USER-PERCEIVED EFFECTIVENESS OF UNMANNED AIRCRAFT SYSTEM (UAS) INTEGRATION IN INFRASTRUCTURE CONSTRUCTION ENVIRONMENTS

A Dissertation
Presented to
The Academic Faculty

by

Sungjin Kim

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy in the
School of Building Construction

Georgia Institute of Technology
May 2018

USER-PERCIEVED EFFECTIVENESS OF UNMANNED AIRCRAFT SYSTEM (UAS) INTEGRATION IN INFRASTRUCTURE CONSTRUCTION ENVIRONMENTS

Approved by:

Dr. Javier Irizarry, Advisor
School of Building Construction
Georgia Institute of Technology

Dr. Ruth Kanfer
School of Psychology
Georgia Institute of Technology

Dr. Daniel Castro-Lacouture
School of Building Construction
Georgia Institute of Technology

Dr. Eric N. Johnson
School of Aerospace Engineering
Georgia Institute of Technology

Dr. Dayana Bastos Costa
Department of Structural and Construction Engineering, School of Engineering
Federal University of Bahia, Brazil

Date Approved: March 29, 2018

This dissertation is sincerely dedicated to:

[My beloved family, my respected father, *Myeongoh Kim*, my lovely mother *Youngsuk Kim* and my little brother *Seongeun Kim* who have always trusted and supported me.]

ACKNOWLEDGEMENTS

Many people have supported me during my Ph.D. journey. This dissertation would not have been accomplished without the guidance and help of my dissertation committee. There is not enough space, nor time, to acknowledge everyone to the extent they deserve. I hope people understand the brevity of this acknowledgment.

First of all, I would like to thank my doctoral advisor and academic father at Georgia Institute of Technology, Dr. Javier Irizarry, for directing my academic research; I gained invaluable experience in unmanned aircraft system (UAS) applications for the construction and civil infrastructure environment and familiarized myself with the unique characteristics of construction worksites, writing various research proposals and publications, and teaching both undergraduates and graduates. Under his guidance, I was given the freedom and trust to pursue my research in my own way, and I greatly appreciate all of his support. I felt very honored to discuss my research ideas and to work with him. Thank you for supporting and encouraging me through my doctoral degree.

I also specially thank Dr. Daniel Castro, a department chair, for kindly providing his guidance and full support during my Ph.D. journey. I would also like to express my appreciation and thanks for their support to other committee members: Dr. Ruth Kanfer, Dr. Eric N. Johnson, and Dr. Dayana Bastos Costa. I thank Dr. Kanfer for providing her insights into my research framework in terms of human, psychological, and cognitive considerations; Dr. Johnson helped me to broaden my background and foundations about UAS, engineering, and technology. I will remember Dr. Bastos Costa for our good times working together at Georgia Tech, as well as for her productive comments and feedback on my dissertation study. I particularly acknowledge the valuable participation of the Georgia Department of Transportation (GDOT), and the financial support of GDOT, through task order No. 2014-30 for Research Project No. 16-09.

Second, I want to thank to my research collaborators, Kyuman Lee and Stephen Haviland (graduate research assistants), Dmitry Bershadsky (UAS pilot), and Jeong Hur (research scientist) from the School of Aerospace Engineering. They provided the modified UAS platform to collect the visual assets and a power generation system equipped truck help to operate the ground control station (GCS) in the test-bed environment during field-testing. In addition, I also specially thank my industry partner, Rick Dobbins of SkySight Imaging Inc. He provided the visual assets collected by two elaborated UAS platforms as well as the three-dimensional (3D) data processed by photogrammetry process during the field-testing in my study.

Third, I would like to express my deep appreciation to my colleagues in the institution as well as to all my friends. Special thanks are extended to Jisoo Park and Soowon Chang who are doctoral students of civil engineering and building construction. They shared their in-depth knowledge and experience for my research. They have also given me tremendous help and encouragement while completing my studies.

Above all, I would like to thank to my family, whose love and support have helped stabilize my life and study while suffering the Ph.D. journey. I truly thank them again for their endless love and sacrifice. Whatever I mention here cannot do full justice to the extent and the value of their contributions.

TABLE OF CONTENTS

LIST OF TABLES

Table 27 – Result of Data Collection (Airport Construction) 129

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

3D	Three-Dimensional
AASHTO	American Association of State Highway and Transportation Officials
ACM	Action-Control Model
AD	Attentional Demand
AE	Architect Engineer
AEC	Architecture, Engineering, and Construction
AGL	Above ground level
AI	Artificial Intelligence
AR	Augmented Reality
AS	Attentional Supply
BCG	Boston Consulting Group
BEA	Bureau of Economic Analysis
BIM	Building Information Modeling
BMG	Bridge Maintenance Group
BMRM	Bridge Structure Maintenance and Rehabilitation Repair Manual
BMU	Bridge Maintenance Unit
CG	Construction Group
CM	Construction Management
CMer	Construction Manager
DEM	Digital Elevation Model
DOT	Department of Transportation
ESC	Electrical Speed Control

FAA	Federal Aviation Administration
FC	Flight Coordinator
FG	Focus Group
FHWA	Federal Highway Administration
FOI	Features of Interests
GC	General Contractor
GCP	Ground Control Point
GCS	Ground Control Station
GDOT	Georgia Department of Transportation
GDP	Gross Domestic Product
GDTA	Goal-Directed Task Analysis
GHM	Goal Hierarchy Model
GIS	Geographic Information System
GPS	Global Positioning System
HCI	Human Computer Interaction
HERO	Highway Emergency Response Operator
HML	High Mast Luminary
HRI	Human Robot Interaction
HTA	Human-integrated Technology Application
IAP	Implementation Action Plan
IG	Intermodal Group
IRB	Institutional Research Board
LiDAR	Light Detection and Ranging
LOA	Level of Autonomous
LOC	Loss of Control

LOD	Level of Detail
MSFS	Multi-Sensor Fusion System
MPA	Multi-layered Performance Analysis
MWL	Mental Work Load
NASA TLX	NASA Task Load Index
NDE	Non-Destructive Evaluation
PE	Project Engineer
PIC	Pilot-in-Command
PMC	Person Manipulating Control
RABIT	Robotics-Assisted Bridge Inspection Tool
RC	Remote Control
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SARM	Situation Awareness Requirement Model
SART	Situation Awareness Rating Technique
SC	Sub-Contractor or Special-trade Contractors
UAS	Unmanned Aircraft System
US	Understanding
USNAS	United States National Airspace System
VLOS	Visual Line of Sight
VO	Visual Observer
VR	Virtual Reality
WCS	world coordinate system

SUMMARY

The architecture, engineering, and construction (AEC) industry has been searching for advanced technology applications to enhance work performance. Many studies indicate that unmanned aircraft systems (UAS) have significant potential to be integrated into various construction and infrastructure management tasks. However, those studies have only focused on the technology applications. They have not considered (1) information requirements, (2) workflow transformations with UAS integration, (3) performance factors, and (4) the efficiency or effectiveness of the above factors. Therefore, previous studies remain at the stage of conceptual applications, and their outcomes have not been integrated or implemented in construction and civil infrastructure projects.

As a human-integrated technology application (HTA), a UAS requires an interaction between human operators and systems. This indicates that this technology should be integrated into construction field-related tasks without decreases in human performance. In the AEC domain, previous studies have not investigated the human operator's task performance and cognitive performance during UAS operation.

The main goals of this study are to: (1) identify the information and task requirements for integrating UAS into the construction task environment; (2) conduct field-testing to collect visual data and process three-dimensional (3D) data through the UAS photogrammetry process; (3) identify the important performance factors and analyze the efficiency and effectiveness of UAS integration; (4) propose a UAS-integrated workflow based on the result of field-testing; and (5) analyze the performance of a UAS operator.

To achieve these goals, this dissertation developed four main research frameworks: (1) information requirement analysis; (2) UAS field-testing data collection; (3) effectiveness analysis; and (4) human performance implications. The first phase of this study employed focus group (FG) interviews with Georgia Department of Transportation (GDOT) professionals and conducted a cognitive task analysis, more specifically a goal directed task analysis (GDTA). A field-testing protocol was developed to collect visual data in three different construction test-bed environments, airport, bridge, and road construction. GDOT personnel participated in the field-testing, and were asked about the performance factors and considerations for UAS integration based on their viewpoints. Based on the 3D model and 2D images, effectiveness and factor analyses were conducted based on the third group interview. This interview included the de-briefing of the field-testing and the demo session for the GDOT participants. Lastly, a user experiment was conducted to evaluate the human operator's task and cognitive performance. Based on directed and subjective measurement methods, the human situation awareness (SA) and mental work load (MWL) were evaluated and analyzed to find the implications of using UAS in construction projects.

The result of this study can provide a better understanding of UAS integration and information needs in the construction and infrastructure domain. The findings based on qualitative evidence and narrative analysis can also demonstrate the effectiveness of UAS integration and the efficiency of the transformed workflow. The main challenge of this study is the limited size of the data sample, but industry representatives with significant work experience were recruited, and the result of this study based on their experience and perception could have significant effects on the UAS integration in their task environment.

The methodology of this study contributes to transforming the research paradigm from the technology-centric method to the human-technology combined approach that considers human performance when adopting HTA in any industry sector. Conducting field experiments and field-testing with user participation can provide practices for UAS operation, and show how this evolving technology can meet the needs of potential practitioners. The findings will contribute to developing the GDOT UAS policy for GDOT personnel, and can function as the foundation to develop practical user guidelines for the construction and infrastructure industry.

\

CHAPTER 1. INTRODUCTION

The architecture, engineering, and construction (AEC) industry has constantly been trying to implement new advanced technologies to increase work productivity and efficiency. A unmanned aircraft system (UAS) has been investigated and integrated into various applications within the AEC industry. The objectives of this research are 1) to identify the required information needed to use the UAS; 2) to disseminate the value of the UAS integration within the infrastructure construction environments; and 3) to investigate the human performance implications of using UAS technology in the AEC domain. The UAS-based new data collecting and processing paradigm could result in better time and quality performance and work productivity in various domains. This study focuses on how effectively the UAS can be integrated and how efficiently this integration can transform the current workflow in the construction jobsite. To achieve these goals, field-testing, interviews, and user experiments have been conducted to collect the perception and experience data from the potential users.

This research contributes to expanding the knowledge about the information that is required to use the UAS effectively and safely and to transforming the research paradigm from a technology-centric method to a human-and-technology-combined method. This chapter discusses the current state of the construction industry, the research motivation and impacts of this study, and the research questions and objectives of this study. At the end of this chapter, a brief outline of this entire thesis is also provided for better understanding.

1.1 The Current State of the Construction Industry

Human-integrated technology applications (HTAs) have been leading the transformation of the manufacturing and production industry, and they have been considered one of the most fascinating, intense, and important innovations of the 21st century. Klaus Schwab, founder and executive chairman of the World Economic Forum, defined this phenomenon as the "Fourth Industrial Revolution," which has also been called "Industry 4.0" (Schwab, 2016). According to his book by "The Fourth Industrial Revolution", the Fourth Industrial Revolution is mostly characterized by wide-ranging HTAs, such as artificial intelligence (AI), augmented reality (AR), virtual reality (VR), and 3D printing, among others (Schwab, 2016). The Boston Consulting Group (BCG) disseminated a technical report called *Shaping the Future of Construction: A Breakthrough in Mindset and Technology* at the 2016 World Economic Forum (BCG, 2016). This report provided an overview of current transformations in the AEC industry. The Fourth Revolution has occurred in the construction, manufacturing, and production industries by providing technological developments and a certain level of automation.

