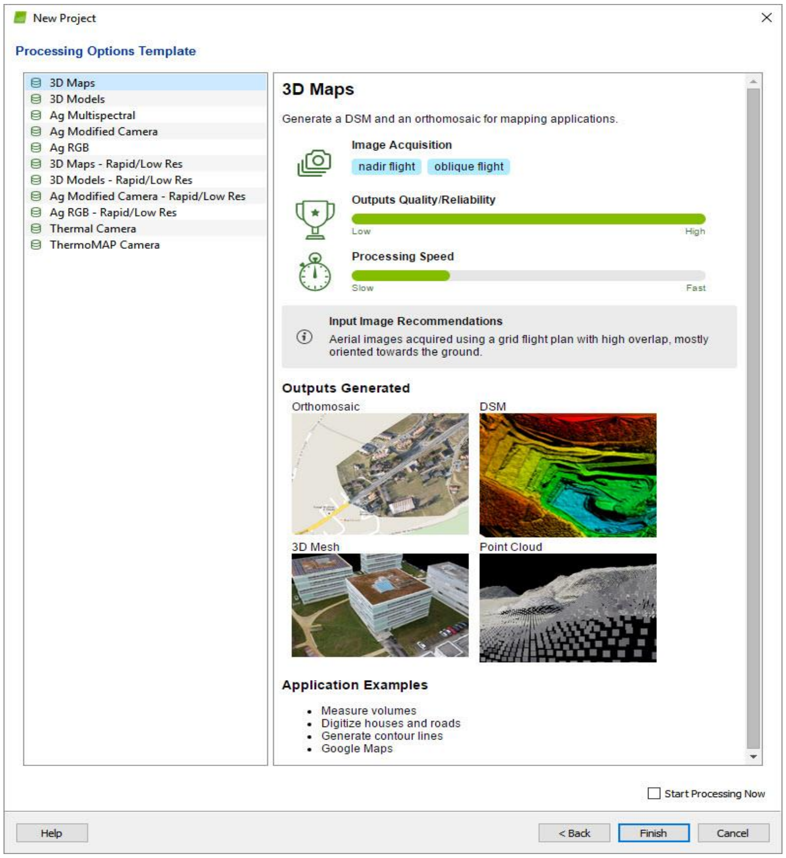


Figure 6-4: Processing Options Template Window

Table 6-2: Characteristics of Each Processing Options Template

Processing Options Template	**Characteristics**
3D Maps	• Generates a 3D map (e.g., point cloud or 3D textured mesh), as well as a DSM and an orthomosaic. • Image acquisition: nadir or oblique flight. • Typical input: aerial images acquired using a grid flight plan with high overlap. • Outputs quality/reliability: high. • Processing speed: slow. • Application examples: quarries and cadasters, among others.
3D Models	• Generates a 3D model (e.g., point cloud or 3D textured mesh). • Image acquisition: oblique flight or terrestrial. • Typical input: any images with high overlap. • Outputs quality/reliability: high. • Processing speed: slow. • Application examples: 3D models of buildings, objects, ground imagery, indoor imagery, and inspection, among others.

Ag Multispectral	• Generates reflectance, index (such as NDVI), classification, and application maps. • Image acquisition: nadir flight with multispectral camera. • Typical input: images from multispectral cameras (Sequoia, Micasense RedEdge, Multispec 4C, etc.). • Outputs quality/reliability: high. • Processing speed: slow. • Application examples: precision agriculture.
Ag Modified Camera	• Generates reflectance, index (such as NDVI), classification, and application maps. • Image acquisition: nadir flight with modified RGB camera. • Typical input: images taken with modified RGB camera. • Outputs quality/reliability: high. • Processing speed: slow. • Application examples: precision agriculture.
Ag RGB	• Generates an orthomosaic for precision agriculture. • Image acquisition: nadir flight over flat terrain with RGB camera. • Typical input: images taken with RGB cameras for agriculture (Sequoia RGB). • Outputs quality/reliability: high. • Processing speed: average. • Application examples: digital scouting; report claiming for precision agriculture.
3D Maps Rapid/Low Res	• Faster processing of the 3D Maps template for assessing the quality of the acquired dataset. • Outputs quality/reliability: low. • Processing speed: fast.
3D Models Rapid/Low Res	• Faster processing of the 3D Models template for assessing the quality of the acquired dataset. • Output quality/reliability: low. • Processing speed: fast.
Ag Modified Camera Rapid/Low Res	• Faster processing of the Ag Modified Camera template for assessing the quality of the acquired dataset. • Output quality/reliability: low. • Processing speed: fast.
Ag RGB Rapid/Low Res	• Faster processing of the Ag RGB template for assessing the quality of the acquired dataset. • Output quality/reliability: low. • Processing speed: fast.
Thermal Camera	• Generates a thermal reflectance map. • Image acquisition: nadir flight with thermal camera. • Typical input: images taken with thermal cameras (such as Tau 2 based cameras: FLIR Vue Pro, FLIR XT). • Output quality/reliability: high. • Processing speed: slow.
ThermoMAP Camera	• Generates a thermal reflectance map. • Image acquisition: nadir flight with thermoMAP camera. • Typical input: images taken with a thermoMAP camera. • Output quality/reliability: high. • Processing speed: slow.

Finally, click **Finish** to close the wizard and start the project. Once the project is created, the **Map View** is displayed. (See Figure 6-5.)

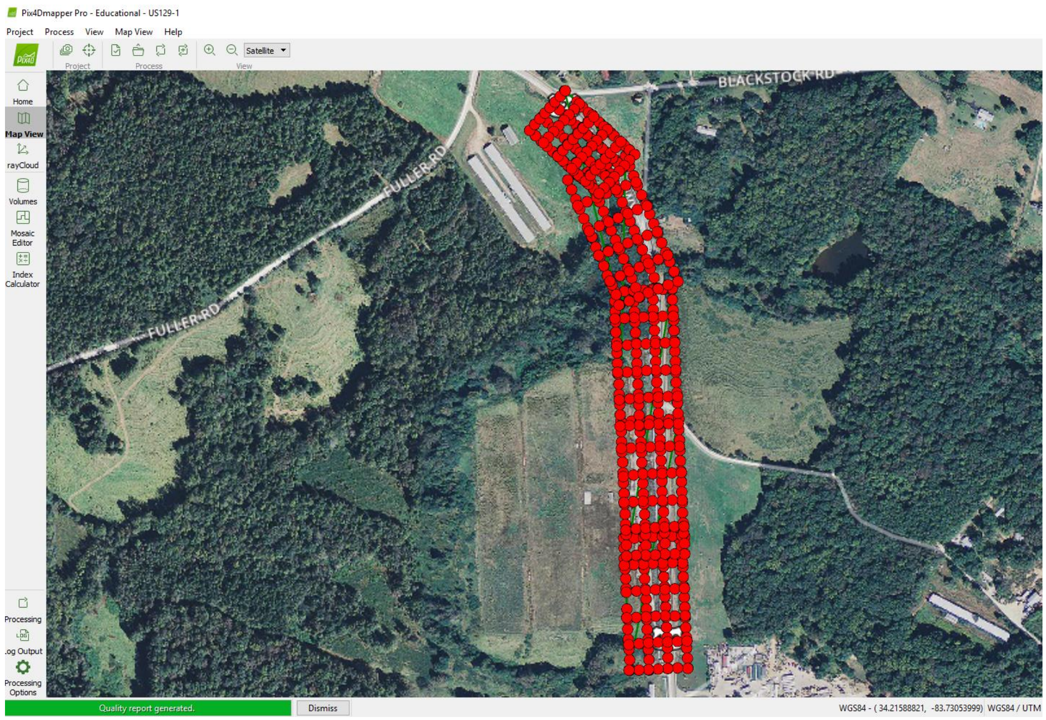


Figure 6-5: Map View Window

Processing

To start processing the project, first click **View, Processing**, on the menu bar. When the **Processing** bar opens at the bottom of the main window, make sure that **1. Initial Processing** is selected, and that **2. Point Cloud and Mesh** and **3. DSM, Orthomosaic and Index** are not selected. Click **Start**. (See Figure 6-6.)

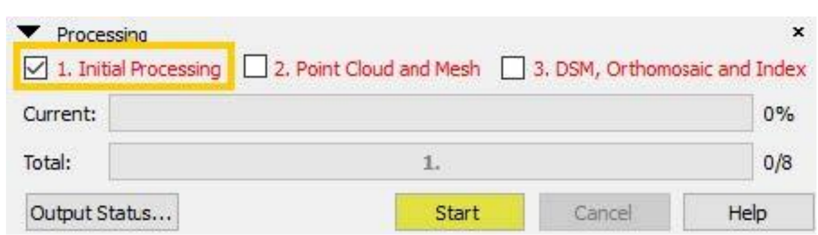


Figure 6-6: Processing Bar (Initial Processing)

Once the initial processing is completed, the quality report is automatically generated. To deactivate its automatic display, unselect the **Display Automatically after Processing** box at the bottom of the **Quality Report** window. When more than one step is processed in sequence and processing is complete, the quality report PDF file is created in the results folder. The following information should be verified in the quality report:

- **Quality Check**: Make sure all check boxes are green, as shown in Figure 6-7. All or almost all images should be calibrated in one block. The relative difference between initial and optimized internal camera parameters should be below five percent. If using GCPs, the GCP error should be below 3×GSD.

Quality Check

Images	median of 34188 keypoints per image	✓
Dataset	547 out of 547 images calibrated (100%), all images enabled	✓
Camera Optimization	1.07% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 7088.3 matches per calibrated image	✓
Georeferencing	yes, no 3D GCP	⚠

Figure 6-7: Quality Check

- **Preview**: On projects that require nadir images and for which the orthomosaic preview has been generated, make sure the orthomosaic does not have holes or distortions. If GCPs or image geo-location has been used, ensure that it has the correct orientation. (See Figure 6-8.)

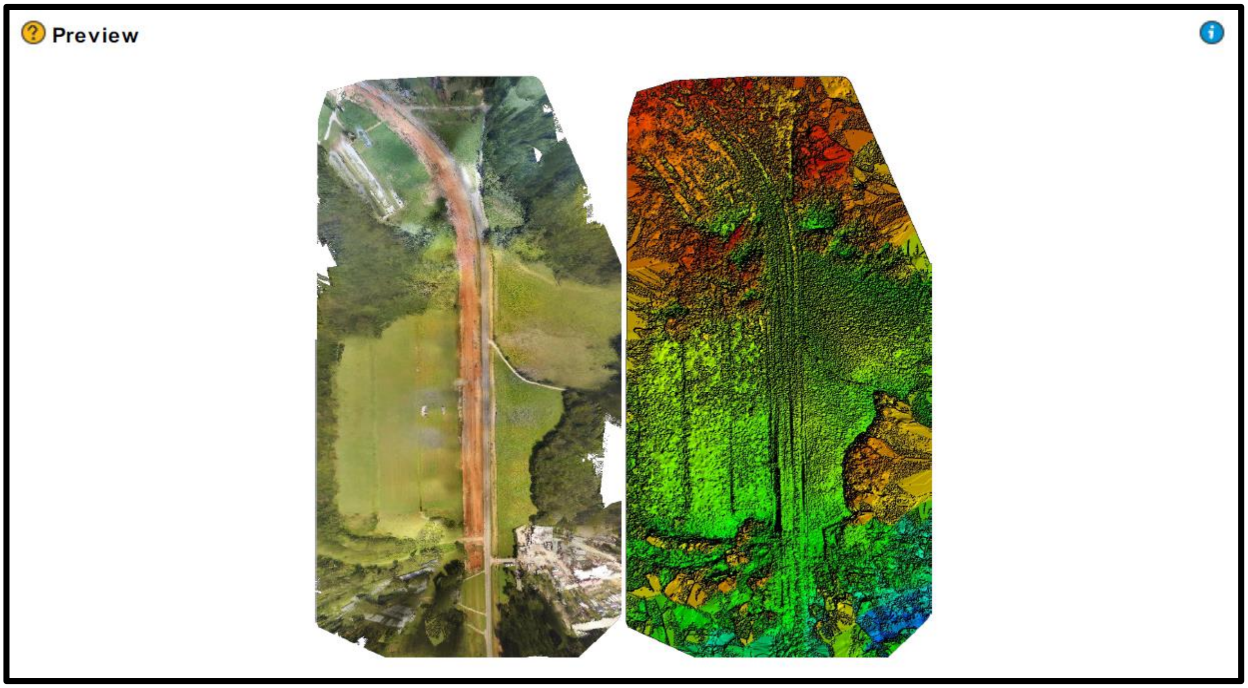


Figure 6-8: Preview of Orthomosaic and Corresponding DSM

- **Initial Image Positions**: If the images have geo-location, verify that the Initial Image Positions figure corresponds to that of the flight plan.
- **Computed Image/GCPs/Manual Tie Points Positions**: If using images with geo-location, make sure the computed image geo-location is good. If using only images with geo-location, check that the uncertainty ellipses are similar in size. If using GCPs, ensure that their error is low (i.e., that the difference between input and computed GCPs is small). If using GCPs and images with geo-location, the uncertainty ellipses should be very small for images close to the GCPs and may increase for images further away.
- **Absolute Camera Position and Orientation Uncertainties**: For projects with image geo-location only, make sure that the absolute camera position uncertainty

is similar to the GPS accuracy and verify that the sigma is smaller than the mean. For projects with GCPs, the absolute camera position uncertainties should be similar to the accuracy of the GCPs. (See Figure 6-9.)

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.083	0.083	0.111	0.020	0.020	0.007
Sigma	0.025	0.015	0.015	0.003	0.006	0.002

Figure 6-9: Absolute Camera Position and Orientation Uncertainties

- **3D Points from 2D Keypoint Matches**: Make sure that enough matches have been computed between the images and that the graph consists of one block. (See Figure 6-10.) If multiple blocks exist, each block should have a different color. The uncertainty ellipses should be of approximately the same size throughout the project.

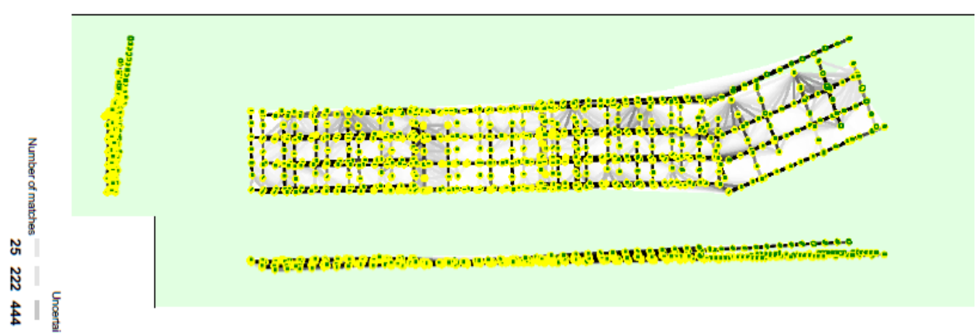


Figure 6-10: Computed Image Positions with Links between Matched Images

Geolocation Details: If using GCPs, make sure they are all taken into account (i.e., none are displayed in red on the Geolocation and Ground Control Points table). Also, verify all marked GCPs. (See Figure 6-11.)

Ground Control Points

GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
9001 (3D)	0.020/ 0.020	-0.010	-0.011	-0.004	0.647	7 / 7
9002 (3D)	0.020/ 0.020	0.021	-0.019	0.041	0.592	4 / 4
9004 (3D)	0.020/ 0.020	-0.009	0.005	0.007	1.210	8 / 8
9011 (3D)	0.020/ 0.020	-0.008	-0.035	-0.114	0.948	9 / 9
9016 (3D)	0.020/ 0.020	-0.031	0.022	-0.098	0.936	10 / 10
9017 (3D)	0.020/ 0.020	0.024	0.016	-0.113	0.922	10 / 10
9012 (3D)	0.020/ 0.020	0.030	0.013	0.180	1.051	14 / 14
Mean [m]		0.002547	-0.001266	-0.014592		
Sigma [m]		0.021055	0.019540	0.098809		
RMS Error [m]		0.021208	0.019581	0.099881		

Figure 6-11: Verification of Ground Control Points

Next, to start the Point Cloud and Mesh step, click **View, Processing**, on the menu bar. When the **Processing** bar opens at the bottom of the main window, select **2. Point Cloud and Mesh**, making sure that **1. Initial Processing** and **3. DSM, Orthomosaic and Index** are unselected. (See Figure 6-12.) Then click **Start**.

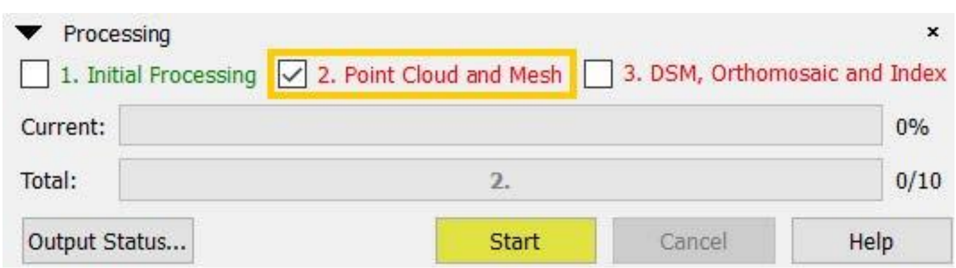


Figure 6-12: Processing Bar (Point Cloud and Mesh)

Lastly, to start the DSM, Orthomosaic and Index step, click **View, Processing** on the menu bar. When the **Processing** bar (Figure 6-13) appears at the bottom of the main window, make sure that **3. DSM, Orthomosaic and Index** is selected and that **1. Initial Processing** and **2. Point Cloud and Mesh** are unselected. Then click **Start**.

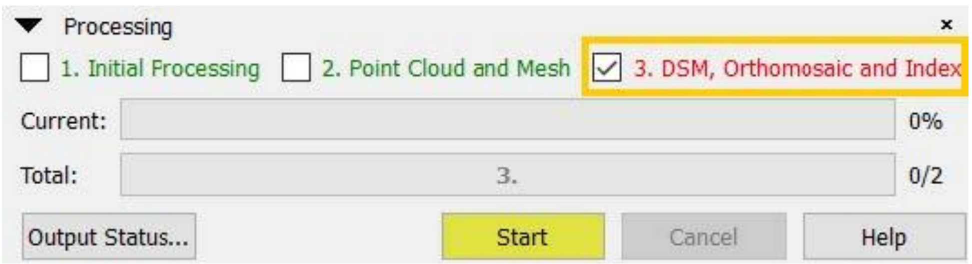


Figure 6-13: Processing Bar (DSM, Orthomosaic and Index)

Once the project has been completely processed, it is possible to use the results in many ways and for different purposes. (See Table 6-3.)

Table 6-3: Uses of the Results

Optional	It can be used to
Using the ray Cloud	• Visualize the different elements of the reconstruction (e.g., camera positions, reprojections (rays), GCPs, manual/automatic tie points, processing area, clipping box, densified point cloud, terrain/objects/other point groups, 3D textured mesh, video animation trajectories) and their properties. • Verify/improve the accuracy of the reconstruction of the model. • Visualize point clouds/triangle meshes created in other projects or with other software. • Georeference a project using GCPs and/or scale and orientation constraints. • Create orthoplanes to obtain mosaics of any selected plane (e.g., building facades). • Assign points of the point cloud to different point groups. • Improve the visual aspect. • Create objects and measure distances (polylines) and surfaces. • Create 3D fly-through animations (video animation trajectories). • Export different elements (GCPs, manual/automatic tie points, objects, video animation trajectories). • Export point cloud files using points belonging to one or several classes.
Using the Volumes	• Draw volumes. • Measure volumes. • Exports the measurements.
Using the Mosaic Editor	• Visualize the DSM (raster GeoTIFF digital surface model). • Visualize the orthomosaic. • Improve the visual aspect of the orthomosaic.
Using the Index Calculator	• Generate an index map/index grid on which the color of each pixel is computed using a formula that combines different bands of the reflectance map(s). • Provide information about the bands of the reflectance map(s) and index map. • Visualize the index map as a colored index map by applying a color mapping to it. • Export a georeferenced colored index map. • Annotate the classes of the index map to generate an application map. • Export an application map as a shape file to be imported in any tractor consoles. • Upload the reflectance map on MicaSense Atlas platform.
Uploading Project Files	• Upload files to the Pix4D Cloud, in order to: ○ Store files in the Pix4D online account. ○ Process projects online. ○ Provide project information to the support team. ○ Upload 3D textured mesh to Sketchfab, for viewing, interacting, and sharing.
Using output files in other software	• Pix4Dmapper outputs are compatible with many other software applications (GIS, CAD, etc.) and can be used for many different purposes.

7. Data Analysis

Upon completion of the field tests and the subsequent data processing, the GT research team discussed the products with the GDOT personnel and industry partners involved in the study. (See Figure 7-1.) These collaborative discussions took place in debriefing sessions on December 11 and 15, 2017, and January 24, 2018, and consisted of three main steps:

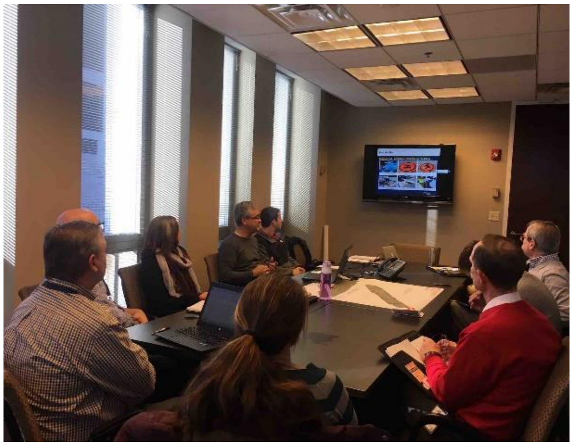
1) Short description and discussion of the field-testing outcomes
2) 2D and 3D data demonstration
3) Structured follow-up interviews and survey.

7.1 Data Analysis Structure and Instruments

A total of 12 GDOT professionals participated in the structured follow-up interviews and survey during the collaborative data analysis sessions. Table 7-1 presents the demographic information collected from these sessions. Participants were asked to assess their familiarity with the technologies investigated or with other UAS platforms and 3D computational models. (See Table 7-1.) The ultimate goals of the interviews and survey questions were as follows:

1) To identify and classify the performance factors affecting UAS integration (Section 7.2)
2) To develop a conceptual UAS-based workflow (Section 7.3);
3) To collect participant perceptions on the usefulness, suitability, or adequacy of the components of the UAS-based workflow to the tasks they perform (Section 7.4)

4) To provide future UAS operators at GDOT with insight into how and to what extent a UAS can help them achieve their task-related goals.



(a) Debriefing meeting with Intermodal Group

(b) Debriefing meeting with Construction Group

(c) Debriefing meeting with Bridge Maintenance Group

Figure 7-1: Debriefing Sessions Setting

Table 7-1: Demographic Information of Debriefing Session Participants

Attribute	Participants (*N=12*)
Gender	
Male	83.3%
Female	16.7%
Age	
Under 30 years	8.3%
31-40 years	41.7%
41-50 years	25.0%
Over 51 years	25.0%
Group	
Construction Group	41.7%
Intermodal Group	33.3%
Bridge Maintenance Group	25.0%
Work experience	
Less than 10 years	66.7%
11-20 years	16.7%
Over 21 years	16.7%
Educational Attainment	
High-school level	50.0%
Undergraduate level	41.7%
Graduate level	8.3%
Familiarity with UAS	
High level	16.7%
Average level	25.0%
Low level	58.3%
Familiarity with 3D	
High level	0.00%
Average level	33.3%
Low level	50.0%
No Familiarity	16.7%

7.2 Performance Factors

GDOT professionals who participated in the debriefing sessions were asked to indicate the extent to which the listed factors would affect UAS use and performance in their tasks. Participants used a Likert scale to determine the relevance of each of these performance factors. The values of the scale ranged from 1 (representing “not relevant”) to 5 (representing “very relevant”). The ranking data were computed and described as mean values. From the post-field-test interviews, the researchers identified the following main performance factors:

1) **Hardware** – Capability of UAS platforms and computer workstations
2) **Usability** – Ease of use (UAS and software)
3) **Time** – Total operating time
4) **Cost** – Total operational cost
5) **Human/Team** – Capability of UAS operators, communication and interaction, team composition, inclusion of third-party personnel
6) **Data Quality** – 2D and 3D data quality
7) **Legal** – Safety management, emergency response, and privacy issues.

The safety of operators and bystanders was identified as the most relevant factor (*avg. = 5.000*). The respondents also identified 2D (*avg. = 4.909*) and 3D data accuracy (*avg. = 4.273*) as critical factors. Data quality was cited as having a significant impact on the performance of UAS-assisted progress monitoring and inspection tasks.

With respect to human and team factors, the participants indicated that team composition was the most relevant factor (*avg. = 4.727*). Another important aspect was the capability of operators (*avg. = 4.364*), which usually involves their cognitive and task performance. The cost factor (*avg. = 4.091*) and the capability of the UAS platform (*avg. = 4.545*) were other relevant factors that were seen as considerably affecting UAS performance in GDOT tasks. In addition, ease of use (*avg. = 3.545*) and operational time (*avg. = 3.000*) were found to be other significant performance factors, and should also be considered for the proper UAS operation. Figure 7-2 shows the participants' ranking of the relevance of the performance factors.

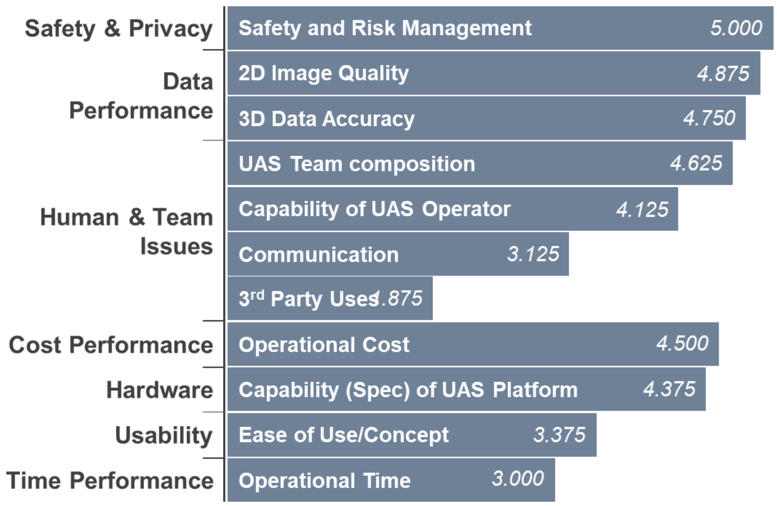


Figure 7-2: Relevance of Performance Factors

7.3 Conceptual UAS-based Workflow

This section presents a UAS-based workflow that can be integrated into construction inspection and progress monitoring tasks, as well as airport and bridge inspection tasks. The total operating time of the developed UAS-based workflow was based on survey respondents' estimates of the operating time of each step in each workflow, given their experience during the field tests. The estimated total operating time for the UAS-based workflow was then compared to the operating time of the existing workflows, to determine their relative efficiency.

The developed UAS-based workflows consist of three main steps: 1) pre-flight, 2) flight, and 3) post-flight. (See Figure 7-3.) The pre-flight stage of the workflow comprises the onsite meeting for pre-data collection and flight mission planning, equipment setup and checking. The post-flight step consists of equipment disassembly, data processing, data analysis (debriefing meetings), and data documentation.

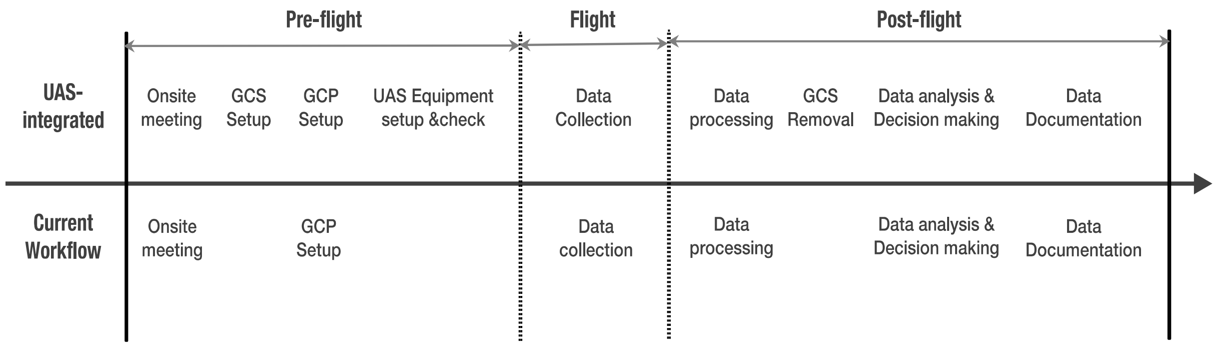


Figure 7-3: UAS-based Workflow vs. Existing Workflow

Pre-Flight Stage

The pre-flight stage consists of four main steps: 1) onsite meeting; 2) GCS set up; 3) GCP set up (if needed); and 4) equipment inspection. The main objective of the pre-flight stage is flight preparation, which involves establishing flight objectives, deciding on the points of interest (specific locations), developing a mission plan based on those points, and setting up the equipment (e.g., GCS, GCP, or other components).

The main goal of the onsite meeting is to determine flight specificities such as the takeoff and landing locations (also alternate landing locations), potential obstructions, and points of interest. The outcome of the meeting should be a detailed flight mission plan. The participants of this meeting should include the PEs and UAS operators.

The GCS should be properly and safely installed somewhere in the work environment (e.g., jobsite, airport, or bridge). The GCS includes the UAS control system, the operators' communication system, backup batteries, and other equipment to support UAS operations as needed. These items may vary depending on the site location and type of project or work environment. After the GCS is set up, the UAS and supplementary equipment must be re-inspected to make sure the platform is ready to fly.

UAS operators, including the pilot-in-command (PIC) and the visual observer (VO), must maintain direct communication during the pre-takeoff checks, before starting the flight mission. This can be accomplished with the use of a two-way radio. This is one of the most important steps to take to avoid non-compliance with many important mission parameters required for a safe flight. Performing the pre-takeoff check can prevent accidents and connection loss during flight. For example, if the pilot neglects to check available battery power, the mission could be affected by sudden power failure. The checklist items include very specific and simple tasks such as checking the UAS battery charge and camera status, among others. Figure 7-4 illustrates the pre-flight stage during one of the field tests.