Recently, the AEC industry has been focusing on integrating HTAs to increase its work productivity (Yaghoubi, Kazemi, & Sakhaii, 2012). For example, since the 1960s, the automobile and music distribution industries have transformed their manufacturing processes from labor-intensive procedures to collaborative-robot methods. Consequently, productivity has increased dramatically, according to the BCG business report (BCG, 2015). However, the construction industry has failed to improve its productivity, despite substantial studies and investments in digitalization and innovation, according to the 2016 Global Construction Survey (CIOB, 2016).

Furthermore, the construction industry has focused on technology enhancements for its operational and management procedures in order to improve work productivity and efficiency. Nonetheless, this domain has still remained a human-intensive industry with low productivity and performance, although in the past decades there have been a number of trials to implement technology applications (BCG, 2015, 2016; Han, 2011; Yaghoubi et al., 2012; Zhai, Goodrum, Haas, & Caldas, 2009). Several statistics present that construction productivity is much lower than the productivity in many other domains (Pekuri, Haapasalo, & Herrala, 2011). For example, the BCG indicates that the overall labor productivity of the entire industrial sector in the United States increased by 153% in 2012 compared to the productivity in 1964; however, the productivity in the construction sector decreased by 19% during the same period (BCG, 2015). Figure 1 demonstrates the productivity trend in the U.S. industry.

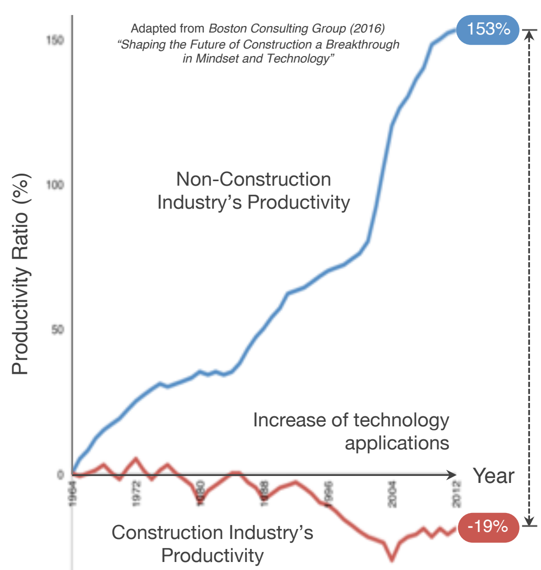


Figure 1 – Productivity in the U.S. (BCG, 2016)

Moreover, figure 2 portrays that the construction labor productivity in the United States has declined an average of 36% for 30 years (1.2% per year) since 1977, and the total construction productivity has decreased about 41% (1.4% per year) over the same period (Pekuri et al., 2011). In addition, this industry is struggling to obtain the full benefits from using innovations, such as automation and robotics, mobile technologies, building information modeling (BIM), and 3D printing, across the life cycle of a project (Armstrong & Filge, 2016). The 2016 Global Construction Survey indicates that the construction domain still has more room for improvement in construction management (CM) (Armstrong & Filge, 2016).

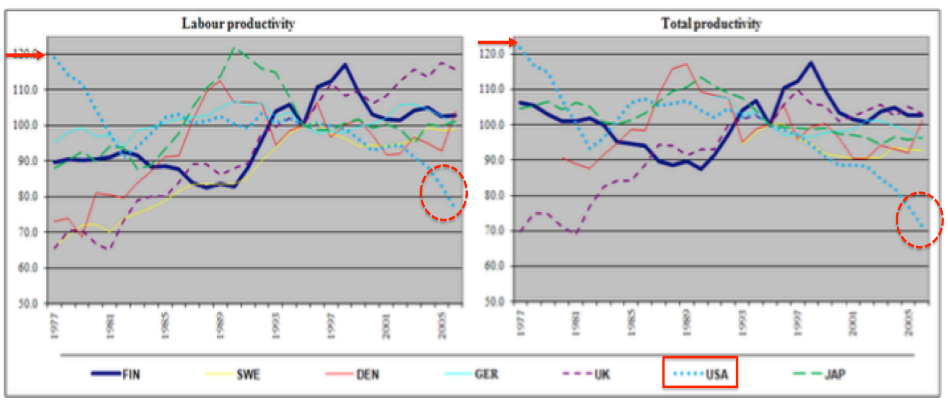


Figure 2 – Labor and Total Productivity in the U.S. Construction Industry (Pekuri et al., 2011)

The construction industry has economically significant effects on the whole economy of the United States. According to the Bureau of Economic Analysis (BEA), the U.S. total real-value-added gross domestic product (GDP) was $18,036.6 billion in 2015, and the construction domain contributed 4.1% of the total GDP with $732.1 billion in 2015 (BEA, 2017). In the third quarter of 2016, the GDP of the construction industry reached a top value of $789.4 billion since its previous high in 2005, and this amount grew by 48.5% from the record-low $528.7 billion in 2015 (Trading Economics, 2017). Figure 3 shows the trend of US GDP from construction between 2005 and 2016. In addition, the total occupational employment in the construction industry, ranging from manager-level personnel such as the general contractor (GC) to various specialty trade contractors (SCs), indicated a total of 8,372,620 employees (6.1% of total U.S. employment) in May 2015 (BLS, 2016).

Figure 3 – Trend of GDP in the Construction Industry (BEA, 2017; Trading Economics, 2017)

1.2 Research Motivation and Impacts

Infrastructure construction projects consist of multidisciplinary knowledge, complex work processes, significant amounts of money, and human resources during the project life cycle. Multiple stakeholders, ranging from project owners, architectural engineers (AEs), construction managers (CMers), GCs, SCs, and suppliers, possess different expertise, interests, and job objectives. Given this inherent characteristic of construction projects, field management activities are emphasized to improve work efficiency and effectiveness on the jobsite. These tasks consist of collecting, processing, and diagnosing data, and then making a decision based on the analysis of the project stakeholders (Ochoa, Bravo, Pino, & Rodríguez-Covili, 2011). In the AEC domain, various HTAs have been integrated into management procedures to enhance efficiency, effectiveness, and safety.

Furthermore, because of the emphasis on integrating technological innovations, the infrastructure and construction industry has been using a UAS in various tasks, such as in safety inspection (Gheisari, Irizarry, & Walker, 2014; Irizarry, Gheisari, & Walker, 2012; Kim, Irizarry, & Costa, 2016), work progress monitoring (Golparvar-Fard, Peña-Mora, & Savarese, 2009; Liu, Jennesse Jr., & Holley, 2016; Vacanas, Themistocleous, Agapiou, & Hadjimitsis, 2015), site condition inspection (d'Oleire-Oltmanns, Marzolff, Peter, & Ries, 2012; Irizarry & Costa, 2016; Perez, Zech, & Donald, 2015; Wen & Kang, 2014), and surveying (Heikkilä & Mikkonen, 2013; Siebert & Teizer, 2014; Wortel, 2009). These studies have illustrated the potential capability of the UAS to be integrated into management-related tasks in the construction environment.

However, these studies have focused only on the technological applications of the UAS. They have not considered the UAS-integrated workflow transformation, nor have they investigated the performance factors that would influence the integration of the UAS into the dynamic construction environment. In the construction and civil infrastructure domains, the UAS applications remain conceptual applications without any specifically defined work procedures.

The other challenge of these studies is that they have not considered the performance factors and the significance of each factor. Since the performance (for example, effectiveness or efficiency) that the factors are based on has not been disseminated, the UAS technology could not be implemented into the construction industry. Irizarry and Costa (2016) noted that the UAS has strong potential to collect data on the various management tasks within the construction environment; however, this analysis also did not consider any information requirements, goals, or considerations of the users to implement the UAS in the construction domain. Thus, the focus of this study is to identify the critical factors and to evaluate the performance needed to integrate the UAS into the construction projects.

Another gap between the current body of knowledge and putting it into practice is failing to consider and investigate the performance of the human operator of the UAS. Operation of the UAS requires significant interaction between the operator as a decision maker and a technology or between the decision makers. The concept of human-robot interaction (HRI) has been considered for technology system design and application research in various fields. The basic goal of this approach is to avoid the decrease in human performance during the operation of robots (Kidd, P., 1992). Therefore, integration of the

UAS as the HTA requires an investigation into human performance in this area. To bridge the disparity between current conceptual UAS applications and their actual implementation into the construction domain, the human operator's cognitive and task-oriented performance should be investigated.

It is important to document the value of UAS integration in the infrastructure construction environment based on the industry professional's experience and perspective. Reinhardt, Garrett, and Scherer (2005) note that the users within the HTA should not be overloaded with extraneous information and not overwhelmed by irregular tasks for data acquisition. Furthermore, this paper also aims to understand the goal-directed information needs of users to avoid inappropriate activities, as well as to support the UAS operator's situation awareness (SA) to ensure safety during the UAS's flight over the construction site. To consider how to efficiently transform the workflow, the current workflow, resources, and team structure should be explored. Based on the identified potential tasks, the UAS field-testing protocol can be developed and executed during the field testing on the test-bed environment. Performance factors can be identified based on the industry personnel's experience and on the perceptions derived from the field testing and user experiments. The experiment participants can be involved in actual UAS flights and data collection on the construction environment. The effectiveness of the UAS operation based on the performance factors can be evaluated, and the human performance implications can also be investigated.

This thesis postulates that it is essential for the potential users of the UAS to have significant AEC industry experience to determine the potential tasks, develop a new workflow, and evaluate the effectiveness of the UAS integration in the construction environment. This study develops four main frameworks: 1) a framework for information analysis; 2) a framework for field testing and experiments; 3) a framework for effectiveness analysis; and 4) a framework for human performance analysis and implications. The potential impacts of this study are to:

1) Provide better understanding about the current status of UAS applications and related research on the civil infrastructure and construction engineering domains;
2) Identify the current and potential tasks for integrating the UAS, as well as the significant factors influencing the UAS integration and its effectiveness in the construction environment;
3) Propose a field-based efficient UAS-integrated workflow of the construction field-management tasks;
4) Document the value of the UAS integration in terms of the effectiveness and efficiency based on the potential end user's experience and perception; and
5) Disseminate the human performance implications where the human-integrated technologies are applied to the AEC domains as well as to any other industries.

1.3 Research Objectives and Questions

The research for this thesis receives its motivation from the three challenges discussed in Chapter 1.2, which are the workflow transformation, the effectiveness of the UAS integration, and human performance. In this section, the research objectives and questions are established and described. Table 1 summarizes the research questions and objectives of this thesis. Table 2 describes the associated research frameworks that will be applied to achieve the goals.

Research Questions:

1) What is the required information for integrating the UAS into the infrastructure construction projects?
2) What performance factors should be considered for the UAS integration?
3) How can the UAS integration transform the current workflow? Is the proposed UAS-integrated workflow effective/efficient to use?
4) Which factors are important? Is the UAS integration in the construction environment effective in terms of the identified factors?
5) What is the relationship between the task performance, experience, and cognitive performance? What are the implications?

Research Objectives:

1) To obtain a better understanding of the information requirements and potential tasks to integrate the UAS into the construction task environments;
2) To identify the performance factors affecting the effectiveness of the UAS integration into the construction worksite;
3) To propose the UAS-integrated workflow for the construction projects;
4) To identify the important factors and to document the value of the UAS integration into the construction domain; and
5) To evaluate the human performance and to provide and recommend the potential implications of the UAS integration

Table 1 – Research Questions and Objectives

#	Questions (Q)	Associated Objectives (O)
1.	What is the required information to integrate the UAS into the infrastructure construction projects?	To obtain a better understanding of the information requirements and potential tasks to integrate the UAS into the construction environments
2.	What performance factors should be considered for the UAS integration?	To identify the performance factors affecting the effectiveness of the UAS integration into construction worksite
3.	How can the UAS integration transform the current workflow? Is the proposed UAS-integrated workflow effective/efficient to use?	To propose a UAS-integrated workflow for the construction projects
4.	Which factors are important? Is the UAS integration in the construction environment effective in terms of the identified factors?	To identify the important factors and to document the value of the UAS integration into the construction domain
5.	What is the relationship between the task performance, experience, and cognitive performance? What are the implications?	To evaluate the human performance and to provide and recommend the potential implications of the UAS integration

Table 2 – Associated Research Approaches

Number	Associated Research Approaches
Q1 and O1	Information Requirement Analysis 1. Focus Group (FG) Interviews 2. Goal-Directed Task Analysis (GDTA)
Q2 and O2 Q3 and O3	Field Testing/Experiment 1. Field Experiment 2. Group-Interview Field Experiment
Q4 and O4	Effectiveness Analysis 1. Debriefing and Demo 2. Group Interview 3. Survey Instrument
Q5 and O5	Human Performance Implication 1. Thematic Analysis

1.4 Definition of the User in This Study

This study evaluated the effectiveness of the UAS integration based on the user's perception. The definition of the user in this study encompasses all stakeholders in charge of the UAS operations ranging from the pre-flight preparation, flight for data collection, and post flight for data analysis and decision making.

1.5 Scope of Target Organizations

The target scope of this study is not limited to academia only. This study also aims to result in a variety of expected practical contributions for other components of the AEC industry, including the GC, the Department of Transportation (DOT), the Federal Highway Administration (FHWA), and other civil-related government agencies and commercial companies. Figure 4 illustrates the target organizations of this study.

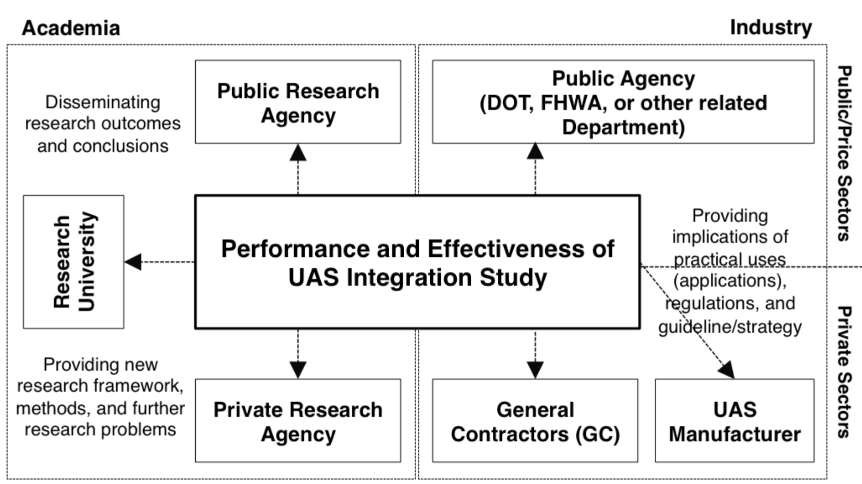


Figure 4 – Target Organizations and Contributions

1.6 Organization of This Thesis

This thesis basically addresses qualitative methods based on the FG interviews, survey questionnaires, field testing and user experiments, and thematic analysis methods in order to evaluate the effectiveness of UAS integration based on user perceptions and experience. To achieve this goal, this proposed study developed four frameworks: 1) information requirement analysis; 2) field-testing data collection; 3) effectiveness analysis; and 4) human performance implication analysis. The following explains the organization of this dissertation:

1) ***Chapter 1*** presents the state of the current construction industry and describes the research problems. The ultimate objective of this research is to propose a new workflow based on UAS integration, to evaluate the effectiveness of the UAS integration, and to investigate the human performance implications of UAS integration into the dynamic infrastructure construction environment.
2) ***Chapter 2*** provides a brief description of the UAS and Federal Aviation Administration's (FAA's) regulations, as well as a review of previous research focusing on UAS applications in the AEC domain, including the state DOT's UAS-related studies. This chapter also provides a description of human-performance-measurement methods for a clearer understanding of this study.
3) ***Chapter 3*** provides the project overview and the activities corresponding to the research methods. The entire research project encompasses four phases: 1) information analysis; 2) field testing; 3) effectiveness analysis; and 4) human performance implications.

4) ***Chapter 4*** presents the requirements for integrating the UAS into the infrastructure and construction environments. To identify the information requirements, this chapter addresses the FG interview with the DOT professionals. Based on the results of the FG interview, the current tasks, work procedures, resources, and potential tasks that can be integrated with the UAS are demonstrated. In addition, the key decision makers of the UAS operations as well as the nature of their knowledge are identified through the GDTA.

5) ***Chapter 5*** demonstrates the UAS field-testing process in the three-different test-bed environments. Based on the results of the information analysis, the field-test protocol is developed and executed in the selected task environments. During the field testing, the second group interview is conducted to identify the performance factors affecting the UAS integration and to investigate the changes in the users' perceptions. In addition, this chapter introduces the visual data collected by the UAS on the construction environment.

6) ***Chapter 6*** describes the UAS photogrammetry process to develop the three-dimensional (3D) data. Based on the field testing, the UAS-integrated workflow is developed, and the significant factors are identified through the third group interview. The effectiveness of the UAS integration regarding the significant factors is also analyzed.

7) ***Chapter 7*** narrates the human performance implications through the thematic analysis. A total of three themes emerged through the entire study. This chapter also demonstrates the user-participation field experiment process and results. GDOT personnel operate the UAS and conduct a total of six tasks in the

construction environments. Based on the subjective survey, their cognitive performance is measured.

8) ***Chapter 8*** presented a multi-layered performance analysis method can address human and technology performance of the HTA. This chapter described how each finding from each study in this dissertation interact as well as how the developed new method can be implemented to investigate a variety HTAs in various task environments.

9) ***Chapter 9*** discusses the implications and limitations of this study based on the changes in the users' perceptions, the effectiveness of the UAS integration and workflow, and human performance. Further research ideas are recommended, and the contribution to the body of knowledge as well as to the construction practice is described.

CHAPTER 2. LITERATURE REVIEW

The literature in this chapter synthesizes all related foundations and all-important concepts for the research questions and methodology to be implemented in this proposed study. The first section introduces unmanned aircraft systems (UAS), including technological concept, Federal Aviation Administration (FAA) regulations for non-recreational UAS uses, several UAS-related studies conducted by State Departments of Transportation (DOTs), and previous studies investigating UAS applications for the AEC industry.

This study considers human performance, and is closely related to the human robot interaction (HRI) concept that has been extensively disseminated to multi-disciplinary domains, such as social science, business, psychology, and engineering. The last section describes the HRI concept, including the role-based HRI model, situation awareness (SA), and mental work load (MWL).

2.1 Unmanned Aircraft Systems (UAS) in the AEC Domain

There are various terms for UAS, such as aerial robots, remotely piloted aircraft, robot aircraft, unmanned aerial robots, or unmanned aerial vehicles (UAV), commonly known as drones to the public. Regardless of the name used, UAS have a common root concept, namely “No onboard pilot unit” (FAA, 2017). However, the system has three indispensable components: (1) the vehicle platform, (2) telecommunication sensors, and (3) ground control station (GCS) including human aspect (i.e. flight crews) (Austin, 2011). Since the UAS is tele-operated through the communication between the human operators and telecommunication sensors, the UAS could be regarded as a tele-robotic system, and this could be also associated with the HRI concept (Sheridan, 1992).

The FAA defines the official terminology for these model aircraft platforms as UAS, which applies to the whole operating system, including operators, platform and other telecommunication sensors (FAA, 2016b). The UAS platform should be capable of flight without direct human intervention (FAA, 2016b). In this thesis, UAS will be used as the official terminology instead of UAV or other names in order to be compatible with the FAA’s official rules and definitions. This section presents an overview of the UAS concept, including FAA regulations.

2.1.1 UAS Overview

UAS can only exist if they have notable advantages compared to manned aircraft. Their performance can be affected by the system's designs and structures, as it can be highly reliant on the system specification, which consists of four hardware components: *(1) Communication, (2) Operation, (3) Control, and (4) Payload* (Austin, 2011). These elements are mechanically or electrically operated by the flight crews at the GCS. The UAS platforms are designed to incorporate all of these components and to maximize their performance for certain missions.

1) The *communication part* exchanges flight-related data between the UAS platform and the human at the GCS. A remote control (RC) receiver reads the flight command from the GCS and transports the command into the onboard control system. Another element is a telemetry transmitter sending the flight information data, including battery capacity, velocity, and location to the GCS. There is also a video transmitter capable of sending the visual data, such as images or videos from the camera on the platform.
2) The *operation part* usually consists of electrical motors, electronic speed controllers (ESC), propellers, and various types of battery. Each ESC receives operation signals generated from the flight control system, and it can transmit the DC power generated at the battery to AC power in order to start to operate each motor. The number of motors and propellers on the platform depends on the type of UAS platform.
3) The *control part* mainly consists of the flight controller and the multi-sensor fusion system (MSFS). In addition, several sensors such as global positioning system (GPS), accelerator, magnetic sensor, and gyroscope are attached to the platform in order to evaluate the flight condition of the platform itself during flight. The MSFS is able to compute the optimal kinetic condition based on the

data measured by the sensors and to convey the information to the flight control. The flight control system calculates the engine speed based on the flight commands received from the RC receiver and the kinetic information. The computed engine speed is transmitted to the operation part, particularly the ESC, in order to operate the UAS platform.

4) The UAS is able to conduct different types of tasks. Various applications may request different types of sensors or cameras in the platform. The *Payload* is considered as an important aspect of system design for successful mission completion. This is considered in two basic types: (1) Non-dispensable load, such as sensors or cameras equipped and permanently attached to the platform, and (2) Dispensable load, which are additional attachments for particular missions, such as armament for military missions, or mail-box for delivery services (Austin, 2011). With the rapid advances in technologies, the developments in the UAS payload will be expected to be used frequently for more and various tasks.

The GCS operators and the flight command system, including the RC transmitter, video/telemetry receiver, and other maintenance equipment, should interact with each other as well as with the UAS platform. The flight crew mainly includes one or more remote pilot in command (PIC) depending on the number of platforms to be operated. A PIC is responsible for all procedures ranging from safe takeoff to landing of the platform. One or more visual observers (VO) assist the PIC to observe other air traffic and to maintain visual line of sight (VLOS) of the platform during flight (FAA, 2016b). Figure 5 describes the functional UAS design and system architecture.