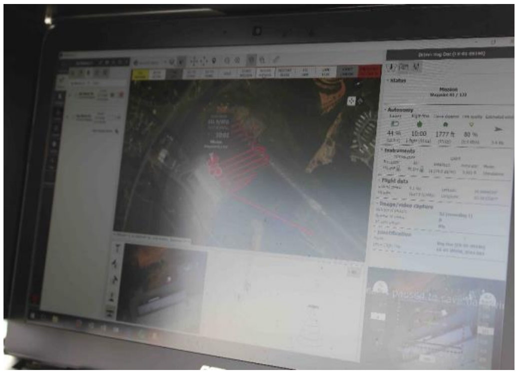
(a) Pre-flight Meeting (b) GCS Setup (c) GCP Installation

Figure 7-4: Pre-flight Stage

Flight Stage (Data Collection)

During flight, VOs are responsible for visually tracking aircraft position so that pilots can focus on flight control and collection of visual assets. VOs must also check flight conditions using a mission checklist. Three main points are critical during the flight stage: 1) confirmation that the aircraft is under the pilot's control and that the GPS has engaged (by hovering approximately 10 feet above ground immediately after takeoff); 2) verification that all control sticks operate correctly while in hover mode; and 3) certainty that battery charge levels are safe for flight. The aircraft, router (if used), and the transmitter should be at adequate levels of charge (above 50 percent) to prevent connection loss during flight. Flight duration should be kept to no more than 15-20 minutes, depending on the UAS platform in use and its battery capacity. When the pilot determines that a mission has been completed, a signal should be made to the VO to prepare for landing. The VO then checks on landing location conditions. The landing location should be the same as the takeoff location, as determined during the pre-flight planning meeting. If the location is clear and safe for landing, the VO sends an approval signal to the PIC. Then, the PIC must verify that the camera provides a clear view of the landing location, and then proceed to land. If landing location is not available due to obstructions or other issues, an alternate landing location can be used. Figure 7-5 illustrates the flight stage during one of the field tests.

(a) Takeoff



(b) Data collection

Figure 7-5: Flight Stage

Post-Flight Stage

The post-flight stage comprises the data processing tasks. The time needed for data processing depends on the number of images collected, the resolution of the images, and the specifications of the software application used. Data can be directly downloaded to local storage media, or it can be transferred to web-hosted storage, which can take from a few minutes to several hours. The variability of web-hosted storage is a function of the bandwidth of communication networks and depends on the read-write speeds of the storage devices used.

In this study, local storage was used, since it is the most efficient data transfer method. Web-hosted storage is recommended for backup purposes and for non-time-sensitive data sharing. Once data are downloaded, processing involves cataloging the visual assets collected by location and work task. This step may require significant time, since it is completely manual. Once data has been transferred, it can be processed according to the task needs of the various groups.

Once the images have been processed, stakeholders can discuss, evaluate, and use the results for their tasks. Should another flight be required, proper takeoff and landing locations can be determined, as well as points of interest to be inspected.

Estimated Operating Time

Survey participants were asked to estimate the operating time of each step of the proposed workflow, as well as of the existing workflow for the tasks they perform. The most time-consuming steps of the UAS-based workflow were identified as the pre-flight setup of the GCS and supplementary equipment, and post-flight data processing. The respondents estimated that the GCS and equipment setup take an average of five hours, whereas data processing was estimated at three hours. Indeed, since data processing is automated, it can be performed after business hours, with project personnel able to leave the computers and software to run the photogrammetry process by itself overnight, if necessary.

In contrast, the most time-consuming step for both the existing task methods and a UAS-integrated method would be the placement of GCPs when needed. This particular step would apply to tasks that require precise location data such as for construction monitoring tasks (e.g., volume calculations or elevation and distance measurements), some airport inspection tasks for which measurements are needed, and bridge inspection tasks that require precise elevation data. GDOT personnel estimated that, in most situations, it could take approximately 10 hours to establish GCPs. Therefore, the total operating time of a flight will vary, depending on whether a new GCP is needed for each flight mission. This is to say that the UAS-based workflow can include an existing GCP layout or may require a new one that would require more operating time.

In summary, the UAS-based workflow offers significant improvements to data collection and analysis. Based on time estimates, UAS-based inspection of a given construction site, airport, or bridge would take an average of 0.42 hours; whereas, with the existing method, the inspection of the same jobsite or location would take 1.83 hours. In the UAS-based workflow, stakeholders take 0.5 hours to perform data analysis, and make decisions. By contrast, with the existing method, data analysis by stakeholders would require an average of 3.53 hours. With respect to the total operating time, an average of 11.92 hours was estimated for the UAS-based workflows—assuming that a new GCP layout is not required or that GCPs are already installed. With the existing method, the total estimated operating time was an average of 18.075 hours. However, if a new GCP setup is needed for the UAS-based data collection, the total time would increase and the UAS-based integrated method would take longer than the existing method. Table 7-2 shows estimated operating times for the tasks considered in both workflow scenarios.

Table 7-2: Estimated Workflow Operating Times

Workflow step	UAS-based method (hour)	Manual method (hour)
1. Onsite meeting (pre-data collection, flight mission planning)	0.500	0.042
2. GCS setup and installation	1.000	0.000
3. GCP setup and installation	0.000	10.000
4. Equipment setup	4.000	0.000
5. Data collection	0.420	1.833
6. Data processing	3.000	1.750
7. GCS removal	1.500	0.000
8. Data analysis and decision-making	0.500	3.533
9. Data documentation	1.000	0.917
Total estimated operating time	**11.920**	**18.075**

7.4 Usefulness/Suitability Analysis

During the de-briefing meeting, GDOT participants were asked to complete a survey designed to assess their perceptions of the usefulness/suitability of identified performance factors to their tasks. Specifically, the survey asked how useful/suitable a UAS-based method would be to each task, based on performance factors described in Section 7.2. The purpose of the analysis is to better understand the implications of UAS integration into GDOT operations, in terms of data collected, teams performing the data collection, the changes to workflow, and the safety of the process. The usefulness/suitability of each factor was based on the participants' subjective perceptions of the UAS-based workflow during the field tests and in the debriefing sessions. A Likert Scale with values ranging from 1 (representing "not useful/suitable") to 5 (representing "very useful/suitable") was used. Mean rating values are used to describe results.

7.4.1. Usefulness/Suitability of Visual Data (2D and 3D)

Participants in the debriefing sessions were presented with the results of data processed through the photogrammetry software Pix4D, as well as with the images and videos collected during the field tests. The following sections present the results for each of the groups that participated. Participants from each group completed the provided survey and rated the usefulness/suitability of the presented UAS-based visual data related to their tasks. This visual data included 2D still images, infrared images, videos, and orthomosaic and point clouds (3D) obtained from the photogrammetric processing.

7.4.1.1 Construction Group: Participants indicated that 3D data are highly useful/suitable (*avg. = 5.000*) to construction inspection and progress monitoring. 2D still images are also highly useful/suitable (*avg. = 5.000*) to all tasks (i.e., construction progress monitoring, site inspection, and surveying). Infrared images were rated as not useful/suitable to any of the CG's tasks (*avg. = 1.000*). Figure 7-6 presents a histogram of the CG's ratings of the usefulness/suitability of the visual data (2D and 3D data) to its tasks.

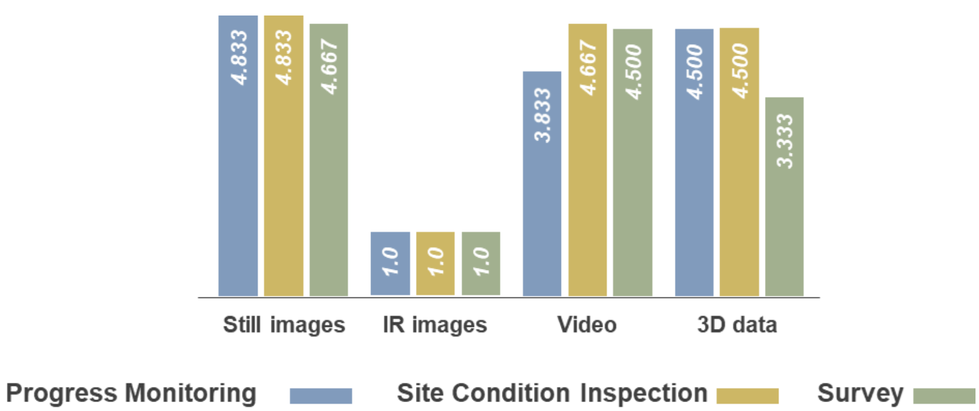


Figure 7-6: Usefulness/suitability of Visual Data (CG)

In terms of best viewpoints to capture useful data, CG participants indicated close-up viewpoints were highly useful/suitable for progress monitoring (*avg. = 5.000*) and survey tasks (*avg. = 5.000*). On the other hand, site condition inspections would need to be performed from high altitude vantage points (*avg. = 5.000*). Depending on the task scope and goal, the flight mission should be adjusted so that the PIC is able to collect high-quality visual data from the best-suited viewpoints. Figure 7-7 shows the best-suited viewpoints to CG's tasks.

Figure 7-7: Best-suited Viewpoints for Data Collection (CG)

7.4.1.2 Intermodal Group: The participants in the Intermodal Group (IG) indicated that still images were not very useful/suitable to the assessment of runway approach slope to threshold (*avg. = 2.000*). Infrared images were also rated as not useful/suitable to any airport inspection-related task (*avg. = 1.000 or 2.000*). Videos were rated as relatively useful/suitable (*avg. = 3.000*) to the assessment of runway lighting conditions, wind indicator operations, and threshold and fueling area condition assessment. Figure 7-8 shows the IG participants ranking of 2D data usefulness/suitability to their tasks.

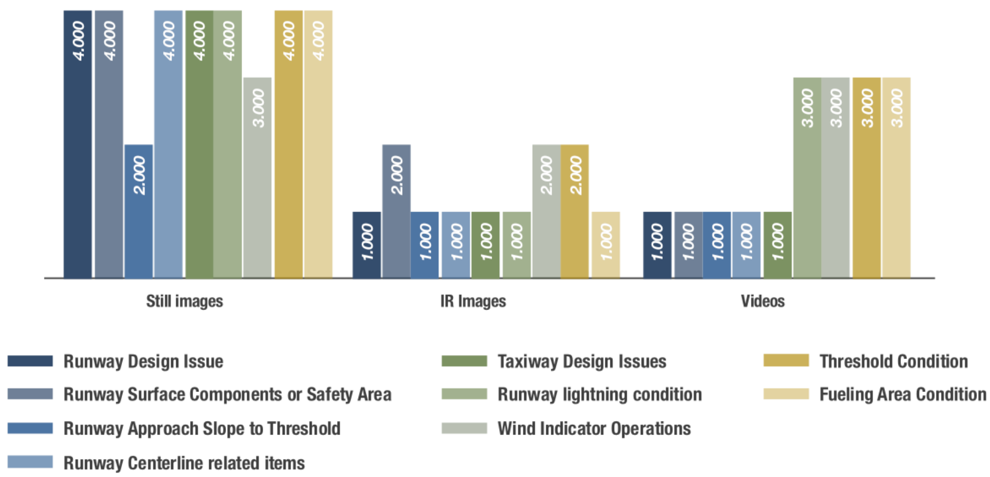


Figure 7-8: Usefulness/suitability of 2D Data (IG)

IG participants indicated that 3D data were highly useful/suitable (*avg. = 5.000*) to the assessment of runway and taxiway design issues, runway surface components or safety areas, runway approach slope to threshold, and runway centerline-related items.

IG participants indicated that close-up viewpoints were very useful/suitable for the inspection and monitoring of runway surface components or safety areas, wind indicator operations, runway lighting, threshold, and fueling area conditions (*avg. = 4.000*). On the other hand, the inspection of runway and taxiway design issues require medium to high altitude vantage points (*avg. = 4.000*). Figure 7-9 shows the best-suited viewpoints for IG tasks.

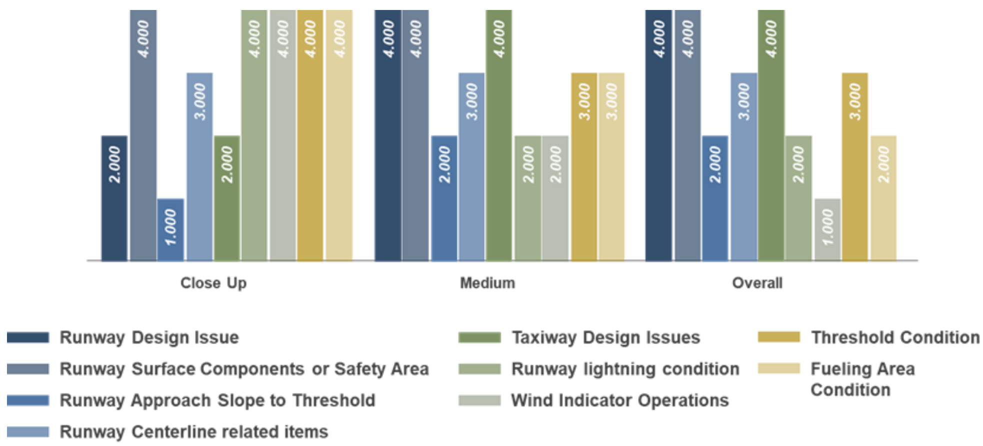


Figure 7-9: Best-suited Viewpoints for Data Collection (IG)

7.4.1.3 Bridge Maintenance Group: Participants of the Bridge Maintenance Group (BMG) rated still images as very useful/suitable to the inspection of deck core holes, structure debris, and large voids (*avg. = 4.000*). Infrared images, on the other hand, were rated as not useful/suitable to any bridge inspection-related task (*avg. = 1.000 or 2.000*). Video images were also rated as very useful/suitable (*avg. = 4.000*) to the assessment of structure debris, exposed footing, and large voids. Figure 7-10 shows the usefulness/suitability of 2D data to BMG tasks.

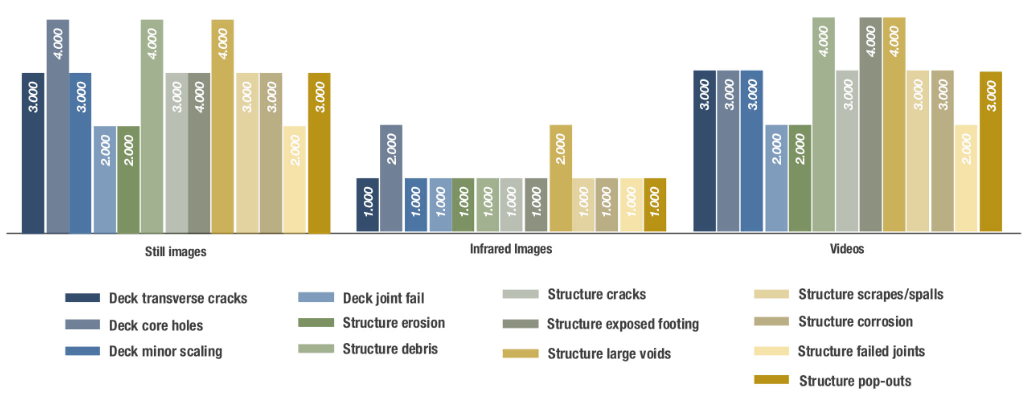


Figure 7-10: Usefulness/suitability of 2D Data (BMG)

Participants also indicated that 3D data was highly useful/suitable (*avg. = 5.000*) to the assessment of structure erosion, debris, exposed footing, and large voids.

The participants from all three groups were also asked about the best viewpoints to capture useful visual data. Three options were provided: detailed close-up view, medium altitude view, and high-altitude overview.

According to BMG participants, close-up viewpoints were highly useful/suitable for the detection of deck transverse cracks, core holes, structure cracks, and corrosion (*avg. =5.000*). Conversely, high altitude vantage points were not considered useful/suitable for bridge inspection tasks (*avg. = 1.000 or 2.000*). (See Figure 7-11.)