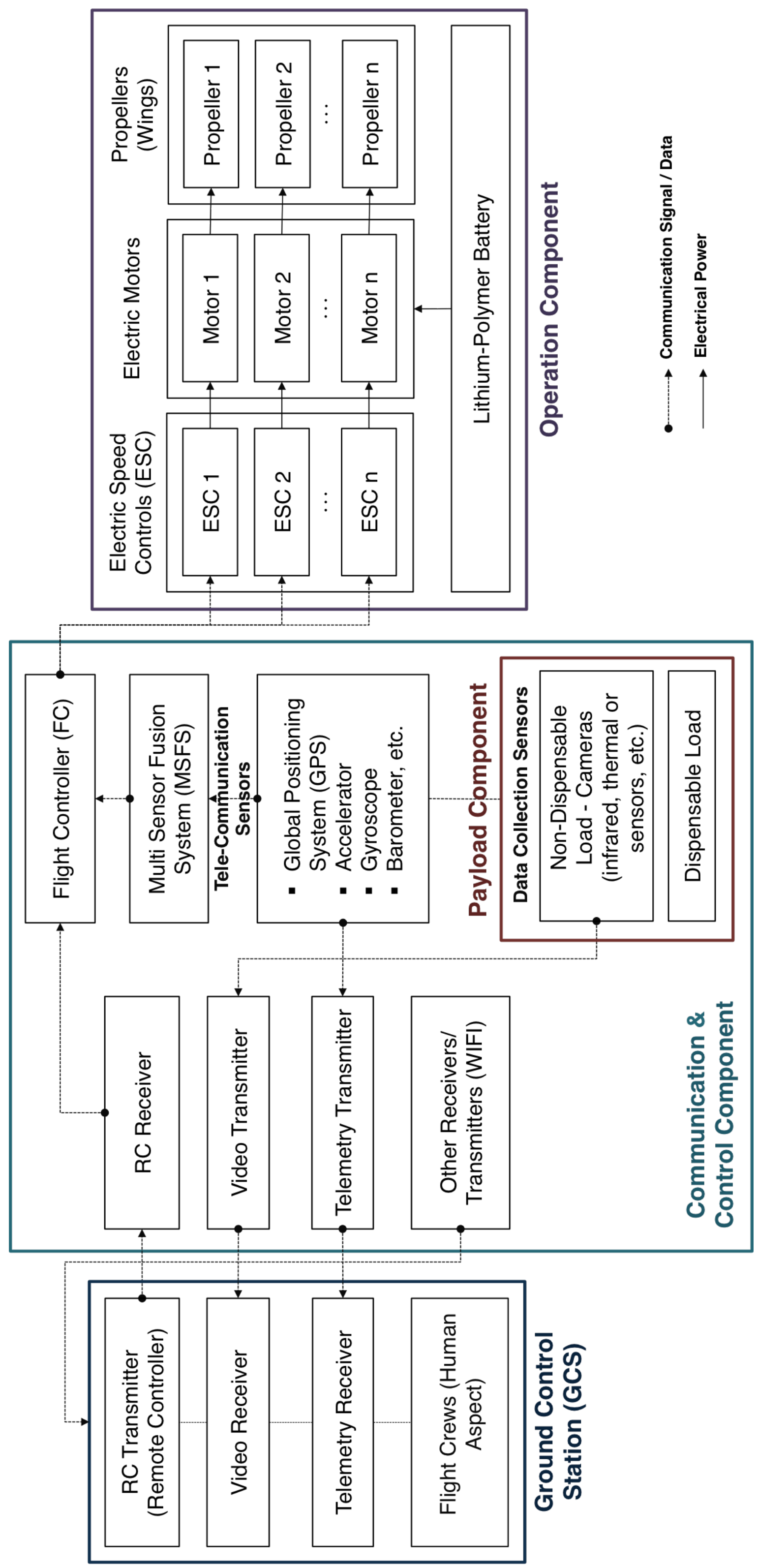


Figure 5 – UAS System Structure (applied from Austin, 2011)

2.1.2 Federal Aviation Administration (FAA) Regulatory Environment

A UAS integration into the construction environment in the United States must comply with FAA regulations. The FAA has established the official term "Unmanned Aircraft System (UAS)" instead of UAV or drone (FAA, 2016b).

The FAA established PART 107 for non-recreational small UAS operations in the United States (FAA, 2016a, 2016b). This rule requires the composition of UAS flight crews to include a PIC and a VO to safely operate within the regulatory environment. National Policy Notice 8900.207 also indicates that all UAS crews must implement crew resource management (CRM) including team building, decision-making, and communication for UAS operational approval (FAA, 2013). The most critical UAS components are the human element and the platform equipped with communication or data collection sensors.

According to the *14 CFR PART 107, "SMALL UNMANNED AIRCRAFT SYSTEMS",* newly enacted by the FAA in 2016, the UAS should be capable of sustained flight in the U.S. National Airspace System (USNAS) (FAA, 2015, 2016b), and must be within the VLOS of the operating person or the other flight crew. Moreover, the small aircraft is defined as a platform weighing less than 55 pounds, including the platform and equipment. Table 3 summarizes the 14 CFR PART 107 rules. Figure 6 shows the remote pilot certificate.

Table 3 – FAA 14 CFR PART 107 Summary

Category	Regulations
Operational Limitation	▪ Weigh less than 55 lbs. (25 kg) ▪ VLOS flight only (VO highly recommended) ▪ Any UAS operation that is not recreational in nature and not performed by the government ▪ Prohibits flying UAS over non-involved person ▪ PIC must have an FAA remote pilot certification ▪ All SUAS must be registered with FAA ▪ Daylight-only operations ▪ Maximum speed of 100mph (87 knots) ▪ Maximum altitude of 400ft above ground level (AGL) ▪ No hazardous materials on board.
PIC Responsibilities	▪ A person operating a small UAS must either hold a remote pilot airman certificate with a small UAS rating or pilot certificate (remote pilot in command) ▪ Remote PIC must be kept under the FAA rule during all flights ▪ Remote PIC should report to the FAA within 10 days in case of any accidents, injury, UAS failure, or property damage (USD $500)

Figure 6 – FAA PART 107 Remote Pilot Certificate

2.1.3 Department of Transportation (DOT)'s UAS Studies

The U.S. DOT has been focusing on operational UAS procedures and potential applications. A number of State DOTs in the United States have conducted UAS-related studies on their infrastructure, transportation, construction, and operation. A total of 15 State DOTs have explored the potential applications with UAS integration, and disseminated the results to various types of publications, such as research reports, magazines, conference proceedings, or peered-review journal papers.

A total of 19 studies related to State DOT studies are reviewed in this section. They discuss bridge inspection (States of Arkansas, California, Florida, Michigan, Minnesota, Nevada), highway and traffic monitoring (States of Arkansas, Michigan, Utah, Virginia, and Washington), geotechnical investigation (State of California), and other applications (State of Ohio). The State of North Carolina has developed an UAS operational procedure guide based on 14 CFR PART 107 (NCDOT, 2017b). The State of Illinois set up a task force team to investigate legislation related to UAS operation, and provided recommendations for UAS operations (IUASOTF, 2016). The State of Georgia has conducted the two studies since 2012. The UAS application's feasibility and economic study to investigate the benefits of UAS integration (Gheisari, Karan, Christmann, Irizarry, & Johnson, 2015; Irizarry & Johnson, 2014; Karan, Christmann, Gheisari, Irizarry, & Johnson, 2014). The second study has been investigating the potential tasks can be integrated with the UAS on their task environments since 2016 (Irizarry, Kim, Johnson, & Lee, 2017).

2.1.3.1 State of Arkansas

Arkansas State Highway and Transportation (ASHT, 2013) examined different UAS platforms to collect aerial visual data in order to find useful equipment for monitoring real-time traffic movement and for inspecting highways, bridges and facilities within the State of Arkansas. However, this study did not conduct field experiments with UAS platforms because of the FAA regulation (Frierson, 2013).

2.1.3.2 State of California

In California, Caltrans (2014) was interested in learning more about using UAS to support geotechnical field investigations within the State of California, as well as in learning about legislative issues affecting UAS use within the State. The report describes the role of FAA regulations and reviews the studies of several state agencies' studies on the application of UAS. The report recommends that proof-of-concept testing should be conducted before implementing UAS for transportation applications and geotechnical field inspections (Karpowicz, 2014). Caltrans (2008) also developed an aerial robot, "Aerobot" that is capable of vertical takeoff and landing in order to inspect highway bridges and elevated structures (Moller, 2008). This robot can be operated with a video camera placed close to the elevated structure while the controller works to control the robot on the ground. In addition, the robot has the ability to inspect the objects safely, quickly, effectively, and efficiently. The goal is to improve the capabilities and task performance of the "Aerobot", however, the robot has never been deployed on actual sites, as this prototype had technical as well as implementation issues in the field test (Moller, 2008).

2.1.3.3 State of Florida

Florida DOT (FDOT, 2015) proposed an approach to assist the inspection of bridges and high mast luminaires (HMLs). The new approach involved integrating UAS equipped with high-resolution cameras for transmitting visual data in near real-time into the HML's inspection process. FDOT conducted a proof-of-concept experiment in order to gain insights on the limitation of the UAS. This study evaluated the UAS platform components and image qualities under varying scenarios, such as altitude, payload used, and maneuverability. In addition, field tests on HML and bridge defect inspections were conducted. This report also proposed future research in terms of UAS uses for structural inspections (Otero, Gagliardo, Dalli, Huang, & Cosentino, 2015).

2.1.3.4 State of Georgia

The Georgia DOT (GDOT, 2014) investigated the economic and operational benefits of UAS use on GDOT operations by studying GDOT divisions' operations that have the potential for using UAS. Semi-structured interviews were conducted in order to identify the basic goals of the operators in each division, their major decisions for accomplishing the goals, and the information requirements for each decision (Gheisari et al., 2015; Irizarry & Johnson, 2014; Karan et al., 2014). In addition, GDOT conducted the follow-up study in order to identify potential tasks with UAS integration within their operations, and to develop UAS operational guidelines based on the field tests for their three groups: construction, bridge maintenance, and the intermodal group (Irizarry, Kim, Johnson, & Lee, 2017).

2.1.3.5 State of Illinois

The Illinois DOT (IDOT, 2016) and the task force team in the State of Illinois worked on providing an overview of comprehensive laws and rules for UAS operations within the State of Illinois. They focused on developing recommendations for UAS operations, usage, and regulations. This study aimed at understanding the concept of UAS, its applications, FAA regulations, insurance for UAS operation, as well as safety and privacy issues (IUASOTF, 2016).

2.1.3.6 State of Kansas

The Kansas DOT (KDOT, 2016) studied UAS implementation on their operations. This study conducted a survey and SWOT analysis in order to figure out how to improve the safety and efficiency of UAS operations and to reduce the cost of the applications for KDOT operations. They concluded that UAS could be used for bridge inspection, radio tower inspection, surveying, road mapping, high mast light tower inspection, and stockpile measurement among KDOT's various responsibilities (McGuire, Rys, & Rys, 2016)

2.1.3.7 State of Michigan

The Michigan DOT (MDOT, 2015) and Michigan Tech Research Institute (MTRI) evaluated five main UAS platforms with a combination of optical, thermal, and Light Detection and Ranging (LiDAR) sensors to assess critical transportation applications such as bridge inspection, traffic monitoring, or roadway asset inspection. The study conducted an UAS lab-test in order to ensure its practicality and safety during UAS field tests. Later field tests on two bridges, two pump stations, two traffic monitoring sites, and one roadway asset site were conducted in order to evaluate the UAS-based imagery.

As a result, an implementation action plan (IAP) for UAS use for bridge deck assessment, traffic monitoring, roadway asset inspection, improved LiDAR and thermal data processing, and confined space inspection was proposed. In addition, the study presents eight recommendations for future research on UAS: (1) operations and maintenance uses and costs, (2) development of UAS visual data use analysis and process, (3) slope stability assessment, (4) more formal crash scene imaging, (5) aerial imaging to meet MDOT's survey supports, (6) optimal methods to store and share large UAS-based data, (7) improvement of thermal imaging, and (8) improvement of UAS positioning accuracy (Brooks et al., 2015).

2.1.3.8 State of Minnesota

The Minnesota DOT (MnDOT, 2015) studied a UAS-based bridge inspection system. The study evaluated UAS technology and its safety and effectiveness as a bridge inspection tool. It also conducted field tests at four bridges in Minnesota. In the experiments, MnDOT addressed safety, FAA rules, and inspection methods with several imaging devices. The three types of visual assets collected included (1) still image, (2) video, and (3) infrared image. It also developed 3D models of bridge elements and site maps. The report demonstrated that the UAS could be an effective method to inspect riverbank conditions of bridges, and could provide important pre-inspection information for planning large-scale inspections in a cost-effective manner (Zink & Lovelace, 2015).

2.1.3.9 State of Nevada

The Nevada DOT (NDOT, 2015) proposed a study for developing and implementing UAS technology for the efficient inspection of highway bridges. The objectives of this proposed study are: (1) to develop efficient autonomous UAS-equipped sensors for bridge inspection; (2) to develop a software that integrates the visual data collected from various cameras; (3) to develop an algorithm to automatically detect a crack in a bridge; and (4) to demonstrate the implementation and validation through lab- and field-based testing (Pekcan, La, Kelley, & Rapp, 2015).

2.1.3.10 State of New Hampshire

The New Hampshire DOT (NHDOT, 2016) proposed new research to investigate how to increase safety and efficiency and to decrease the cost of UAS operations in the NHDOT. The purpose of this study is to analyze the cost benefit, data process and security, and human safety factors and aspects of the DOT transportation projects. The expected outcome of this study is to enhance the performance of traffic flow monitoring and assessment of infrastructure conditions, and to educate NHDOT employees to use UAS for their tasks (Hunt, 2016).

2.1.3.11 State of North Carolina

The North Carolina DOT (NCDOT, 2016) recently developed a study guide for UAS operators. This study included FAA regulations for the legal use of UAS as well as the type of airspace and flight restrictions that must be considered for UAS operations. In addition, the study reviewed various potential UAS applications in the State of North Carolina, and provided up-to date UAS-related information including FAA regulations, as well as a guide to temporary flight restrictions and aeronautical charts. This study contributed to ensuring that UAS operators or researchers, not only in North Carolina but across the United States, understand and comply with the regulations related to UAS (NCDOT, 2017a, 2017b).

2.1.3.12 State of Ohio

The Ohio DOT (ODOT, 2013) tested UAS for capturing aerial imagery and for developing surface models in a project-planning phase. The imagery was orthorectified and used in ODOT's geographic information system (GIS). The imagery was processed with the Pix4D application, which is software that can processes images using photogrammetry in order to produce highly geospatially accurate orthorectified aerial images. The resulting three-dimensional (3D) point cloud of the surface can enhance project visualization and analysis. ODOT indicates future UAS application plans, which include evaluating several types of UAS and sensors for bridge pier condition assessment (Judson, 2013).

2.1.3.13 State of Utah

The Utah DOT (UDOT, 2012) focused on improving their performance of using a UAS for highway-related problems or projects. UDOT collected aerial images with the UAS during and after the completion of a highway corridor project. The imagery collected was utilized to identify wetland plant species at Lake Utah. The high-resolution photos allow for immediate updates to the UDOT's GIS database and contribute to a historical record of construction phases. According to this study, the UAS can be a tool for real-time data collection and documentation during a construction process (Barfuss, Jensen, & Clemens, 2012).

2.1.3.14 State of Virginia

West Virginia University and the Virginia DOT (VDOT, 2009) developed a UAS named “Foamy” to prove the concept of aerial data acquisition for transportation worksite management or traffic monitoring. Two sessions of field tests were conducted. This study performed an error analysis to identify various factors that affect position accuracy. As a result, a significant number of position estimation errors were found. In order to improve the accuracy, a time synchronization board was used to accurately control the image acquisition process and time (Gu, 2009).

2.1.3.15 State of Washington

The Washington DOT (WSDOT, 2008) evaluated UAS capabilities for exploring institutional issues. Field tests were conducted on mountain slopes above state highways. Particularly the maintenance division used the UAS for monitoring snow avalanche control in order to reduce highway closure time and hazards to motorists. In addition, the UAS was able to capture aerial images suitable for traffic surveillance and data collection during the field test (McCormack & Trepanier, 2008).

Table 4 summarizes each State DOT’s UAS studies related to civil applications in the AEC domain.

Table 4 – UAS-related Studies of State DOT

Number	State DOT	Implementations	References (Authors (Year))
1	Arkansas	Traffic movement monitoring, highway, bridge and facilities inspection	(Frierson, 2013)
2	California	Geotechnical field investigations	(Karpowicz, 2014)
		Bridge inspection	(Moller, 2008)
3	Florida	Bridge and HML inspection	(Otero et al., 2015)
4	Georgia	Economical and operational benefits of UAS Integrations on DOT operations	(Gheisari et al., 2015; Irizarry & Johnson, 2014; Karan et al., 2014)
		Potential Tasks with UAS	(Irizarry et al., 2017)
5	Illinois	UAS regulation and operational recommendations	(IUASOTF, 2016)
6	Kansas	General UAS Integration into DOT operations	(McGuire et al., 2016)
7	Michigan	Bridge inspection, traffic monitoring, and roadway condition assessment	(Brooks et al., 2015)
8	Minnesota	Bridge inspection	(Zink & Lovelace, 2015)
9	Nevada	Bridge Inspection	(Pekcan et al., 2015)
10	New Hampshire	UAS feasibility study Riverbank inspection and planning process	(Hunt, 2016)
11	North Carolina	UAS operator guideline Development	(NCDOT, 2017a, 2017b)
12	Ohio	3D model and GIS for construction project planning	(Judson, 2013)
13	Utah	Highway condition monitoring and assessment	(Barfuss et al., 2012)
14	Virginia	Construction work environment inspection and traffic monitoring	(Gu, 2009)
15	Washington	Highway maintenance and traffic surveillance	(McCormack & Trepanier, 2008)

2.1.4 UAS Applications in the AEC Domain

In this section, various recent studies about UAS application in the AEC domain are reviewed and summarized.

2.1.4.1 <u>Potential UAS Applications in Construction</u>

Demoz Gebre-Egziabher and Xing (2011) developed a framework for the concept of operations that use the small UAS to support various kinds of transportation infrastructure monitoring. The authors identified a potential risk that has to be managed for the application, namely that of a collision between the UAS and the infrastructure to be monitored. This study also proposed various solutions to ensure a safe separation between the UAS platform and the infrastructure objects being inspected. However, most of the solutions are highly reliant on the multisensory approaches that combine a digital map of the infrastructure integrated GPS and inertial navigators.

Blinn and Issa (2016) tried to explore possible applications of UAS for the construction industry in their study. They explored the feasibility of UAS applications in active construction environments. The study compared the current tasks without UAS and aerial images obtained from UAS through a survey of industry personnel. They concluded that aerial photos and videos captured by UAS could be used for project management and controls on construction sites. In terms of costs, this study showed that the use of UAS can reduce costs compared to the current method, which only takes aerial images on jobsites.

Irizarry and Costa (2016) also investigated potential UAS applications for construction management tasks. The study involved interviews with construction managers as well as a questionnaire survey in order to collect qualitative and quantitative data. The results of this study concluded that construction work progress monitoring and jobsite logistics could benefit from UAS applications.

2.1.4.2 Construction Safety Applications

Kim, Irizarry, and Costa (2016) identified the performance factors, user requirements, and operational challenges of UAS applications for construction inspection, particularly for safety on construction sites. The questionnaire survey was distributed to construction safety and project managers in the field. A total of 31 factors and 17 measures were derived to evaluate the performance of UAS operations. In addition, UAS flight plans and proper documentation methods were identified as the most important user requirements, and FAA regulations and pilot certification were considered the most significant challenges for safe UAS operations in the construction environment.

Gheisari and Esmaeili (2016) also identified the user and technical requirements of potential UAS-based safety applications. A total of 22 safety managers participating in the survey indicated that the most dangerous operations that UAS are capable of improving are: (1) working around traffic or a crane, (2) working near an open area, and (3) working in the blind spot of heavy equipment. The three most important technical issues include: (1) real-time communication, (2) high-precision navigation system, and (3) sense-and-avoid.

2.1.4.3 Roadway Construction, Assessment and Traffic Monitoring

Candamo, Kasturi, and Goldgof (2009) described a vision-based roadway detection algorithm to be used by the small UAS at a low altitude. The performance of the system developed by the authors was demonstrated in urban surveillance and traffic monitoring. Cheng, Zhou, and Zheng (2009) presented a method to detect and count traffic from a video recorded by a UAS. The goal of this study was to monitor activities at traffic intersections to detect congestions and predict the traffic flow. They developed a vision-based algorithm to detect and count the vehicles in the visual image sequence of the traffic scene. W. S. Hart and Gharaibeh (2010) explored UAS equipped with a digital imaging system and GPS in order to improve the effectiveness and safety of roadside conditions and construction inventory surveys. This study conducted field experiments on ten sample roadways in Texas. The condition of the sample was evaluated by observing visual assets collected from UAS. They also considered weather and field conditions to evaluate the operational performance of the UAS during the field test.

2.1.4.4 Bridge Inspection

Metni and Hamel (2007) studied the bridge monitoring application of UAS equipped with a computer vision sensor. They presented a novel control method of the UAS for quasi-stationary flights above the bridge model. Guerrero and Bestaoui (2013) developed the zermelo-traveling salesman problem method to generate an optimal UAS flight route to inspect bridge structures. According to the simulation, the UAS flight for bridge inspection with the sensor could be more effective and have maximum flight times in windy environments

Hallermann and Morgenthal (2014) tried to develop a method for visual bridge inspection with aerial photography taken by UAS, and an autonomous or semi-autonomous flight inspection method for detecting damage on a bridge. Laa, Gucunski, Kee, and Nguyen (2014) implemented a robotics system to collect and analyze the data for autonomous bridge deck inspections. The navigation system was developed to collect visual assets and conduct a non-destructive evaluation (NDE). This system aims to reduce the cost and time needed to inspect the bridge deck and the risks to human resources.

Ellenberg, Branco, Krick, Bartoli, and Kontsos (2014) conducted a feasibility study of potential UAS applications on infrastructure inspection and evaluation. A computational image-processing algorithm was also developed in the study. The algorithm was capable of identifying markers placed on the structure and computing the distance and angle between the UAS and the markers. During the study, two lab-based pilot tests and one field-based experiment (bridge environment) were performed in order to evaluate the performance of UAS applications for visual infrastructure inspection, such as detecting defects or damages. This study contributed to a better understanding of how UAS and image-processing algorithms can be integrated for infrastructure inspections. The studied application showed more accurate and objective results than the traditional method.

Khan et al. (2015) investigated the use of UAS applications for inspecting bridge structures at inaccessible locations. They conducted a pilot test on a mock-up bridge model as well as real highway bridges. The aim was to understand the process of providing inspectors with multi-spectral imagery as preliminary assessments of bridge elements. They concluded that possible further research could develop the vision-based UAS application needed to collect and process data in order to evaluate the bridge condition.

Chan, Guan, Jo, and Blumenstein (2015) reviewed the current state of bridge inspections with UAS platforms. This study aims at understanding the historical development, capabilities for inspections with aerial visualization, and requirements of UAS-based bridge inspections. In addition, they conducted a case study to analyze the cost effectiveness, indicating that around $3,000 of the inspection costs could be saved by reducing the need for traffic control, and because of the fewer resources required for the inspection of substructure and superstructure elements. The case study also supported the evaluation of UAS performance on bridge inspections.

Gucunski, Kee, La, Basily, and Maher (2015) developed the robotics assisted bridge inspection tool (RABIT) for bridge deck condition assessment. This paper validated the performance of the developed system. Gillins, Gillins, and Parrish (2016) presented a methodology for UAS-integrated bridge inspection and the results from a pilot inspection of a bridge in Oregon using UAS and the developed methodology.

2.1.4.5 3D Model Applications

d'Oleire-Oltmanns et al. (2012) studied how to improve the accuracy of 3D visualized data through using UAS applications on soil erosion control. Different test-bed environments were selected to collect the visual data, using fixed-wing UAS as well as satellite-based remote-sensors. Based on the installed ground control points (GCP), the collected images could be geo-referenced and processed to generate 3D models. The study compared the performance of models generated with each method based on accuracy. The GCP-based workflow showed very high-level accuracy, and the approach proved to be useful for measuring erosion in very high detail.

Rodriguez-Gonzalvez, Gonzalez-Aguilera, Lopez-Jimenez, and Picon-Cabrera (2014) proposed a methodology to reconstruct 3D models using aerial images obtained during UAS flights. The methodology employs computer vision processing and photogrammetric algorithms in order to extract key points and match them s from multiple collected images. The 3D model can be reconstructed on the basis of image orientation. Field tests were performed to validate the UAS-integrated methodology and to assess the quality of the reconstructed 3D models. As result, the UAS image-based 3D model had more accurate and reliable data and more effective cost performance compared to a 3D model generated by terrestrial laser scanners.