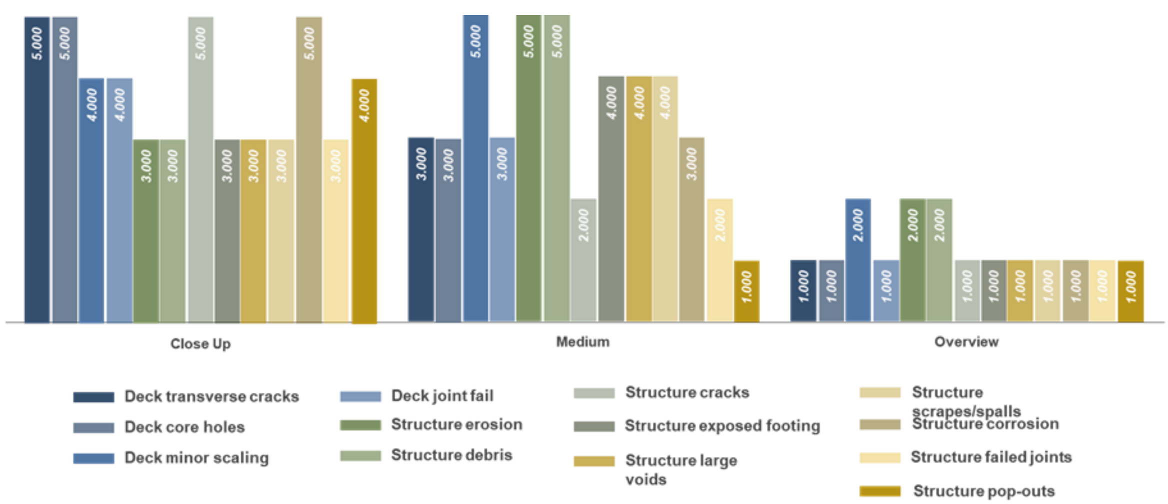


Figure 7-11: Best-suited Viewpoints for Data Collection (BMG)

7.4.2. Adequacy/Suitability of Team Composition

GDOT participants were asked about the adequacy of team composition for UAS operations, based on their field-test experience. In general, the operational team would consist of a PIC, VO(s), PE(s) and an FC (facility coordinator). The respondents indicated that such a team composition was not very suitable to the development of flight missions (*avg. = 1.550*), or to the performance of data collection (*avg. = 2.180*) or data processing (*avg. = 2.090*). However, the same team composition was rated as very adequate for the performance of post-flight data analysis (*avg. = 4.180*). In general, GDOT personnel indicated that the team composition would allow for effective decision-making and data management/documentation (*avg. = 4.180*). Figure 7-12 shows the adequacy of the team composition by workflow phase.

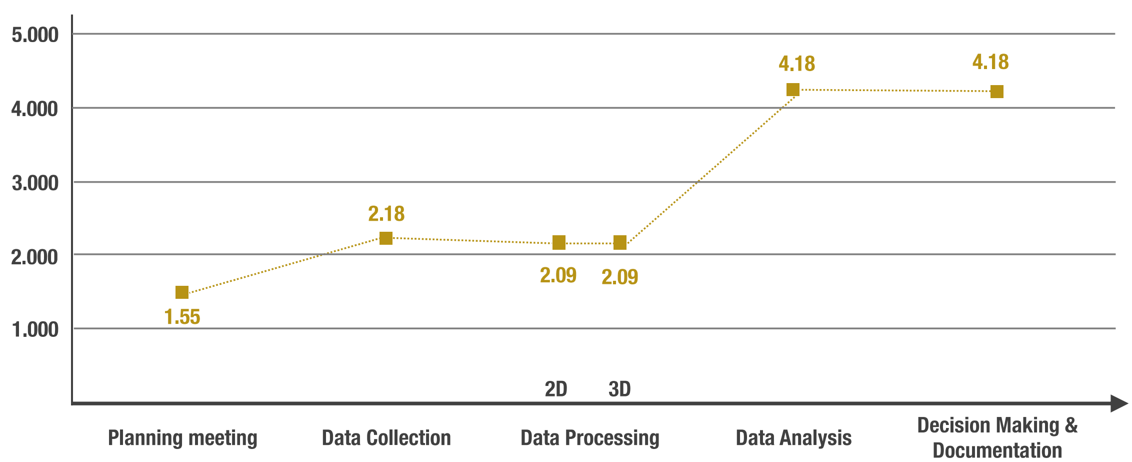


Figure 7-12: Adequacy of Team Composition

7.4.3. Adequacy/Suitability of UAS-based Workflow

Participants from all groups were also asked to evaluate the adequacy of the UAS-based workflow, i.e., to indicate how suitable it was to UAS operations. They rated data collection as the most challenging step of the workflow (*avg. = 3.200*), as shown in Figure 7-13. Handling the UAS platform requires training and, to some extent, is subject to a pilot's cognitive ability. On the other hand, the UAS-based workflow was rated as very suitable to visual data processing, data analysis, and decision-making (*avg. = 4.000)*. These findings suggest that as pilots receive more training on the UAS platform to better perform data collection, the UAS-based workflow would become better integrated into GDOT operations.

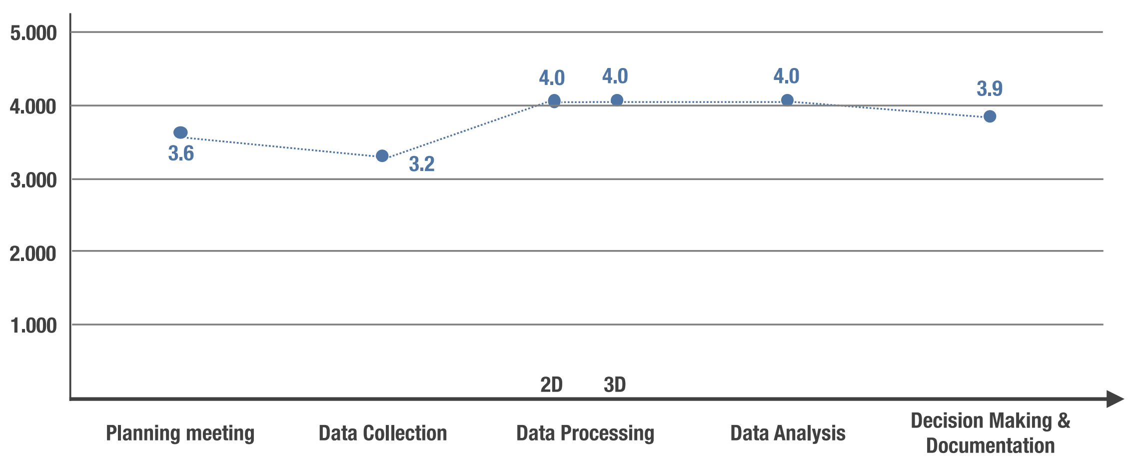


Figure 7-13: Adequacy of UAS-based Workflow

7.4.4. Efficiency of UAS-based Workflow

Participants from all groups rated the efficiency of the developed UAS-based workflow in contrast to the existing workflow (with no UASs involved). Participants agreed that the

UAS-based workflow improves data collection (*avg. = 4.630*), analysis (*avg. = 5.000*), and documentation (*avg. = 4.603*). However, 2D and 3D data processing were found to be inefficient when compared to the existing method (*avg. = 2.000 and 1.380*). Indeed, as discussed above, these tasks take longer with the UAS-based workflow than with the existing method. These results are shown in Figure 7-14.

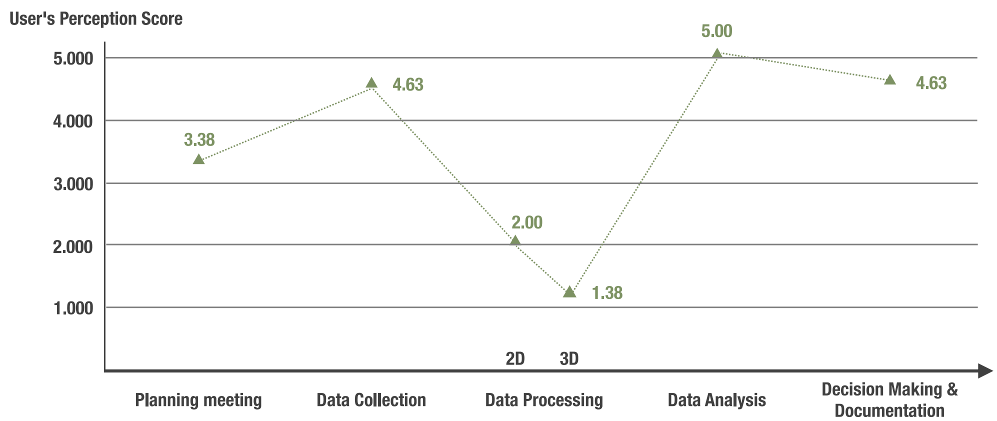


Figure 7-14**:** Efficiency of UAS-based Workflow

7.4.5. Safety Considerations

Safety is critical during the pre-flight and data collection flight stages of UAS operations. In some cases, it is necessary to perform pre-operation flights to determine the appropriate altitude for data collection, distance to points of interest, and potential obstacles to safe operations. The participants all said that both public safety (*avg. = 2.200*) and UAS operator safety (*avg. = 2.600*) should be carefully considered. Data collected during the pre-flight phase—from dry runs or "pre-ops" flights—will allow the UAS team to develop a flight mission plan that considers the UAS team safety, public safety, and privacy of the general public. Personnel indicated that safety on data collection flights would be enhanced as result of this approach (*avg. = 4.600 or 4.500*). Figure 7-15 shows this perceived improvement in safety performance and effectiveness.

Figure 7-15: Safety Improvements (Public and UAS Team)

7.4.6. Summary of Analyses

Mean values were calculated for all the components analyzed as follows: relevance of safety procedures (*avg. = 3.850*); adequacy of the team composition (*avg. = 4.090*); efficiency of the UAS-based workflow (*avg. = 3.250*); adequacy of the UAS-based workflow (*avg. = 3.700)*. Findings suggest that UAS operations require a team composition suitable for analyzing visual data and effective decision-making. However, further studies are required to improve team effectiveness during flight mission development and data collection. With improved team composition and communication, the team would be able to improve data quality as well as the efficiency of work procedures. Figure 7-16 shows the overall effectiveness of UAS operation in terms of performance factors.

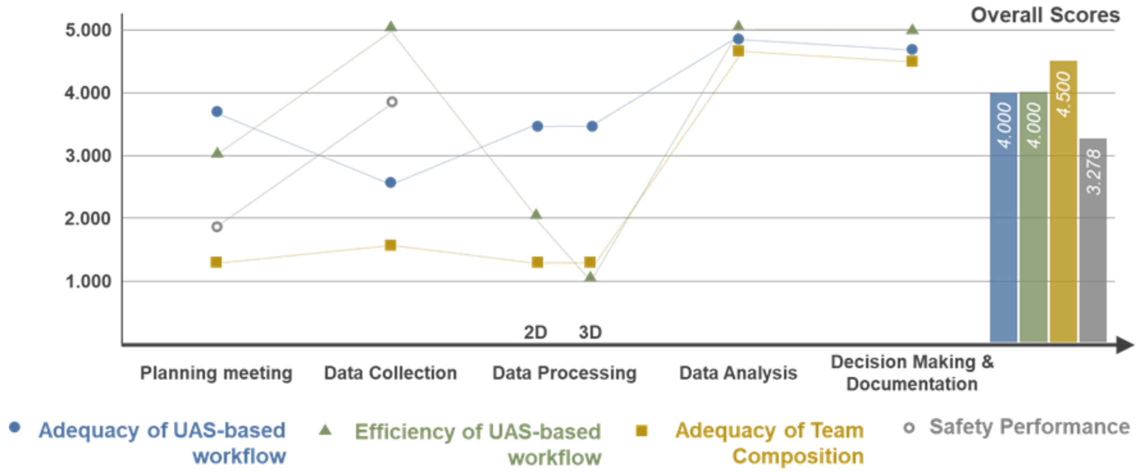


Figure 7-16: Summary of Analyses

8. Legal, Safety and Privacy Considerations

The following considerations support long term, safe, and effective UAS integration into the GDOT operations studied. These can be taken as recommendations for accomplishing this objective. Any future UAS operational policy should comply with FAA regulations. Privacy measures, emergency response plans, and insurance standards should all be clearly described in this policy. The 14 CFR Part 107 rules have established a useful overall structure for safe and efficient UAS integration into GDOT operations. Additional considerations are provided below.

Safety Considerations

All operations should pay attention to private property, pedestrians, and traffic surrounding the flight area. An emergency response plan must be put into effect in case of accidents or loss of communication between the operator and the aircraft. The emergency response plan should include a classification of emergencies and corresponding contingency measures. Also, the plan should be provided to the operation personnel in hard copy format and made available for consultation at the GCS.

As much as possible, GDOT should educate the public about the characteristics and risks of UAS operations, including the aircraft and sensors used, the goals and types of flight missions, the type of data collected, as well as the risk mitigation measures and emergency procedures.

Adequate UAS operator training is not only legally required, but essential in a practical sense. Nonetheless, unforeseen circumstances and accidents may happen; and, in order to make up for eventual harm or prejudice to victims, insurance for UAS damage liability would be needed at minimum coverage levels.

Privacy Considerations

UAS operations should avoid flights over private property, pedestrians (107.39a), and traffic (107.39b)—not only because of safety issues, but also due to privacy matters. Any future GDOT UAS operational policy should draw from the Health Insurance Portability and Accountability Act (HIPAA) to develop protective mechanisms for personal information of victims in the event of accidents.

Legal Considerations

By law, in order to fly within the U.S. National Airspace System (NAS), an aircraft must be registered, the pilot must be certified, and the operation may need to get prior approval depending on the type of operator (hobbyist vs. commercial). The FAA requires that hobbyist UAS operation within a five-mile radius of an airport must be coordinated with the airport operator. The hobby UAS operators must communicate with the airport or heliport administration and obtain permission to fly, if the airport/heliport facilities are located within five miles of the UAS flight area. In GDOT's case, operations are considered commercial and therefore may require prior authorization when operating within five miles of an airport depending on airspace classification. Prior authorization would be required if operating in controlled airspace including Class G controlled airspace. UAS operations also require visual observers to keep track of the aircraft during flight (it must stay within his or her VLOS) to avoid unforeseen circumstances and accidents. Given these considerations for UAS operation, GDOT would need to choose one of the following options: 1) hire a certified pilot on a contract basis or, 2) provide personnel with adequate training and certification.

The rules for non-recreational UAS operations enforced by the FAA are included within Title 14 of the Code of Federal Regulation (14 CFR), Part 107. (See section 8.1 below.) In order to fly UASs that weigh 55 pounds. or more, operators would need to go through the FAA Section 333 exemption process (See section 8.2 below). For governmental entities, a public Certificate of Waiver or Authorization (COA) is required to fly UASs. (See section 8.3 below.)

8.1 Title 14 of the Code of Federal Regulation, Part 107

In order to adhere to the FAA rules regarding small UAS operations, an operator must be aware of and meet various requirements (14 CFR, Part 107). (See Table 8-1 below.)

Table 8-1: Main Requirements of 14 CFR, Part 107

	Work/Business purpose flights
Remote Pilot Certification	• Must be at least 16 years of age • Must pass an initial aeronautical knowledge test at an FAA-approved testing center • Must undergo Transportation Safety Administration (TSA) security screening • Must pass a recurrent aeronautical knowledge test every 24 months
Aircraft Requirements	• Must weigh less than 55 lbs., including payload, at takeoff • Must be registered if over 0.55 lbs. • Must be registered under Part 107 if unmanned aircraft not flown under section 336 • Must undergo pre-flight check to ensure that UAS is in condition for safe operations
Location Requirements	• Fly in Class G airspace*
Operating Rules	• Must keep the aircraft within visual line-of-sight (VLOS)* • Must fly under 400 feet* • Must fly during the day or civil twilight* • Must fly at or below 100 mph* • Must yield the right of way to manned aircraft* • Must NOT fly directly over people* • Must NOT fly from a moving vehicle, unless in a sparsely populated area*

* Part 107 Sections Subject to waiver: Operation from a moving vehicle or aircraft (§ 107.25), Daylight operation (§ 107.29), Visual line of sight aircraft operation (§ 107.31), Visual observer (§ 107.33), Operation of multiple small unmanned aircraft systems (§ 107.35), Yielding the right of way (§ 107.37(a)), Operation over people (§ 107.39), Operation in certain airspace (§ 107.41), Operating limitations for small unmanned aircraft (§ 107.51)

When operating a UAS, pilots also need to consider the airspace classification in the area of operations. It is particularly important to determine whether flights are required within controlled airspace. According to the *Aeronautical Information Manual*, a controlled airspace is defined as “an airspace of defined dimensions within which air traffic control service is provided to both Instrument Flight Rules (IFR) and Visual Flight Rules (VFL) flights in accordance with its classifications” (FAA, 2016). In the United States, the controlled airspaces are designated as in Table 8-2.