Siebert and Teizer (2014) introduced detailed components of UAS, including the hardware and software needed to generate flight path plans. The UAS are also capable of generating 3D point clouds and orthomosaic and digital elevation models (DEM) through the collected flight data after data processing. This research team performed three case studies to evaluate the performance of UAS-based construction survey applications, particularly for earthwork surveys, on the three types of construction worksites: landfill, road construction, and high-speed rail construction. The performance was evaluated on the basis of the error analysis results, and the performance of the proposed application was compared to the conventional survey method. As a result, the UAS-based 3D model showed more accurate measurements than the traditional process of earthwork surveying. This study also demonstrated the technical limitations to be considered, such as battery life and the resolution of images. Further studies were recommended with additional case studies in various scenarios in order to identify other potential UAS-based applications on construction work environments.

Oskouie, Becerik-Gerber, and Soibelman (2015) proposed a framework to integrate image processing and point cloud processing in order to produce quality-improved data for evaluating project conditions. A field test was conducted to validate the proposed framework. An off-the-shelf UAS platform was used to collect aerial images of the test-bed environment, an academic building at the University of Southern California. Commercial photogrammetry software generated a 3D model of the building. The framework processes and the geometric features of interest (FOI) can be detected, extracted, and localized in the 3D point cloud in order to improve the accuracy of the classification. The framework provided multiple laser scanning scenarios including the potential number and locations of the laser scanner. Through an iterative simulation process, the optimal scanning plan could be identified. Further studies will be required to validate the framework with more detailed parameters during field tests.

Kim, Irizarry, Costa, and Mendes (2016) investigated the use of UAS for 3D models in the AEC domain. This paper aims at identifying requirements and challenges from field experiments using an UAS for a 3D model of a university campus and a residential construction site. The experiments involved the following steps: 1) development of UAS flight mission plan and selection of flight mode, 2) capturing and collecting visual assets from UAS during flights, 3) data processing using the Pix4D software program to construct a 3D model from the collected images. The main contribution of this paper is the identification of operational requirements and the challenges involved in the use of UAS to construct 3D models from the images obtained.

2.2 Human-Integrated Technologies and Human Performance

2.2.1 Concept of Human Robot Interaction (HRI)

HRI is the concept to understand the interaction between one or more humans and one or more robots (Goodrich & Schultz, 2007). HRI has become a fundamental or essential concept to be considered for a myriad of robotic systems (Prewett, Johnson, Saboe, Elliott, & Coovert, 2010). Current robotic technology is not fully autonomous, therefore it requires the level of direct controls, such as tele-operations or supervisory control (Casper & Murphy, 2003; Goodrich & Schultz, 2007).

According to the level of autonomy (LOA), there are five levels of autonomy between a human and a robot: (1) tele-operation, (2) medicated tele-operation, (3) supervisory control, (4) collaborative control, and (5) peer-to-peer collaboration. Tele-operation is regarded for robots with a high level of cognitive skills that are able to interact with humans. Figure 7 shows the LOA.

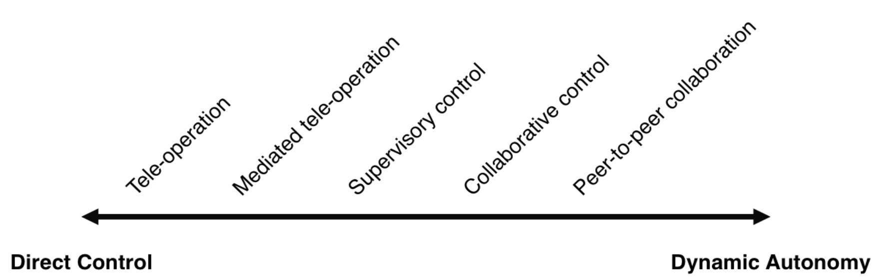


Figure 7 – Level of Autonomy (LOA)

The tele-operated robotic (tele-robotics) system directly communicates with one or several human operators through the interface of the human-integrated technology applications (HTAs). Tele-robotics are defined as “direct and continuous human control of the tele-operator” or “machine that extends a person’s sensing and/or manipulating capability to a location remote from that person” (Sheridan, 1992). According to Sheridan’s perspective on tele-robotics, the human computer interaction (HCI) includes HRI concepts in the case of interaction between tele-robotics and humans (Scholtz, 2003).

2.2.2 UAS as Human-integrated Technology Application (HTA)

Yanco and Drury (2004) classified the HRI taxonomy, demonstrating possible combinations of HRI concepts. One of the combinations is the interaction between multiple humans and a single robot (as shown in Figure 8). In this situation, the human operators can coordinate between themselves (1^{st} interaction) and issue commands to the robot (2^{nd} interaction). At the 2^{nd} interaction step the scale of LOA could be determined.

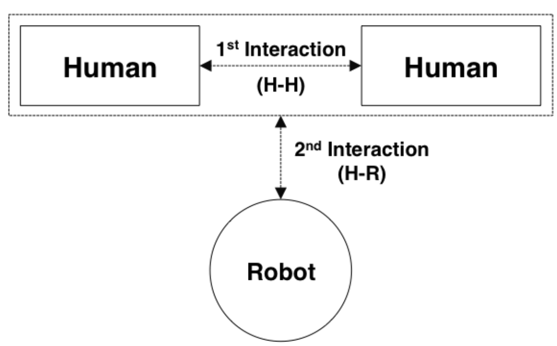


Figure 8 – HRI Taxonomy: Multiple Human and Single Robot Interaction

UAS operations are representative of this taxonomy when a human operator and other related person (i.e. project manager or inspector in the AEC domain) collaborate to fly the UAS platform with appropriate flight planning. The UAS could be operated under all kinds of autonomous situations. The UAS can fly fully manually (tele-operation), semi-autonomously (supervisory control), or fully autonomously (peer-to-peer collaboration) based on the user's decision, but all flight processes should be monitored and controlled by human operators in order to comply with FAA regulations. Therefore, the HRI concept could go beyond tele-operation of the UAS platform as well as allow for some levels of autonomous flight to be carried out by the UAS platform (Scholtz, 2003). Thus, UAS operations should be considered with the HRI aspects. Figure 9 shows a relationship between a set of humans and one single platform for UAS operations and interactions.

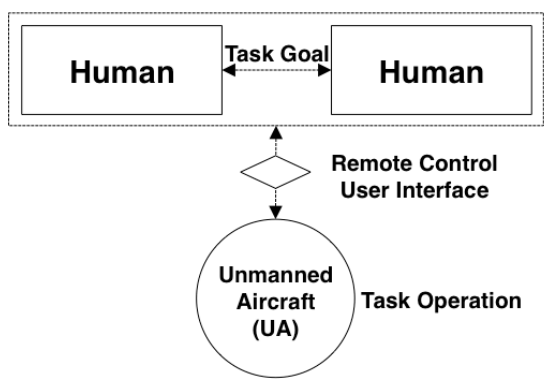


Figure 9 – HRI Taxonomy: UAS Operations

2.2.3 Human Operators' Performance Measures

The performance of human operators interacting with the human-integrated technology should be evaluated and improved, as systems become more complex and automated. Moreover, it is very difficult to accurately evaluate the human operators' performance (Yagoda, 2010). From the perspective of human cognitive psychology, human error, caused by multiple failures during the cognitive process, is a very critical component that affects the performance of the human operator (Furnham, 1994). To reduce the human error, the human operator should maintain good situation awareness (SA) during the operation. Another issue to be considered is the mental work load (MWL), which may affect the operator's SA during the operation. In this study the SA and MWL of the human operator will be considered as important, as cognitive performance can affect the success of a UAS operation. The next section will describe the concept and measurement methods of SA and MWL.

2.3 Situation Awareness and Mental Work Load

2.3.1 Concept of SA

Users are perceiving and comprehending a set of data from surrounding environments changes, and they are often missing the information they needed from the data they perceived (M. R. Endsley & Garland, 2000). This challenge is called the information gap of the user (Figure 10). Based on this problem, the researchers wanted to know how to bridge the information gap, and the concept of "SA" was defined.

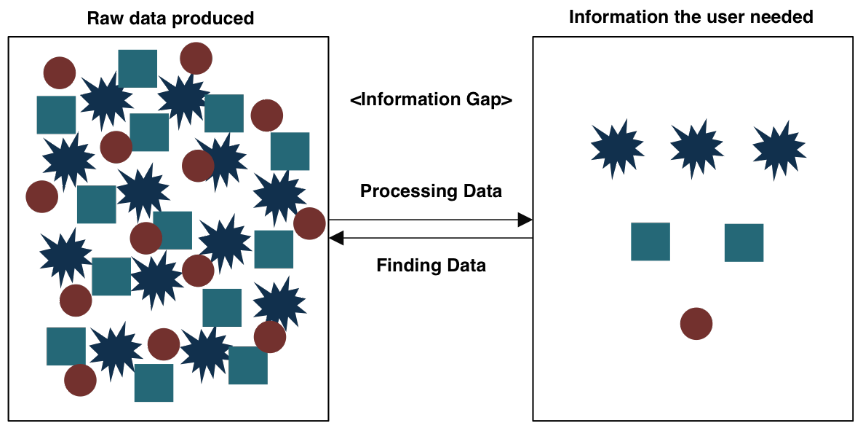


Figure 10 – Information Gap (M. R. Endsley & Garland, 2000)

The SA is basically "being aware of what is happening around you and understanding what that information means to you now and in the future (M. Endsley, R, Bolte, & Jones, 2003)". According to M. R. Endsley (1988), the SA is more formally defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future". The SA has three different hierarchical levels relating to what the user wants to do with the information required: (1) Perception of current situation (Perception); (2) Comprehension of current situation (Comprehension); and (3) Projection of future situation (Projection). The perception, which is the Level 1 SA, means a fundamental SA relates to the user's ability to extract the information from the data. This is the first step to achieve the SA in terms of perceiving the status of relevant components in the task environment. The comprehension, which is the Level 2 SA, is related to how well the users integrate or process the data from the Level 1 SA data perceived. This synthesizes multiple pieces of information from the Level 1 SA. The projection, which is the Level 3 SA, means the highest level of SA related to the user's ability to forecast future situations and actions in the environment (Connelly, Lindsay, & Gallagher, 2007; M. Endsley, R et al., 2003; M. R. Endsley & Garland, 2000).

The relationship between each level of SA is illustrated in Figure 18 (M. R. Endsley, 1995; M. R. Endsley & Garland, 2000). In a complex and dynamic task environment, decision-making is highly reliant on various environmental factors that could have a significant effect on the SA of the user, and the performance is very dependent on the user's decision, as shown in Figure 11. In other words, the improved SA could lead to better decision-making and task performance.