Table 8-2: Designated Airspaces in United States (Adapted from FAA (2016))

Airspace Class	**Definition**
Class A	From 5,500m (18,045 ft.) mean sea level (MSL) up to and including Flight Level (FL) 600.
Class B	From the surface to 3000m (9,842 ft.)MSL.
Class C	From the surface to 1,200 m (4,000 ft.) above the airport elevation.
Class D	From the surface to 760 m (2,493 ft.) from the airport elevation.
Class E	An airspace that is not classified as A, B, C, and D
Class G	Uncontrolled airspace with no IFR operation.

1.Flight Level (FL) is defined as a nominal altitude in hector-feet while being a multiple of 500-ft. FL 600 is equal to 18,200 m (60,000-ft.)

Some 14 CFR Part 107 rules provide option waivers, which allow for a small UAS operation to deviate from certain operating rules, should the FAA find that the proposed operation could be performed safely. The certificates of waiver may include special provisions designed to ensure that the small UAS operation offers a level of safety equivalent to that stipulated by Part 107 rules.

8.2 Section 333 Exemption – Aircraft weighing more than 55 pounds

The 14 CFR Part 107 rules discussed above are only applicable to unmanned aircraft that weigh up to 55 pounds at takeoff. In order to fly a UAS that weighs 55 pounds or more, operators would need to go through the FAA Section 333 exemption process. In this case, operating rules and aircraft requirements are identical or similar to small UAS rules. The FAA determines the pilot requirements for the 333 exemption petitions on a case-by-case basis.

The Section 333 of the FAA Modernization and Reform Act of 2012 (FMRA) grants the Secretary of Transportation the authority to determine whether an airworthiness certificate is required for a UAS to operate safely within the NAS.

8.3 Certificate of Waiver or Authorization

To legally operate a UAS, governmental entities and organizations (e.g. state governments, law enforcement agencies, public universities, and local municipalities) must meet one of the following requirements:

- Fly under the small UAS rule—adhere to the rules in 14 CFR Part 107, including aircraft and pilot requirements. (See Section 8.1.)
- Obtain a public Certificate of Waiver or Authorization (COA) that allows for nationwide flights within the Class G airspace at or below 400 feet, self-certification of UAS pilots, and the option to obtain emergency COAs (e-COAs) under special circumstances.

A Certificate of Waiver or Authorization (COA) is a permit issued by the Air Traffic Organization to a public operator for a specific UAS operation. The COA application form requires the following information: concept of operation and type of mission, operation location, altitude, communications, and flight procedures. After submission, the FAA conducts a comprehensive operational and technical review of the application to ensure that the UAS can operate safely with other airspace users. As of 2018, the wait time for application review is 90 days. The COA application also requires proof of the airworthiness of the UAS. This proof can be obtained either by submitting an Airworthiness Statement or through the FAA Certificate of Airworthiness. More recently, the FAA has begun to implement the Low Altitude Authorization and Notification Capability (LAANC), which facilitates access to controlled airspace near airports through near-real-time processing of airspace authorizations below approved altitudes. Requests for access can be made through mobile applications from approved service providers.

8.4 State UAS Laws

Several state general assemblies or state legislatures have developed their own laws and regulations concerning UAS operation. Appendix ee provides a compilation of state laws concerning UAS use. In Georgia, all commercial UAS operations are subject to the 14 CFR Part 107 rules. Appendix ff presents excerpts from a Georgia state law on UAS operation. It is important to note that there is on-going litigation in many states over questions of whether federal law supersede local laws aimed at regulating UAS operations.

9. Recommendations for UAS Integration Guidelines

This chapter will discuss recommendations for UAS integration at GDOT based on lessons learned from tasks considered in the research project. The recommendations provided consider FAA regulations that were applicable during the field tests and at the time of this writing.

9.1 Applicable Regulations Affecting GDOT UAS Integration

Regulations applicable to GDOT UAS operations are discussed in detail in Chapter 8. These regulations put the following limitations on certain aspects of UAS use:

- The FAA mandates that the PIC maintain line-of-sight with the vehicle during flight. However, one of the advantages of using UASs is to gain access to locations that are difficult to reach, e.g., bridge elements or distant points on runway or in road construction zones. Maintaining line-of-sight becomes difficult for certain terrain and topographical situations, severely limiting inspection abilities. It may be possible to obtain a waiver for these situations, but the time required for the approval of such waivers may limit the practicality of using a UAS for the task. Since developing technologies are expected to meet the line-of-sight requirements in the near future, they will soon cease being an issue for GDOT UAS operations.
- Current FAA regulations prohibit UASs from passing over traffic, requiring lane closures. Waivers for flight over traffic are possible, but the proximity to traffic is the deciding factor. Again, as indicated above, the timing for waiver approval could

be an issue. However, it is possible to mitigate this risk by developing flight plans that collect imagery at oblique angles that do not require passing over traffic.

- FAA rules limit UAS use on tasks that can benefit from the use of thermal images, e.g., deck delamination detection through thermal inertia (which requires taking thermal images of a surface in two different ambient temperatures with maximum possible temperature gradient, i.e., daytime and nighttime). Indeed, according to the FAA, flights are limited to daytime operation. Waivers for nighttime flights are possible but pose the same challenges as indicated above.
- According to FAA regulations, the maximum flight altitude is 400 feet Therefore, it would be impossible to inspect any structures exceeding this altitude. This requirement does not affect the inspection of most bridges in the GDOT purview. However, lower altitudes reduce the area captured in images and the number of images required to cover larger horizontal areas. Again, a waiver is possible to work around this restriction, but for many GDOT applications, it may not be practical.

9.2 Operational Considerations

In addition to regulatory requirements that could affect UAS use for the GDOT tasks considered in this study, there are other issues to consider for UAS operations. The following are recommendations related to various operations-related topics.

UAS Operations Planning

These recommendations apply to a broad range of GDOT tasks that could benefit from UAS integration beyond the ones considered in this study. Before a UAS operation is performed, the following steps could be implemented;

- Any GDOT employee intending to employ a UAS and taking on the role of PIC should develop a flight plan that includes at a minimum the following information:
  - An airspace review that identifies the class of airspace in which the operation will take place. This will help the PIC determine whether a waiver will be required. Special consideration should be given to locations at or close to operating airports. In case of close proximity to such facilities, the PIC should arrange for a Notice to Airmen NOTAM to be issued by the relevant party. In the case of GDOT, the Intermodal Group could assist. It is also important that the PIC verify whether there are active temporary flight restrictions (TFRs) in effect that may include the intended operational area. There are many mobile applications that PICs could use to aid in the airspace review, e.g., the FAA's Before You Fly app and AIRMAP, among others. (See Figure 9-1.) AIRMAP has the benefit of being a Low Altitude Authorization and Notification Capability (LAANC) provider and would allow PICs to make Controlled Airspace Authorization requests and receive instant authorization where available.

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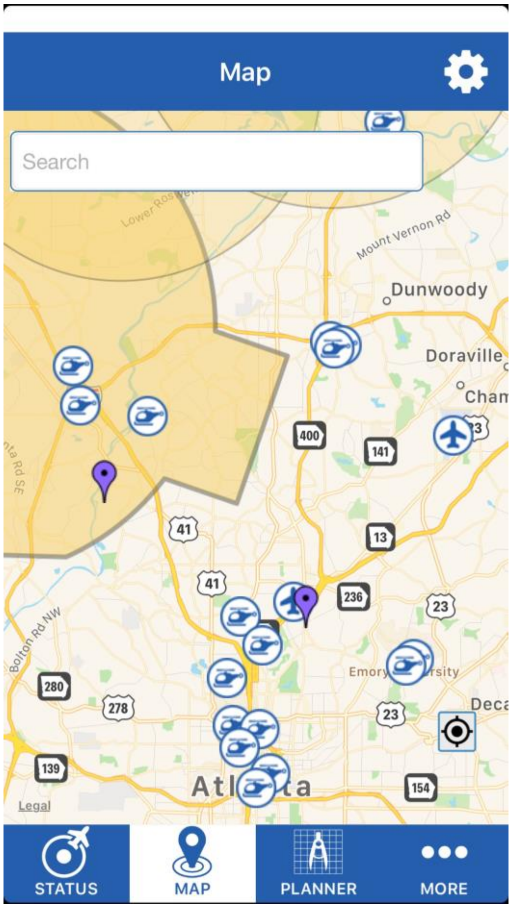
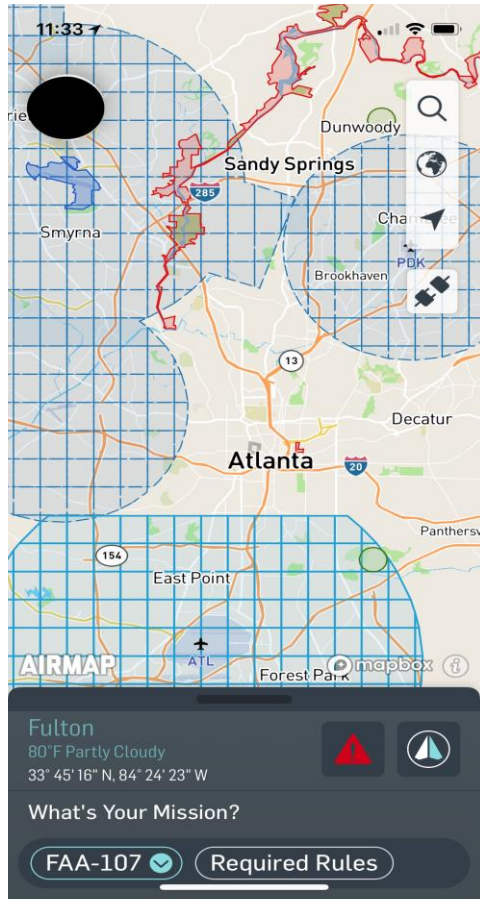


FAA Before You Fly (B4U Fly) Mobile Application



AIRMAP Mobile Application

Figure 9-1 Examples of mobile applications for airspace reviews before UAS operations

- It is critical to obtain forecasted weather-related information for the operating area. Considering weather conditions (e.g., rain, snow, or thunder storms) and temperature is essential for safe and efficient UAS flight performance. PICs should also consider that, per FAA regulations, the minimum weather visibility distance is three miles from the control station.
- PICs should provide a diagram depicting the area of operations and should identify any limitations to operations. Takeoff area, main landing area, and alternative landing areas should be indicated in the diagram. This diagram

will facilitate a risk assessment, to identify hazards or obstructions to operations. In addition, the diagram can be used to identify the need to secure land owner permissions for access during operations.

- As part of the planning process, UAS pilots should determine whether privacy is a concern and employ reasonable precautions to avoid capturing images of the public except those that are incidental to the project.
- The PIC should provide a statement of the purpose of the UAS operation and how it is related to the tasks they will perform. This can be used as a record of the need and purpose of the UAS for the task. This description should include the maximum expected altitude of proposed operation. According to FAA regulations, the maximum flight altitude is 400 feet above ground level (AGL). It could be higher if the UAS remains within 400 feet of a structure.
- The schedule for the operation should be drawn up to ensure that it meets daytime operation requirements. Flight can be accomplished during daylight or in civil twilight (30 minutes before official sunrise to 30 minutes after official sunset, local time) with appropriate anti-collision lighting. If nighttime operations are needed, the relevant waiver should be secured, and the waiver identifier should be included.
- The expected duration of the flight should be calculated. A more detailed value for the duration can be obtained from the UAS telemetry data or from the time stamps of the visual data collected, if needed.

- It is important to describe the communication plan between the PIC and any VOs involved, as well as emergency/contingency procedures in case of incidents, e.g., a lost link with the UAS, lost communication with the UAS, UAS power loss, and unexpected emergency landings.
- Important note regarding autonomous UAS Flights: A UAS is capable of flying autonomously on GDOT project sites as long as they follow developed UAS flight plans. However, autonomous flight requires PICs to monitor the UAS ground control station at all times. They cannot engage in any other tasks during UAS flights. They are also responsible for keeping track of the UAS flight missions with visual observers, as needed.

UAS Operation Execution

Once the flight plan has been approved by GDOT and the PIC is at a site ready to perform the UAS operation, the following recommendations could facilitate the performance of safe UAS operations:

- A pre-flight checklist should be completed by the PIC. Although software applications are available for completing pre-flight checklists, care should be taken to ensure that they meet GDOT record-keeping requirements. According to GDOT's UAS policy published on November 7, 2017, all UAS pilots are required to complete a Pre and Post flight report for all UAS flights. Appendix gg includes an example of a pre-flight checklist used by the research team.
- Takeoff checklist items could also be used by the PIC by including them in the pre-flight checklist. Software applications are also available for completing takeoff

checklist items, but, again, care should be taken to ensure they meet GDOT recordkeeping requirements. Refer to Appendix gg for an example of a takeoff checklist items used by the research team.

- Once an operation is completed, and the UAS has safely landed, a post-flight checklist should be completed. The same considerations regarding the pre-flight and takeoff checklists apply here.
- After the operation is completed, the PIC should copy the data collected, including images and video, to the GDOT controlled servers. GDOT should apply its chosen method to ensure the security of the data and its accessibility to interested personnel. If a third party (e.g., a contractor) is used to perform UAS operations, existing GDOT procedures regarding data transfer should be implemented.
- During operation, the following general flight requirements should be considered:
    - Battery life: The flight must be conducted with enough remaining battery to ensure safe landing at the home point or any other landing point determined on the flight plan; and the UAS should have enough reserve battery life to ensure its safe landing at an alternative site, if landing at the primary landing site is not possible.
    - Flight speed: The maximum flight speed is 100 mph (87 knots).
- Choice of technology for operation: GDOT personnel should spend time evaluating the intended operation to determine which platform is best suited for data collection. During the field tests, several platform types were used (e.g., different sizes of multi-rotor and fixed wing models, among other) and, depending on the task performed, some were found to be more useful than others. The experiences

chronicled in this report can help GDOT personnel choose the appropriate UAS platform for their tasks.

- Contracting UAS services: If it is determined that an outside vendor is better suited for a particular UAS operation, GDOT should ensure the following:
    - Any UAS service provider selected to perform operations for GDOT should meet existing requirements for consultant services and be able to execute associated policies and procedures.
    - Any UAS service provider selected to perform UAS operations for GDOT will follow all GDOT UAS policy requirements additional to any general policies applicable to service providers.

UAS Fleet and Data Management

The following are recommendations for the management of any UASs owned by GDOT. They are based on FAA regulations, best practices, and lessons learned during the field tests of this research project.

- FAA regulations stipulate that any UAS weighing 0.55 pounds or more must be registered with the FAA, regardless of type of use (i.e., commercial or recreational). Therefore, any GDOT-owned UAS that exceeds the 0.55-pound criterion must be registered. Registration costs $5.00 and can be completed on the FAADroneZone website (https://faadronezone.faa.gov). Once registered, all GDOT UASs must display the appropriate markings as required. One GDOT employee should be designated as responsible for UAS registration on behalf of the department, and that person should be in a position of authority in any GDOT UAS program.

- For GDOT-owned UAS aircraft, equipment malfunctions should be noted in the appropriate post-flight checklist.
- All GDOT-owned UAS equipment should be properly maintained according to manufacturer recommendations. In addition to having scheduled annual inspections, all UAS equipment should also undergo pre- and post-flight inspections. Any maintenance performed should be documented in maintenance logs, as required. Each UAS unit should have its own maintenance documentation. Information that should be required in such forms includes the UAS identification number, date of maintenance, maintenance performed, inspection performed, and any necessary additional notes or comments.

UAS Pilot in Command Requirements

- GDOT should provide potential UAS pilots with access to training resources on safe UAS operation. Training beyond FAA Part 107 regulations is recommended. Courses offered by UAS pilot ground schools are available from service providers in many locations. These courses help potential UAS pilots understand the National Airspace System (NAS) and learn the rules associated with safe flight within it. This training can prepare individuals to take the FAA Part 107 certification exam in order to obtain the Small Unmanned Aerial System Rating Certificate.
- All GDOT UAS PICs or PICs from contracted service providers must possess FAA Part 107 certification to operate UASs on behalf of GDOT.

10. Conclusions and Future Research

Unmanned Aerial Systems (UAS) or “drones” are becoming a part of everyday life, with a constantly growing impact on the way many tasks are performed. This study aimed to propose guidelines for UAS integration into tasks performed by selected groups within the Georgia Department of Transportation. The guidelines developed from this research are based on the results of several activities: focus group sessions with personnel from the department’s Intermodal, Construction, and Bridge Maintenance groups; a workshop mainly with personnel from these groups, and some from the HERO and Legal groups; and field tests in the work environments of the three main groups included in the study. From the focus group sessions, seven test sites were identified and tasks were performed with UAS at each site. From the data collected, GDOT personnel was able to assess usefulness and usability of the process and the products obtained. The following conclusions are presented based on the results of the activities undertaken in the research study and organized according to the objectives of the study.

1) The first objective of the study was to determine the technological feasibility of utilizing UASs in the operations of GDOT divisions. GDOT personnel found that in general, they could use UAS for the tasks considered in the study. However, they recognized that training would be needed to obtain the technical skills required for safe use of the UAS devices. In addition, they recognize that in not all situations the best approach would be for GDOT personnel to employ UAS, but to have a third party perform data collection with the UAS devices. This was noted in tasks related to airport inspections. It was noted that a third party could perform the tasks in a shorter time and

more efficiently given the large area that needs to be covered on each inspection. Another suggestion from GDOT personnel was to have a dedicated group within the department who would provide UAS data collection as a service to the various areas of the department. Thus, centralizing all aspects related to the acquisition, use, and maintenance of UAS at GDOT. In conclusion, it was determined that the application of UAS for the tasks considered in the study is technologically feasible provided that GDOT personnel receive proper training.

2) The second objective of the study was to understand the advantages and limitations of UAS adoption (as well as its legal, safety, and privacy implications) for tasks identified from the analysis of GDOT divisions. The advantages of UAS integration into GDOT tasks considered are clear. Removing personnel from dangerous environments and situations encountered, for example, when inspecting hard-to-reach locations on bridges and roadways as well as when inspecting airport runways is a significant advantage. The time saved in collecting visual data such as images of issues encountered during the aforementioned inspection tasks is another benefit of the application of UAS. The same visual data can be converted in measurable data such as point clouds when the appropriate software tools are used. GDOT personnel considered the data collected and the results of obtained from processing visual data as useful. The results included 3-dimensional point clouds, and orthomosaic images of the facilities inspected and construction projects included in the study. One area of concern was the tools, skills, and time required to process collected data. GDOT personnel would benefit from training to use the tools needed to process data such as photogrammetry software. Another area of concern related to data collected is storage of data. During

the study, GDOT personnel discussed options for storage that would leverage existing systems and data maintenance policy the department has in place. In terms of legal and privacy issues, it was found that GDOT has mechanisms to protect data collected using current methods available to the department. In terms of liability of UAS operators employed by GDOT, it was recommended that GDOT manages such liability to protect its personnel as well as require contractors to provide their own liability insurance as it is standard practice in the department.

3) The third objective of the study was to propose FAA-compatible guidelines for integrating such systems into GDOT operations. The recommended guidelines for the implementation of UAS within various GDOT groups rely on current FAA regulations governing the use of UAS in the NAS. Existing regulations are considered workable in terms of GDOT requirements for the tasks considered in the study. Since GDOT has control to access of most of its work environments, management of safety conditions related to UAS operations is possible. This would be particularly beneficial to tasks related to airport inspections and railway inspections, where GDOT has strict access control of facilities or right-of-way. However, safety precautions are needed when operating in active airports or projects that are in close proximity to the general public as the case of construction work on public roadways. On active airports, UAS operations would be preceded by the filing of a Notice to Airman (NOTAM) for the operation period. For UAS operations on roadway projects, particularly on expansion, re-alignment and other projects involving roadways in use, UAS operations would follow recommended guidelines that comply with FAA regulations. A significant concern of GDOT personnel is the liability presented by the use of UAS devices when

used in close proximity to the general public. In order to adequately implement UAS for GDOT operations, a liability management strategy should be implemented to provide clear guidance to employees regarding liability protection by GDOT while they perform UAS related tasks on the department's behalf.

4) The last objective of the study was to hold a workshop for GDOT personnel about the use of UAS technology for the investigated tasks. The workshop provided personnel with information on UAS technology in general, FAA regulations related to UAS, software tools for data collection mission planning, and software tools for image processing to obtain actionable data, and the opportunity experience, first-hand, the use of an UAS on a simulated task similar to what GDOT would perform at a construction site.

Future research on the integration of UAS into GDOT operations should consider the following;

- Advanced use of data collected with UAS: In this study, data collected included images, videos, and infrared images. There are sensors being developed that can collect visual data as well as other environmental data that could benefit GDOT operations. Future research could consider the use of advanced sensors for additional GDOT tasks such as non-destructive inspections of infrastructure, monitoring of environmental conditions, infrastructure asset management, and emergency management tasks. Other potential applications that could be studied would consider the use of machine learning and artificial intelligence to collect and analyze UAS-based data for applications such as traffic management, automated verification of contractor work, and automated assessment of inspection criteria at facilities such as airport, bridges, and roads among others.

- Monitoring of status of implementation: As GDOT implements UAS for the tasks identified in the study and others, it will be important to track performance of personnel as they implement the technology. Data on location of flights, purpose, data collected, issues encountered, use of the data, and others, will allow GDOT to determine the success of UAS integration into department operations.
- Use of UAS technology beyond the applications considered in the study: In order to explore the full potential of UAS technology for GDOT applications, other areas in addition to the ones included in the study should be considered. At the time of this the writing of this report, FAA regulations prevent the use of UAS at night or over people, or beyond visual line of sight. However, these restrictions are bound to be relaxed in the near future providing the department with the opportunity to explore applications such as remote monitoring of construction operations as well as traffic management among others.

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12. Appendix

12.1 Appendix aa: IRB Approval Letter

Georgia Tech | Office of Research Integrity Assurance

Protocol Number: H14409
Funding Agency: Unilever Manufacturing Inc, GA
Department of Transportation
Review Type: Exempt, Category 2
Title: UAV Applications in Construction
Number of Subjects: 100

June 27, 2016
Javier Irizarry
School of Building Construction
0155

Dear Dr. Irizarry:

The Institutional Review Board (IRB) has carefully considered **amendment # 2** for protocol #***H14409*** referenced above. Your approval is effective as of **06/27/2016**. The proposed procedures are exempt from further review by the Georgia Tech Institutional Review Board.

Minimal risk research qualified for exemption status under 45 CFR 46 101b. 2.

Thank you for allowing us the opportunity to review your plans. If any complaints or other evidence of risk should occur, or if there is a significant change in the plans, the IRB must be notified.

If you have any questions concerning this approval or regulations governing human subject activities, please feel free to contact Dennis Folds, IRB Chair, at 404/407-7262, or me at 404 / 894-6944.

Sincerely,

Scott S. Katz, MS, CIP
Compliance Officer
Georgia Tech Office of Research Integrity Assurance

cc: Dr. Dennis Folds, IRB Chair

Unit of the University System of Georgia   An Equal Education and Employment Opportunity Institution

12.2 Appendix bb: Participant Consent Form

Georgia Institute of Technology
STUDY INFORMATION SHEET

Project Title: Field Test Based Guidelines Development for the Integration of Unmanned Aerial Systems (UASs) in GDOT Operations.
Principal Investigator: Javier Irizarry, Ph.D.
Co Investigator: Eric N. Johnson, Ph.D.
Students: Sungjin Kim and Kyuman Lee
Duration of Study: One Hour to Two Hour
Total Compensation: none
Number of Participants: About 15 Volunteers (Directors and administrators at GDOT divisions/offices)
Participation Limitaion: Normal or corrected to normal vision.

You are invited to participate in a research study. This study investigates the potential applications of Unmanned Aerial Vehicles (UAV) for Construction Related Activities. Learning about the benefits from UAV visual assets, including pictures and videos, can assist contractors and owners to identify problems regarding for instance logistisc, safety conditions, productivity constrains and wastes on construction jobsites and also can support them for real time monitoring and performance improvements.

INFORMATION
You will be asked to participate in a focus group session where you will respond to questions asked about the tasks that you could perform with the help of an UAV. The whole process will take 1hr-2hr.

BENEFITS
There will be no direct benefit to you but there may be benefits to the construction industry in the form of increased understanding of issues related to safety and productivity. This understanding can help in improving conditions on construction sites.

RISKS
There are no foreseeable risks in participating in this study.

CONFIDENTIALITY
The following procedures will be followed to keep your personal information confidential in this study. The data that is collected about you will be kept private to the extent allowed by law. To protect your privacy, your records will be kept under a code number rather than by name. Your records will be kept in locked files and only study staff will be allowed to look at them. Your name and any other fact that might point to you will not appear when results of this study are presented or published. To make sure that this research is being carried out in the proper way, the Georgia Tech IRB will review study records.

CONTACT
If you have any questions about this study or its procedures, please contact Dr. Javier Irizarry at telephone (404) 385-7609 or javier.irizarry@coa.gatech.edu or Dr. Dayana Costa at (404-385-2519) or eric.johnson@ae.gatech.edu.
If you feel you have not been treated according to the descriptions in this form, or that your rights as a participant have not been honored during the course of this project, you may contact the Office of Research Compliance at 404-894-6942, or by email to any of these: irb@gatech.edu; melanie.clark@gtrc.gatech.edu; kelly.winn@gtrc.gatech.edu; barbara.henry@gatech.edu.

PARTICIPATION
Your participation in this study is voluntary. If you decide to participate, you may withdraw from the study at any time without penalty. If you withdraw from the study your data will be returned to you or destroyed.

CONSENT
I have read this form and received a copy of it. I have had all my questions answered to my satisfaction. I agree to take part in this study.

Subject's signature________________________________ Date__________
Person Obtaining Consent __________________ __________________
Name Printed Signature

12.3 Appendix cc: Data Collection Sheet

Georgia Tech — School of Building Construction, School of Aerospace Engineering

GDOT — Georgia Department of Transportation

RP-16-09 Field Test Based Guidelines Development for the Integration of Unmanned Aerial Systems (UASs) in GDOT Operations

Focus Group Session Data Collection:

Questions will be posed to participants in order to define tasks assisted by UAS. With the collected data, UAS based task field experiments will be designed. Use one set of data collection forms per identified task.

Potential UAS Assisted Task Work Environment:

Potential UAS Assisted Task:

Is this a current task or a new task?

☐Current ☐ New

Location of sites where UAS could be used:

☐Near ☐ Far ☐Indoors ☐ Outdoors ☐

Others

Notes:

Time of year when task would be performed:

☐all seasons ☐a prevailing season ______________________

Notes:

1 | Page

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Approximate duration of the task:

Site Safety Issues Related to Task: (ex. Hard hat area, fall protection)

Issues affecting your tasks in either indoor or outdoor environments?

☐Heat ☐Cold ☐Wind ☐Rain ☐Snow

☐Humidity ☐Perspiration ☐Others ___________________

If others, explain:

Site specific training requirements for task:

Equipment necessary to access the site (enabling tools)

Data Collection

Training and or qualifications necessary to use tools needed to collect usable data:

Generic vs. specialized tools needed for the task:

Tools used as a means to an end, i.e. tool necessary to enable work on site but not involved in the direct data collection process, i. e. tools used as an enabler and not as a sensor:

RP-16-09 Field Test Based Guidelines Development for the Integration of Unmanned Aerial Systems (UASs) in GDOT Operations

Data Access

Paper vs. electronic format:

Mobile/handheld device needed?

2D/3D CAD/visualization tools/software needed?

Internet Access Needed?

Any other software needed?

Common sensors needed (Video/picture (Real-time), GPS, Surveying Tools)?

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Collected Data Processing

What is the raw collected data and how does that relate to the actually needed data?

Some discussion ideas:

☐Directly collectable data vs. inferred data

☐Data requirements: accuracy, timeliness, repeatability

☐Importance: necessary primary data vs. easily collectable data providing context

☐Cost vs. value of data collection

Notes:

Is the data collected indeed the data needed?

Some discussion ideas:

☐Immediate post-processing actions necessary to extract the required data (in cases where a direct collection isn't possible)

☐Cost vs. value: post-processing, data storage

☐Classification: useful vs. useless, public vs. non-public

☐Training requirements to do the post-processing.

Notes:

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Operational Requirements and Unmanned Aircraft System in your Division

Project load breakdown: total number of projects per year, average number of parallel projects:

Project type breakdown: in-house data usage vs. external/shared data usage:

IT: data storage, data sharing, agreements, data classification and access (public vs. non-public)

Who are the key decision-makers/performers of those tasks?

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What are the goals and sub goals when performing each task?

What are the decisions that should be made for achieving each goal?

What are the information requirements for making those decisions and performing task goals?

Is aerial photography needed for any tasks/operations described?

☐Yes ☐No

If yes, please note any tasks/operations and, why are they needed?

RP-16-09 Field Test Based Guidelines Development for the Integration of Unmanned Aerial Systems (UASs) in GDOT Operations

Is the 3D Map based on a point cloud needed for any tasks/operations described?

☐Yes ☐No

If yes, please note any tasks/operations and, why are they needed?

What are the issues that should be considered if a UAS is integrated in your tasks/operations?

Any other comments:

Suggestions for possible sites to test the discussed tasks:

12.4 Appendix dd: Demographic Information Data Collection Form

School of Building Construction
School of Aerospace Engineering

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Focus Group Session Attendants

Date of the Session: ________________

Attendees			
Name	**Division (Position)**	**Contact Information (Phone or Email)**	**Participant ID#**
			001
			002
			003
			004
			005
			006
			007
			008
			009
			010
			011
			012
			013
			014

Georgia Tech — School of Building Construction
School of Aerospace Engineering

GDOT

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Demographic Questions / User

Participant ID: ____________

Gender: ☐ Male ☐ Female

Age:
☐ under 25 ☐ 25 – 30 ☐ 31 – 35 ☐ 36– 40 ☐ 41– 50 ☐ over 50

What is the job title of your current position? ________________________

Please briefly explain your role and responsibilities:

____
____
____

Years of experience in current position:
☐ 1 – 5 years ☐ 6 – 10 years ☐ 11 – 20 years ☐ 21 – 25 years ☐ over 25 years

Total years of experience in related field:
☐ 1 – 5 years ☐ 6 – 10 years ☐ 11 – 20 years ☐ 21 – 25 years ☐ over 25 years

Size of the department/office you work in?
☐ Less than 25 employees
☐ 25 to 50 employees
☐ 50 to 100 employees
☐ More than 100 employees

Educational/training background (e.g. Civil Engineering, Finance, Architecture, …)

____

Education/training attainment:
☐ High school diploma ☐ Bachelors Degree ☐ Masters Degree ☐ PhD Degree

RP-16-09 Field Test Based Guidelines Development for the Integration of Unmanned Aerial Systems (UASs) in GDOT Operations

Experience or Understanding of UAS

Do you know what Unmanned Aircraft Systems (UAS) or "drones" are?