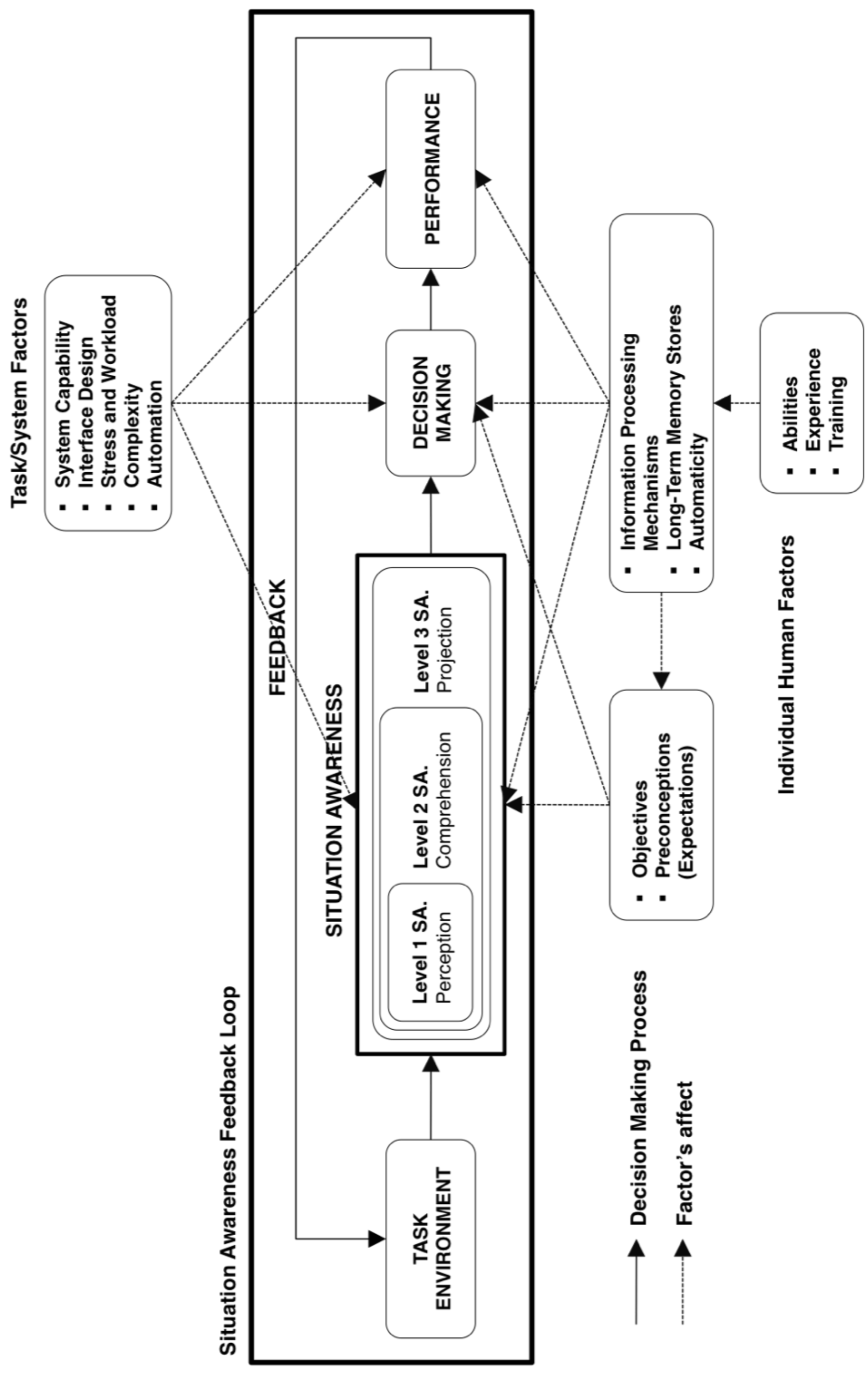


Figure 11 – SA-based Decision-Making Model (M. R. Endsley, 1995)

In the SA-based decision-making model, this describes task/system factors as well as individual factors affecting the user's decision-making process and task performance. However, there are other factors, such as organizational or technological constraints, that can have significant effects on the decision-making process (M. R. Endsley & Garland, 2000). In addition, human-integrated technologies should be designed to support individual operators' or team's decision-making, while considering individual human behavior, team behavior, and interaction between individual human operators or between humans and the system (M. R. Endsley, 1995).

For UAS operation within the dynamic construction and infrastructure environment, the concept of SA should be considered with various factors. The key decision-makers' main- and sub-goals that can support SA enhancement should be identified. To identify the critical information and information requirements, the goal-directed task analysis (GDTA) can be employed in the research.

2.3.2 Measurement of SA

Several SA measurement methods have been investigated and developed to identify the advantages and disadvantages of each measurement method. Measuring SA provides significant insights into how the operator can develop a coherent operational picture from the various sets of data, and useful criteria to evaluate the performance during the execution of the tasks (M. R. Endsley & Garland, 2000). The SA measurement method can be classified into two main approaches: (1) indirect measurement of SA, and (2) direct measurement of SA. Indirect measurement tries to infer the personal cognitive process involved in obtaining and processing SA by means of two methods: (1) process-based measurement, and (2) performance-based measurement. (M. Endsley, R et al., 2003; M. R. Endsley & Garland, 2000). Direct measurement directly evaluates a person's SA through subjective and objective measurement methods.

Process-based methods describe the way subjects process information obtained from the task environment through eye tracking, information acquisition, or analysis of communication. The physiological changes of subjects could be related to their cognitive activities or thoughts, but this does not mean connecting the physiological status and the level of SA (M. Endsley, R et al., 2003). The performance-based measurements assume that the better performance has better SA. In general, the performance metrics can include the productivity, time to perform the task, the accuracy of the response, and the number of errors committed (M. R. Endsley, 1995).

In the subjective method, the subjects are asked about their SA on a scale. One representative method is the situation awareness rating technique (SART) which is a post-subjective rating method (Taylor, 1990). The last method is the objective measurement method, which collects the user perceptions of the specific situation and scores their SA accuracy (M. Endsley, R et al., 2003). One representative method of the objective approach is the situation awareness global assessment technique (SAGAT). Advantages, disadvantages and considerations of direct SA measurement methods (i.e. SART and SAGAT) that will be used in this study are presented in Table 5 (M. Endsley, R et al., 2003). It is very difficult to identify clear task performance by using the indirect SA measurement method (M. R. Endsley, 1995).

Table 5 – Direct SA Measurement Methods (M. Endsley, R et al., 2003)

		Advantages	Disadvantages	Considerations
Direct SA Measurement Methods	**Subjective Measure (SART)**	▪ General construction of measures ▪ Width and ease of use ▪ Correlation between performance and workload measures	▪ Not correlated between objective measures ▪ Limited individual SA elements ▪ Workload elements in scale confounded with the SA	▪ Easily administrated with lab or field experiment settings ▪ Could be used with other SA measurement method ▪ Useful to evaluate the team SA
	Objective Measure (SAGAT)	▪ Could minimize the SA bias ▪ Allow assessment of shared SA within team ▪ Adaptable to realistic dynamic environments	▪ Requires determined specific scenario ▪ May have negative effects on the flow of real environment	▪ Requires detailed analysis of SA requirements (GDTA) ▪ Multiple data collectors are needed

2.3.3 Measurement of MWL

The subjective MWL assessment method is very critical because the HRI concept does not have any benchmarks to measure the human operator's MWL; moreover, it is currently very difficult to find experts to operate the system (Rubio, Díaz, Martín, & Puente, 2004). Other reasons for using subjective MWL measures are ease of use and the standardized sensitivity of MWL assessment (Wierwille & Eggemeier, 1993). Wierwille, Rahimi, and Casali (1985) also noted that the subjective MWL measurement method is much more reliable and sensitive to errors or loads than the physiological-based method. The operators' MWL is at least if not much more important than their physiological process and response within the HRI aspect (Yagoda, 2010).

One representative method is the NASA task load index (NASA TLX), which has a standardized rating scale system (S. G. Hart & Staveland, 1988). This study initially identified ten subjective workload-related factors: (1) mental demand; (2) temporal demand; (3) physical demand; (4) performance; (5) efforts; and (6) frustration level as shown in Table 6.

Table 6 – Description of NASA's TLX MWL Rating Scale

Elements Combined	Endpoints	Description/Questions
Mental Demand	Low/High	How much mental and perceptual activity (thinking, deciding, calculating, remembering, looking, and searching) was required?
		Was the task easy or demanding, simple or complex, exacting or forgiving?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Physical Demand	Low/High	How much physical activity was required (pushing, pulling, controlling, and activating)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Performance	Poor/Good	How successful do you think you were in accomplishing the goals of the task set by yourself? How satisfied were you with your performance in accomplishing these goals?
Efforts	Low/High	How hard did you have to work (mentally or physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Table 7 shows the list of SA measurement questions to be asked. All questions are standardized and referred to the SART (M. R. Endsley & Garland, 2000).

Table 7 – SA Measures in SART

Domains	Elements	Descriptions
Attentional Demand	Instability of Situation	This means the likeliness of situation to change suddenly.
	Variability of Situation	This means the number of variables that require attention.
	Complexity of Situation	This means the degree of complication of situation.
Attentional Supply	Arousal	This means the degree that one is ready for activity.
	Spare Mental Capacity	This means the amount of mental ability available for new variables.
	Concentration	This means the degree that one's thoughts are brought to bear on the situation.
	Division of Attention	This means the amount of division of attention in the situation.
Understanding	Information Quantity	This means the amounts of knowledge received and understood.
	Information Quality	This means the degree of goodness of value of knowledge communicated.
	Familiarity	This means the degree of acquaintance with situation experience.

CHAPTER 3. RESEARCH METHODOLOGY

This chapter presents an entire framework that outlines the integration of unmanned aircraft system (UAS) into the construction task environment. An overview of the research framework is described in the first section, and the subsequent section demonstrates the information analysis, field-testing and experiment process, as well as the effectiveness and thematic analysis of this study in detail.

3.1 Overview of Framework

Current research in terms of UAS implementation in the construction domain focuses on proposing various conceptual applications without field-testing and without considering effectiveness, workflow transformation, and human performance. To address the challenges in previous studies, this study proposes a new research methodology encompassing human, technology, and engineering domains. This framework aims at documenting the value of UAS integration in the dynamic construction and civil infrastructure environment. In addition, this study intends to address the research questions and achieve the goals through four main methods (as shown in figure 12):

1) Information requirement analysis
2) Field-testing and experiment
3) Effectiveness analysis and workflow transformation
4) Human performance analysis

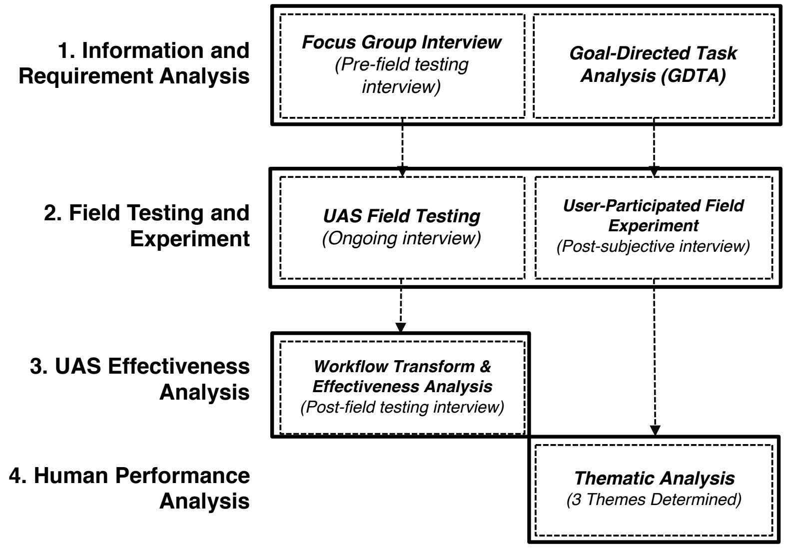


Figure 12 – Overview of Research Framework

The "information requirement analysis" has two sub-frameworks (1) focus group (FG) interview and (2) goal-directed task analysis (GDTA). FG interviews are conducted with a construction, a bridge maintenance, and an intermodal group from the Georgia Department of Transportation (GDOT). This interview explores the general information, such as current work process and environment, the resource they use, and potential tasks to be integrated with UAS. The GDTA can provide the task goals and situation awareness (SA) requirements of the human operators where the humans use UAS in the construction inspection task environment. In the following step, "UAS field-testing", test-bed environments for the field-testing are selected, and the common potential tasks identified from the information analysis are conducted by using UAS during the field-testing. A field-testing protocol is developed and implemented during the field-testing step. An interview with the GDOT collaborators is conducted to identify their perception changes from the first interview as well as the performance factors influencing the effectiveness of the UAS in the construction and infrastructure environment. In addition, a participatory user field-experiment is conducted during the workshop for the GDOT, and the participants conducted UAS flights to complete the given tasks on the construction site.