☐ Yes ☐ No

Do you have experience with UAS?

☐ Yes ☐ No

If yes. How long have you had experience with UAS for?

☐ Less 1 year ☐ 1-2 years ☐ 2-5 years ☐ more than 5years

What did you use UAS for?

☐ Hobby ☐ Work Projects ☐ Testing or training ☐ others

12.5 Appendix ee: Compilation of Various State UAS Laws

State UAS Laws (compiled from Rupprecht Master List of Drone Laws (Organized by State & Country))

State	Law or Regulation	Comment
AL	No State laws	City of Oxford ordinance prohibits flying a drone over city-owned property.
AK	HB 255 (2014)	Puts limits on how law enforcement can use drones in their operations, including how and whether they can save images and video captured by drone.
	Local laws	In the Southeastern area, during an open commercial salmon fishing period, UAVs may not be used for any activity related to commercial salmon fishing operations.
AZ	SB 1449 (2016)	• UAS cannot interfere with police, firefighters, or manned aircraft. • UAS cannot fly within 500 feet horizontally or 250 feet vertically of any critical facility. • Cities and towns in Arizona that contain more than one park must allow drones in at least one of them. • Cities and towns in Arizona are prohibited from creating their own drone laws. The Arizona State Legislature claims pre-emption for the creation of any regulations concerning drones.
AR	HB 1349 (2015)	Makes it illegal to use a drone to record someone who has a reasonable expectation of privacy.
	HB 1770 (2015)	Prohibits the use of UASs to collect information about or photographically or electronically record information about critical infrastructure without consent.
CA	SB 807 (2016)	Provides immunity for first responders who damage a UAS that was interfering with the first responder while he or she was providing emergency services.
	AB 1680 (2016)	Makes it a misdemeanor to interfere with the activities of first responders during an emergency.
	AB 856 (2015)	Prohibits entering the airspace of an individual to capture an image or recording of that individual engaging in a private, personal or familial activity without permission. This legislation is a response to the use of UAS by the press in covering celebrities and other public figures.
	Local laws	• Town of Los Alamitos ordinance creates restrictions on drone flight and activity within the town. • City of Yorba Linda ordinance bans drone takeoffs and landings outside of a drone pilot’s visual line of sight; within 25 feet of another individual, excepting the drone pilot or drone pilot’s designee; and on private property without the consent of the property owner. This city ordinance also prohibits takeoffs and landings within 500 feet of a special event or emergency response without a city-issued temporary use permit, and any violation of an FAA temporary flight restriction or notice to airmen. • Town of Calabasas ordinance gives local authorities the power to enforce FAA drone-related regulations by making violations of FAA regulations a misdemeanor. This city ordinance also places limits on how close a drone may fly to a school or public event.

		• In addition to the local laws listed above, the National Park Service band the use of drones in all Golden Gate National Parks in the San Francisco Bay Area.
CO	HB 1070 (2017)	Requires the Center of Excellence within the Department of Public Safety to perform a study to identify ways to integrate UAS within local and State government functions relating to firefighting, search and rescue, accident reconstruction, crime scene documentation, emergency management, and emergencies involving significant property loss, injury, or death. This law also creates a pilot program, requiring the deployment of at least one team of UAS operators to a region of the state that has been designated as a fire hazard where they will be trained on the use of UAS for the aforementioned functions.
CT	SB 975 (2017)	Prohibits Connecticut municipalities from regulating drones, but it does allow a municipality that is also a water company to enact ordinances that regulate or prohibit the use or operation of UAS over the municipality's public water supply and land.
	DEEP 23-4-1 (2017)	Prohibits drone use at Connecticut state parks, state forests, or other lands under the control of the Department of Energy and Environmental Protection, unless specifically authorized by the commissioner in a special use license.
DE	HB 195 (2016)	Makes it illegal to fly a drone over events with more than 5,000 people in attendance, including sporting events, concerts, automobile races, festivals. It also makes it illegal to fly a drone over critical infrastructure, which includes but is not limited to: oil & gas refiners, power plants, military facilities, government buildings, and water treatment facilities. Finally, this law prohibits cities and towns in Delaware from creating their own drone laws by claiming pre-emption for the creation of all such laws for the Delaware General Assembly.
FL	HB 1027 (2017)	Pre-empts local regulation of UAS so that only the Florida legislature can make laws concerning the use of drones in the State, but allows local governments to enact drone ordinances related to nuisances, voyeurism, harassment, reckless endangerment, property damage, or other illegal acts. This law also prohibits the operation of drones over or near critical infrastructure in most instances, and prohibits the possession or operation of a weaponized UAS.
	SB 766 (2015)	Prohibits the use of a drone to capture an image of privately owned property or the owner, tenant, or occupant of such property without consent, if a reasonable expectation of privacy exists.
	SB 92 (2013)	Defines what a drone is and limits the use of drones by law enforcement. Under this law, law enforcement may use a drone if they obtain a warrant, there is a terrorist threat, or "swift action" is needed to prevent loss of life or to search for a missing person. This law also enables someone harmed by an inappropriate use of drones to pursue civil action.
	Local laws	• Town of Bonita Springs ordinance limits the flying of drones at Community Park in Bonita Springs to times when the fields of the park are unoccupied. This city ordinance also makes it illegal to fly within 25 feet of people, power lines, buildings, or light fixtures. • City of Miami ordinance prohibits the use of drones over or within a half-mile radius of sporting events or large-venue events, including but not limited to Bayfront Park, Marlins Ballpark, Miami Marine Stadium, Calle Ocho Festival, and any other public parks or facilities during special events. This city ordinance also prohibits drones from being equipped with any type of detachable cargo or carrying any type

		of weapon, and establishes a requirement that a city permit is required for certain "drone-related activities." • Town of Defuniak Springs ordinance prohibits drones from being flown over public or private property without the owner's consent. This ordinance also requires that commercial drone pilots register with the town police department before doing any kind of commercial work using drones in the city. • City of Orlando ordinance places restrictions on flying drones within 500 feet of city-owned parks, schools, and venues such as the Amway Center, Camping World Stadium and Harry P. Leu Gardens. This ordinance also places restrictions on the use of drones within 500 feet of gatherings with more than 1,000 people. A permit is required to fly in these areas, which costs $20 per flight or $150 annually, and those caught in violation of this ordinance will have to pay fines between $200 and $400.
GA	HB 481 (2017)	Pre-empts local governments in the state from creating UAS regulations after April 1, 2017. This law also allows the regulation of the launch or landing of UAS on public property by the state or local governments.
	Local laws	• City of Conyers ordinance prohibits the use of drones within the boundaries of the city horse park, as well as the Cherokee Run Golf Course. • City of Augusta ordinance prohibits drone operations in populated areas within the limits of Richmond County without prior authorization from the FAA and the Augusta, Georgia Commission. An exception to this prohibition is the existing model aircraft field at the intersection of Mike Padgett Highway and Horseshoe Road, as well as any other model aircraft field later approved by the Augusta Georgia Commission. • Cherokee County ordinance establishes that drones can only be flown in areas specifically designated for them.
HI	SB 661 (2015)	Creates a chief operating officer position for the Hawaii UAS test site. This law also establishes an unmanned aerial systems test site advisory board to plan and oversee test site development and appropriates funds to establish the test site.
ID	SB 1213 (2016)	Prohibits the use of drones for hunting, molesting, or locating game animals, game birds, or fur-bearing animals.
	SB 1134 (2013)	Requires warrants for the use of drones by law enforcement, establishes guidelines for their use by private citizens, and provides civil penalties for damage caused by their improper use.
IL	SB 2937 (2014)	Loosens regulations around law enforcement's use of UAS during a disaster or public health emergency, and creates regulations for how law enforcement can obtain and use information gathered from a private party's use of drones. This law also requires law enforcement to follow warrant protocols to compel third parties to share information, and if the information is voluntarily given to police, authorities are required to follow the state's law governing drone data retention and disclosure.
	HB 1652 (2013)	Prohibits anyone from using a drone to interfere with hunters or fisherman.
	SB 1587 (2013)	Allows drones to be used by law enforcement with a warrant to counter a terrorist attack, to prevent harm to life, or to prevent the imminent escape of a suspect. If a law enforcement agency uses a drone, the agency must destroy all information gathered by the drone within 30 days, but a supervisor at the law enforcement agency may retain particular

		information if there is a reasonable suspicion that it contains evidence of criminal activity.
	Local laws	• Village of Schaumburg ordinance prohibits the use of drones within 100 feet of the perimeter of any village property or on any village right-of-way during a special event. • City of Evanston ordinance establishes a moratorium on drone use until reasonable state and federal regulations are enacted.
IN	SB 299 (2017)	Creates new criminal offenses related to the use of drones, which include: • The "sex offender unmanned aerial vehicle offense" occurs when a sex offender uses a UAV to follow, contact, or capture images or recordings of someone, and when the sex offender is subject to conditions that prohibit him or her from doing so. • The "public safety remote aerial interference offense" occurs when someone operates a UAV in a way that is intended to obstruct or interfere with a public safety official in the course of their duties. All offenses created by this law are class A misdemeanors. However, if the guilty party has a prior conviction under the same section, it becomes a Level 6 felony.
	HB 1013 (2016)	Allows the use of drones to photograph or take video of a traffic crash site.
	HB 1246 (2016)	Prohibits the use of UAS to scout game during hunting season.
	HB 1009 (2014)	Creates warrant requirements and exceptions for the police use of drones and real time geo-location tracking devices. This law also creates the crime of "Unlawful Photography and Surveillance on Private Property," making it a Class A misdemeanor, defined as knowingly and intentionally conducting electronic surveillance of the private property of another without permission.
IA	HB 2289 (2014)	Illegal for a state agency to use a UAS to enforce traffic laws. This law requires a warrant, or other lawful means, to use information obtained via UAS in a civil or criminal court proceeding.
KS	SB 319 (2016)	Expands the definition of harassment in the state's Protection from Stalking Act to include certain uses of drones.
	Local laws	City of Wichita ordinance bans the use of drones on or near airport property.
KY	HB 540 (2017)	Allows commercial airports to prepare UAS facility maps, and specifies that UAS operators cannot operate, take off, or land in certain areas designated by an airport's map. This law also prohibits the operation of UAS in a reckless manner, defined as a manner that creates a serious risk of physical injury or damage to property. Anyone who violates these provisions is guilty of a class A misdemeanor, or a class D felony if the violation causes a significant change of course or a serious disruption to the safe travel of an aircraft. In addition, this law specifies that these provisions do not apply to commercial operators in compliance with FAA regulations.
LA	SB 69 (2017)	Specifies that only the state may regulate UASs, pre-empting local regulation.
	SB 73 (2016)	Adds intentionally crossing a police cordon using a drone to the crime of obstructing an officer. This law also allows law enforcement or fire department personnel to disable UAS in the area if they endanger the public or an officer's safety.
	HB 19 (2016)	Prohibits using a drone to conduct surveillance of a school, school premises, or correctional facilities, and establishes a fine of up to $2,000 and up to six months in jail for violations.

	HB 335 (2016)	Authorizes the establishment of registration and licensing fees for UAS in the State, with a limit of $100.
	HB 635 (2016)	Adds UAS use to the crimes of voyeurism and video voyeurism in the state.
	SB 141 (2016)	Specifies that surveillance by an unmanned aircraft constitutes criminal trespass, under certain circumstances.
	SB 183 (2015)	Regulates the use of UAS in agricultural commercial operations.
	HB 1029 (2014)	Creates the crime of unlawful use of an unmanned aircraft system, defined as the intentional use of a drone to conduct surveillance of a targeted facility without the owner's prior written consent. This crime is punishable by a fine of up to $500 and imprisonment for six months. A second offense can be punished with a fine up to $1,000 and one year of imprisonment.
ME	LD 25 (2015)	Requires law enforcement agencies to receive approval before adopting the use of drones, sets out standards for UAS operation by law enforcement, and requires that law enforcement secure a warrant to use UAS for criminal investigations.
MD	SB 370 (2015)	Pre-empts county and municipal authority and specifies that only the state can enact laws to prohibit, restrict, or regulate the testing or operation of unmanned aircraft systems.
MA	No State laws	• City of Chicopee ordinance states that a drone and/or aircraft shall only take off and land on private property owned by the operator or where written permission is granted by the landowner. Said written permission shall include the name and signature of the land owner, the address of the property and the permissible dates and hours of operations. There are a number of other rules for hobbyist (non-Part 107) operators. • City of Boston policy states that drones may be flown recreationally in city parks so long as FAA policies and safe-flight guidelines are followed. • Town of Holyoke ordinance makes it illegal to fly UAS over privately-owned or city-owned property without consent.
MI	SB 992 (2016)	• Prohibits local governments from regulating UASs, except when the regulated drone belongs to the locality. • Specifically allows commercial drone operation in the state if the operator is authorized by the FAA to operate commercially, and permits hobby operation so long as the operator complies with federal law. • Prohibits using a drone in a way that interferes with emergency personnel and prohibits the use of a drone to harass an individual, to violate a restraining order, or to capture images in a way that invades an individual's reasonable expectation of privacy. • Prohibits sex offenders from using a drone to follow, contact, or photograph a person that they are prohibited from contacting. Anyone who uses a drone in a manner prohibited by this law is guilty of a misdemeanor.
	SB 54 (2015)	Prohibits using UASs to interfere with or harass an individual who is hunting.
	Local laws	Town of West Bloomfield ordinance establishes all town parks as no-fly zones.
MN	SF 550 (2017)	Appropriates $348,000 to assess UAS use in natural resource monitoring of moose populations and changes in ecosystems.
	Local laws	• Anoka County ordinance requires drone operators to secure a special use permit from the parks department to fly a drone over county parks.

		• Town of St. Bonifacius ordinance bans drones in all city public airspace.
MS	SB 2022 (2015)	Establishes that using a drone to commit "peeping tom" activities is a felony.
MO	No State laws	
MT	HB 644 (2017)	Prohibits using UAS to interfere with wildfire suppression efforts. Anyone who violates this prohibition is liable for the amount of money equivalent to the costs of their interference. This law also prohibits local governments from enacting an ordinance addressing UAS use in relation to a wildfire.
	SB 196 (2013)	Limits when information gained from UAS use may be admitted as evidence in any prosecution or proceeding within the State as only information that was obtained with a search warrant, or through a judicially recognized exception to search warrants.
NE	No State laws	
NV	AB 239 (2015)	Prohibits the weaponization of UAS, and UAS use within a certain distance of critical facilities and airports without permission. This law also specifies restrictions on UAS use by law enforcement and public agencies, and requires the creation of a registry of all UASs operated by public agencies in the State.
NH	SB 222 (2015)	Prohibits UAS use for hunting, fishing, or trapping.
NJ	SB 3370 (2017)	• Allows UAS operations that are consistent with federal law. • Specifies that UAS owners or operators of critical infrastructure may apply to the FAA to prohibit or restrict UAS operation near the critical infrastructure. • Establishes that operating a UAS in a manner that endangers the life or property of another is a disorderly persons' offense. • Establishes that it is a fourth-degree crime if a person "knowingly or intentionally creates or maintains a condition which endangers the safety or security of a correctional facility by operating an unmanned aircraft system on the premises of or in close proximity to that facility." • Makes it a criminal offense to operate a UAS in a way that interferes with a first responder. • Defines operating a UAS under the influence of drugs or with a BAC of .08 percent as a disorderly persons' offense. • Pre-empts local governments from regulating UAS in any way that is inconsistent with this law.
	Local laws	• Ramapo Indian Hills ordinance prohibits the use of drones on or above school grounds. • Bernards Township ordinance prohibits the use of drones in or over any park or recreation facility. • Chatham Township ordinance prohibits the use of drones in public airspace under 400 feet.
NM	SB 556 (2013)	Prohibits the use of drones for unwanted surveillance
NY	No State laws	• New York City restriction declares that drones are illegal to fly in New York City, and advises anyone who sees a drone being flown to call 911. This restriction does not seem to be an actual law passed by the city, but a policy that the city has adopted. • City of Syracuse ordinance bans the use of drones by city officials until adequate federal and state laws are passed regarding the government use of drones in a manner that protects citizens' First and Fourth Amendment rights.

NC	HB 128 (2017)	Prohibits UAS operation near a correctional facility, excluding certain people operating in an official capacity or with written consent from the warden.
	HB 337 (2017)	Allows UAS use for emergency management activities, including incident command, area reconnaissance, search and rescue, preliminary damage assessment, hazard risk management, and floodplain mapping. This law also makes other changes to align the state law with federal law, and exempts model aircraft from UAS training and permitting requirements.
	SB 446 (2015)	Expands the authority of the state's chief information officer to approve the purchase and operation of UAS by the state, and modifies the state regulation of UAS to conform to FAA guidelines.
	SB 744 (2014)	Commercial drone pilots operating in the State of North Carolina must: • Commercial UAS/drone operators operating under 14 CFR Part 107 or a 333 Exemption within North Carolina are required to have a valid NC UAS Commercial Operators Permit. • Commercial operators must take and pass NCDOT's UAS Knowledge Test and then apply for a state permit. • To obtain a permit, operators must provide the state proof of their remote pilot certificate or other authorization to conduct commercial UAS operations from the FAA (see Federal above). • Permitted operators agree to these terms & conditions. Recreational drone pilots flying in North Carolina are not required to obtain a license or permit from the state's Division of Aviation. However, recreational users are still subject to NC UAS rules and regulations. Government/public-use drone pilots operating in the State of North Carolina must: • Take and pass NCDOT's UAS Knowledge Test and then apply for a State permit. • Agree to these terms & conditions
	Local laws	• Town of Chapel Hill ordinance allows local authorities to enforce existing FAA drone regulations. • City of Kannapolis ordinance bans the use of drones in city parks.
ND	HB 1328 (2015)	Provides limitations for the use of UAS for surveillance, and prohibits arming a UAS with lethal weapons.
OH	HB 292 (2014)	Creates the aerospace and aviation technology committee. One of the committee's duties is to research and develop aviation technology, including unmanned aerial vehicles.
	Local laws	• City of Cleveland ordinance authorizes city police to enforce FAA laws with regards to drones. • City of Celina ordinance bans drones in airspace over city-owned property, including parks.
OK	HB 2559 (2016)	Prohibits the operation of UAS within 400 feet of any critical infrastructure facility.
OR	HB 3047 (2017)	• Modifies the law prohibiting UAS weaponization, making it a class C felony to fire a bullet or projectile from a weaponized UAS. • Allows law enforcement to use UAS to reconstruct an accident scene. • Prohibits the use of UAS over private property in a manner that intentionally, knowingly, or recklessly harasses or annoys the owner or occupant of the property.
	HB 4066 (2016)	Modifies definitions related to UAS and makes it a class A misdemeanor to operate a weaponized UAS, and regulates the use of drones by public

		bodies, including requiring policies and procedures for the retention of data. This law also prohibits the use of UAS near critical infrastructure, including correctional facilities.
	SB 5702 (2016)	Specifies the fees for the registration of public UAS.
	HB 2710 (2013)	• Allows a law enforcement agency to operate a drone if it has a warrant and for enumerated exceptions including for training purposes. • Requires that a drone operated by a public body be registered with the Oregon Department of Aviation (DOA), which shall keep a registry of drones operated by public bodies. • Creates new crimes and civil penalties for mounting weapons on drones and interfering with or gaining unauthorized access to public drones. • Allows that, under certain conditions, a landowner can bring an action against someone flying a drone lower than 400 feet over their property. • Requires that the DOA must report to legislative committees on the status of federal regulations and whether UAV's operated by private parties should be registered in a manner similar to the requirement for other aircraft.
PA	No State laws	• Town of Lower Merion ordinance bans drones in all town parks. • City of Pittsburgh ordinance bans drones in city parks or playgrounds.
RI	HB 7511 (2016)	Gives exclusive regulatory authority over UAS use to the State of Rhode Island and the Rhode Island Airport Corporation, subject to federal law, and pre-empts local governments from creating their own UAS laws.
SC	No State laws	
SD	SB 22 (2017)	Exempts UAS aircraft that weigh less than 55 pounds from aircraft registration requirements.
	SB 80 (2017)	• Requires that UAS operation comply with all applicable FAA requirements. • Prohibits operation of drones over the grounds of correctional and military facilities, making such operation a class 1 misdemeanor. If a drone is used to deliver contraband or drugs to a correctional facility, the operator is guilty of a Class 6 felony. • Modifies the crime of unlawful surveillance to include intentional use of a drone to observe, photograph, or record someone in a private place with a reasonable expectation of privacy and landing a drone on the property of an individual without that person's consent. Unlawful surveillance is a Class 1 misdemeanor.
	Local Laws	City of Aberdeen ordinance permits drone operations in city airspace for hobby or recreational purposes only.
TN	SB 2106 (2016)	Makes it a crime to fly a drone within 250 feet of a critical infrastructure facility for the purpose of conducting surveillance or gathering information about the facility.
	HB 2376 (2016)	Clarifies that it is permissible for a person to use a UAS on behalf of either a public or private institution of higher education, rather than just public institutions.
	HB 153 (2015)	Prohibits using a drone to capture an image over certain open-air events and fireworks displays.
	SB 1777 (2014)	Makes it a Class C misdemeanor for any private entity to use a drone to conduct video surveillance of a person who is hunting or fishing without their consent.
	SB 1892 (2014)	Makes it a Class C misdemeanor for a person to use a UAS to intentionally conduct surveillance of an individual or their property. This law also makes it a crime to possess those images (Class C

		misdemeanor) or distribute and otherwise use them (Class B misdemeanor).
	SB 796 (2013)	Enables law enforcement to use drones in compliance with a search warrant, to counter a high-risk terrorist attack, and if swift action is needed to prevent imminent danger to life. Evidence obtained in violation of this law is not admissible in State criminal prosecutions, and those wronged by such evidence can seek civil remedy.
UT	HB 217 (2017)	Prohibits a person from intentionally, knowingly, or recklessly chasing, actively disturbing, or harming livestock through the use of UAS.
	SB 111 (2017)	• Pre-empts local regulation of UAS and exempts UAS from aircraft registration in the state. • Addresses UAS use by law enforcement, allowing use for purposes unrelated to a criminal investigation. • Requires law enforcement create an official record of UAS use that provides information regarding the use of the drone and any data acquired. • Makes it a Class B misdemeanor to fly a UAS that carries a weapon or has a weapon attached. • Modifies the offense of criminal trespass to include drones entering and remaining unlawfully over property with specified intent. • Specifies that a person is not guilty of what would otherwise be a privacy violation if the person is operating a UAS for legitimate commercial or education purposes consistent with FAA regulations. It also modifies the offense of voyeurism, a Class B misdemeanor, to include the use of any type of technology, including UAS, to secretly record video of a person in certain instances.
	HB 296 (2015)	Allows law enforcement agencies to use an unmanned aircraft system to collect data at a testing site and to locate a lost or missing person in an area in which a person has no reasonable expectation of privacy.
	SB 167 (2014)	Regulates the use of UAS by state government entities, establishing that a warrant is required for a law enforcement agency to "obtain, receive or use data" derived from UAS use.
	SB 196 (2014)	Requires law enforcement to obtain a warrant before using drones in a place where an individual has a reasonable expectation of privacy.
VT	SB 155 (2016)	Regulates the use of drones by law enforcement and requires law enforcement to annually report on the use of drones by the department. This law also prohibits the weaponization of drones.
VA	HB 2350 (2017)	Makes it a Class 1 misdemeanor to use UASs to trespass upon the property of another for the purpose of peeping or spying.
	SB 873 (2017)	Specifies that the fire chief or other officer in charge of a fire department has authority to maintain order at an emergency incident, including the immediate airspace.
	HB 412 (2016)	Prohibits UAS regulation by local governments.
	HB 2125 (2015)	Requires that a law enforcement agency obtain a warrant before using a drone for any purpose, except in limited circumstances.
	HB 2012 (2013)	Prohibits drone use by any state agencies "having jurisdiction over criminal law enforcement or regulatory violations" or units of local law enforcement until July 1, 2015.
WA	No State laws	• City of Bellevue Parks & Recreation Department policy declares that drones are not permitted in Bellevue parks, except at Marymoor Park Airfield and 60 Acres Park. • City of Seattle ordinance prohibits drones and other remote-controlled aircraft in parks.

		• Pierce County ordinance places limits on the use of drones by government agencies.
WV	HB 2515 (2015)	Prohibits UAS use for hunting.
WI	SB 338 (2016)	Prohibits using a drone to interfere with hunting, fishing or trapping.
	AB 670 (2016)	Prohibits UAS operation over correctional facilities.
	Local laws	• Town of Greenfield: Prohibits persons from launching or landing a drone outside of their visual line of sight; within one-hundred (100) feet of any person except the operator and assistant operator; within five hundred (500) feet of any festival, event, picnic, protest or public assembly of more than one-hundred (100) people; in a manner so as to endanger the safety of any person or property; within five hundred (500) feet of any emergency vehicle which is operating its emergency lights or siren, to any active police, fire or emergency response incident, to schools that are in session, and jails. • City of Hudson Common Council prevents the use of a drone with the intent to photograph, record or observe someone in a place where they have a reasonable expectation of privacy, like in their backyard or their residence, and imposes a fine of $200 for violations. Though the State of Wisconsin already regulates use of drones in this manner, this city ordinance makes it easier for local law enforcement to enforce. • City of Chetek: Limits the altitude of drone flights near Chetek Municipal Airport. • Outagamie County: Prohibits drone operation on airport grounds. • City of Green Bay: Prohibits drone flight below 400 feet within specified boundaries of special events, including Green Bay Packer games at Lambeau Field.
WY	SF 170 (2017)	Requires the Wyoming Aeronautics Commission to develop rules regulating where unmanned aircraft can take off and land. The commission is also permitted to develop reasonable rules regulating the operation of unmanned aircraft through coordination with the unmanned aircraft industry and local governments. This law also specifies that the commission does not have the power to regulate unmanned aircraft operation in navigable airspace, and makes it unlawful to land an unmanned aircraft on the property of another person, but operators can pilot an unmanned aircraft over their own property.

12.6 Appendix ff: Georgia State UAS Laws

The following texts are excerpts from the Georgia State UAS laws.

House Bill 481 (Kevin Tanner, 2017)

HB 481 regulates the operation of UASs on public property by State or local governments, among other resolutions. Chapter 1 of Title 6 of the Official Code of Georgia Annotated is provided below.

6-1-4 of Official Code of Georgia Annotated

(a) (1) As used in this Code section, the term 'unmanned aircraft system' means a powered, aerial vehicle that:

- *Does not carry a human operator and is operated without the possibility of direct human intervention from within or on the aircraft;*
- *Uses aerodynamic forces to provide vehicle lift;*
- *Can fly autonomously or be piloted remotely;*
- *Can be expendable or recoverable.*

(2) Such term shall not include a satellite.

(b) Any ordinance, resolution, regulation, or policy of any county, municipality, or other political subdivision of Georgia State regulating the testing or operation of unmanned aircraft systems shall be deemed preempted and shall be null, void, and of no force and effect; provided, however, that a county, municipality, or other political subdivision of this state may:

(1) Enforce any ordinance that was adopted on or before April 1, 2017;

(2) Adopt an ordinance that enforces FAA restrictions or provides for or prohibits the launch or intentional landing of an UAS from or on its public property except with respect to the operation of an UAS for commercial purposes.

(c) The State, through agency or departmental rules and regulations, may provide for or prohibit the launch or intentional landing of an unmanned aircraft system from or on its public property.

12.7 Appendix gg: Sample UAS Operations checklists

Georgia Institute of Technology
School of Building Construction
CONECTech LAB

Georgia Tech

UAS Model Specific Mission Checklist and Flight Log Data (DJI Phantom 3)

UAS Mission Checklist Items	Flight 1 Checked	Comments	Flight 2 Checked	Comments
A) Pre-Flight Checklist				
1. Remove Transmitter from Case	❑		❑	
2. Router ON	❑		❑	
3. Transmitter ON	❑		❑	
4. Toggle Switches - Full UP	❑		❑	
5. Remove UAS from case	❑		❑	
6. Camera Clamp and Lens Cap Removed	❑		❑	
7. Micro SD Card Inserted	❑		❑	
8. UAS Battery Inserted	❑		❑	
9. Place UAS in clear and safe launch and recovery location if return to HOME engaged	❑		❑	
10. Propulsion System Check	❑		❑	
11. UAS Battery ON	❑		❑	
12. SIM card inserted	❑		❑	
13. USB cable inserted	❑		❑	
14. Wi-Fi Connection to Monitor Verified	❑		❑	
15. DJI App loaded	❑		❑	
16. DJI App connected to camera	❑		❑	
17. SD Card Formatted	❑		❑	
18. Camera Full UP	❑		❑	
19. Satellite Connections Verified (number)	❑		❑	
20. Charge Levels Safe for Flight (UAS, Router and Transmitter) (%)	❑		❑	
21. Video Recording START	❑		❑	
22. Observer Ready	❑		❑	
23. TAKEOFF	❑		❑	

UAS Mission Checklist Items	Flight 1 Checked	Comments	Flight 2 Checked	Comments
B) After Takeoff Checklist				
1. Hover approximately TEN FEET above ground to confirm UAS under control	❑		❑	
2. All sticks operate correctly while in hover - verified	❑		❑	
3. Charge Levels Safe for Flight (UAS, Router and Transmitter) (%)	❑		❑	
C) Pre-Landing Checklist				
1. Camera - Full UP	❑		❑	
2. Video Recorder - STOP	❑		❑	
3. Landing Zone - CLEAR / SAFE	❑		❑	
D) Post-Landing Checklist - Returning to Flight Immediately				
1. Battery Remove and Replace	❑		❑	
2. Wi-Fi Connection to Monitor Verified	❑		❑	
3. DJI App connected to camera	❑		❑	
4. Observer Ready	❑		❑	
5. TAKEOFF	❑		❑	
			❑	
End of Mission Checklist			❑	
1. Battery OFF	❑		❑	
2. Transmitter OFF	❑		❑	
3. Router OFF	❑		❑	

Flight Log Data	Flight 1 Value	Comments	Flight 2 Value	Comments
Date:				
Location:				
Weather conditions:				
Time (Start):				
Time (Finish):				
Flight Duration (if more than one indicate times separately)				
Number of Visual Assets Obtained				

12.8 Appendix hh: Focus Group Participants

1- Billy Cantrell	KCI Tech (Proj. Engineer)
2-Robbie Brittain	GDOT (Construction Proj. Engineer)
3-Jeana Beaudry	KCI Tech (Proj. Engineer)
4-Harold D. Mull	GDOT (Director Construction Engineer)
5-Toby M. Hammonds	GDOT (CPME)
6-Bob O'Daniels	State Bridge Inspection Manager
7-Darrell Johnson	Regional Bridge Inspection Engineer (specialist)
8-Jeremy Durrence	Regional Bridge Inspection Engineer (specialist)
9-Job Walker	Bridge Inspection Technician
10-Charles Blue	Bridge Inspection Supervisor (Specialized Team)
11-Dana McCrary	Regional Bridge Inspection Engineer (specialist)
12-Josh Cofer	Bridge Inspection Supervisor (Top-side Team)
13-Lamu Chanthavong	Rail Management
14-Ariel Hekler	Rail Planner
15-Joseph Robinson	Aviation Project Manager
16-Colette Edmisten	Assist Aviation Project Manager
17-Alan Hood	Aviation Safety Data Manager