Based on the 2D visual data collected during the field-testing, three-dimensional (3D) data are processed and developed through the UAS photogrammetry process. With these visual products, the post field-testing interview and demo session are conducted to identify the significance of performance factors as well as the workflow with the UAS integration. In addition, the performance in terms of effectiveness and efficiency is evaluated based on the users' perceptions and experience. A thematic analysis is conducted to analyze the human performance.

Figure 13 illustrates details of the research methodology. The following sections explain each phase of the research methodology in more detail.

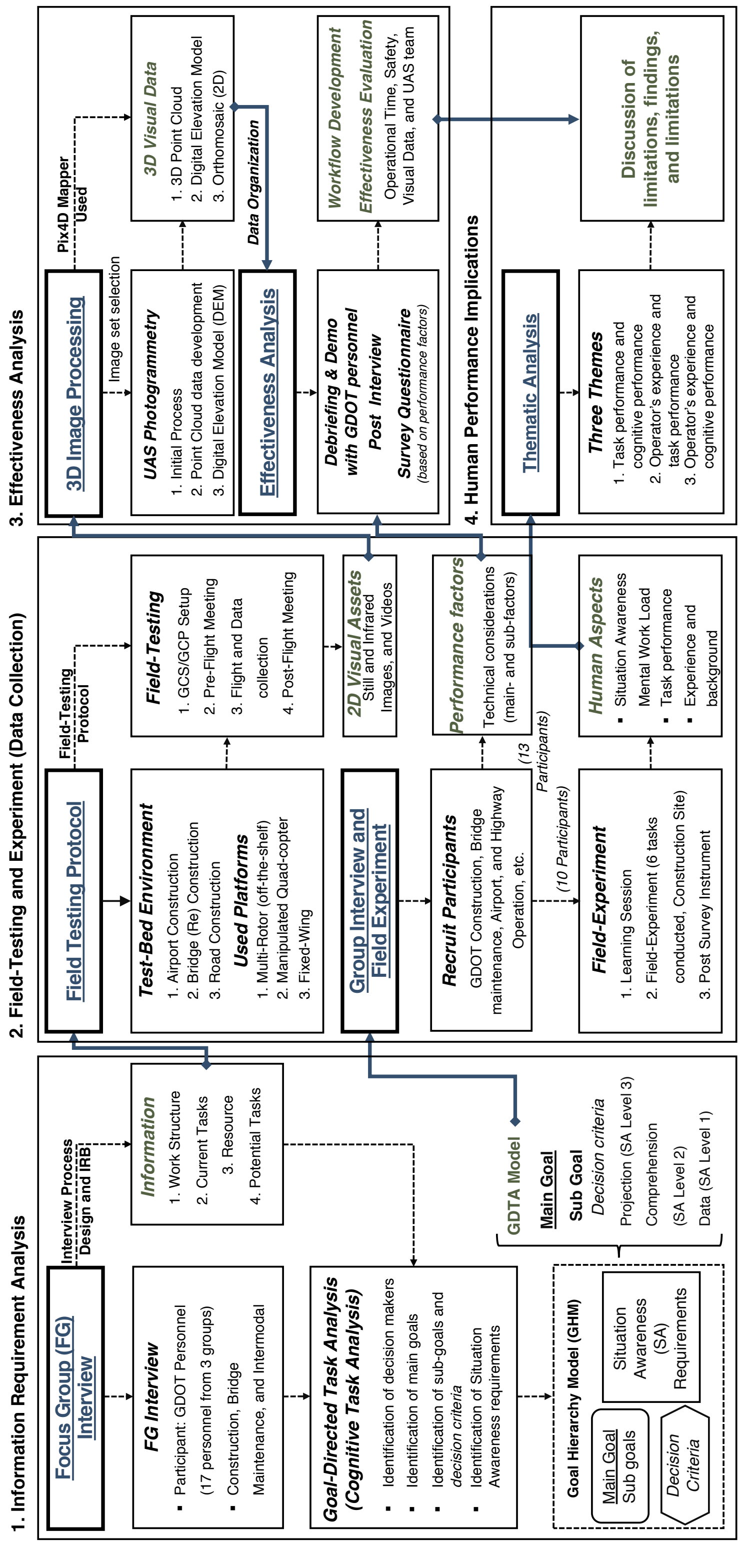


Figure 13 – Research Methodology

3.2 Information Requirement Analysis

The first phase of this study provides an in-depth understanding of the information requirements for UAS integration in construction and civil infrastructure projects. Two methods, (1) FG interviews and (2) GDTA are employed in this section to collect qualitative data from GDOT industry professionals with in-depth experience in the construction and infrastructure domain. Based on the collected data, the GDTA can provide more detailed information, including the nature of goals and SA requirements. The detailed results will be demonstrated in the next chapter. Figure 14 illustrates the information requirement analysis method.

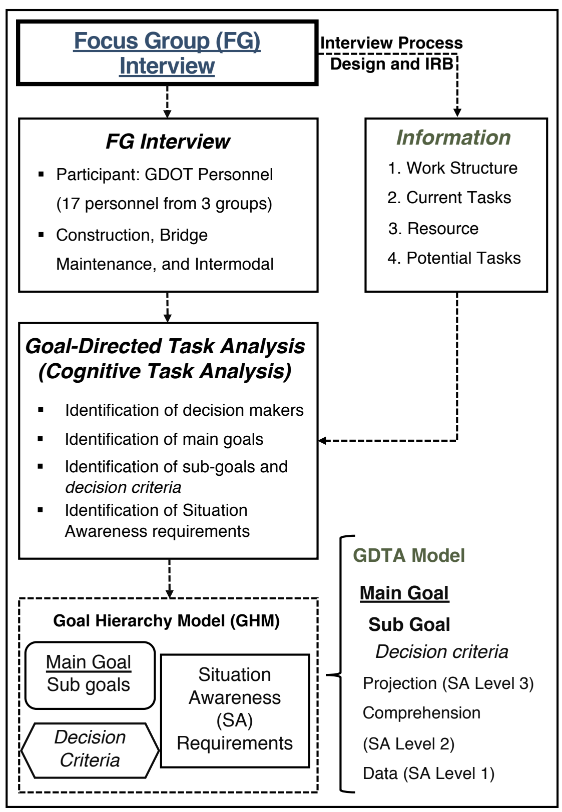


Figure 14 – Framework for Information Requirement Analysis

3.2.1 FG Interview

A FG interview, a type of group interview, is an effective methodology to collect qualitative data about a specific topic (Kitzinger, 1995; Sim, 1998). This method is particularly widely used for exploring and examining the nature of knowledge and experience of participants, and can aim to demonstrate how they think as well as why they think that way (Kitzinger, 1995). This study employed an FG interview because this technique is very helpful to investigate the potential attitudes and information requirements of the participants (Denning & Verschelden, 1993).

3.2.1.1 FG Objectives

The current specific tasks conducted by these three groups in GDOT, the resources they use, and the work process for decision-making based on the collected data are revealed from the FG sessions. The potential tasks with UAS integration within the operations of each group are also identified (Irizarry et al., 2017). The main goals are as following:

1) Compiling a list of current tasks with detailed descriptions of the organizational structure, work process, and the resources to perform the tasks;
2) Defining the potential UAS-integrated tasks within the DOT's operations;
3) Identifying the general information requirements and goals of using UAS, such as operational concepts, technological requirements, work environment conditions, or user characteristics; and
4) Developing a field-testing protocol.

3.2.1.2 FG Data Collection Plan

The FG data collection plan was established to achieve the above goals. Both unstructured and structured interview questions for the FG were developed. A consent form, including the questions, interview procedures, benefits and compensation was evaluated and approved by Georgia Tech Institutional Review Board (IRB) which is charged with the protection of human research subjects. The IRB approval form is attached in Appendix A.1., and IRB consent form is also referenced in A.2. The data collection sheet (shown in Appendix A.4) developed by the Georgia Tech research team has structured questions. In addition, an attendance sign-up sheet with unique numeric identification codes for participants and demographic questionnaires are also developed in Appendix A.3. and distributed to all participants. Figure 15 shows the FG data collection plan.

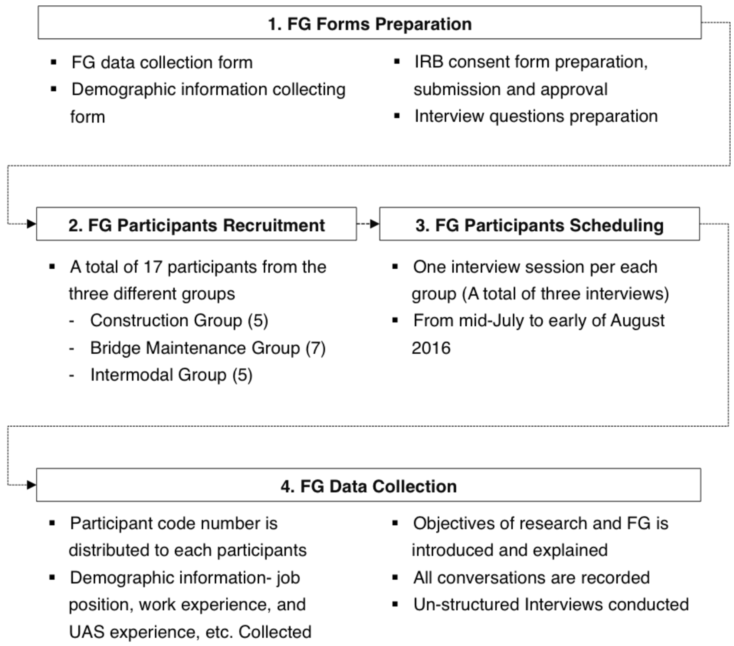


Figure 15 – Focus Group Data Collection Process

3.2.2 FG Interview Participants

A FG interview generally consists of the moderator, facilitator, and the interviewees. The FG moderator is generally in charge of leading the discussion during the FG interview, and he or she should generate the interests of participants in the topic and encourage them to have a variety of communication in the discussion (Kitzinger, 1995; Sim, 1998). In this study, the FG coordinator is both moderator and facilitator and the FG participants are involved in the FG interviews.

3.2.2.1 FG Coordinator

The FG coordinators include a moderator and a facilitator during the FG interview session. A moderator examined the research project goal, the objectives of the FG interview, and the focus subjects to be learned from the participants. The facilitators recorded all conversations during the data collection process in order to allow precise verbatim analysis during the data analysis process.

3.2.2.2 FG interviewees

The FG data sample comprised 17 GDOT employees in the major three fields of construction, bridge maintenance, and intermodal, who volunteered to participate in the interview. The intermodal group is in charge of managing airport, railway, and ground transportation infrastructure systems.. The interviews were conducted separately for each group between July and August 2016, and each session took about two to three hours.

The first FG with five participants from GDOT District 1 construction group (CG) took place at their Gainesville office on July 12th, 2016. The second one was performed with seven interviewees from the bridge maintenance group (BMG) at the Georgia Transportation Management Center on July 19th, 2016. For the last FG interview, the Georgia Tech research team had a discussion with a total of five personnel from the intermodal group (IG), three of them from aviation and two from the railway team, at the GDOT office in Georgia One Center, Atlanta on August 1st, 2016. Table 8 shows the background information for the FG interview with the GDOT.

Table 8 – FG Interview Information

FG Participants		Number of Participants	Location	Date and Time
GDOT	CG	Five	GDOT District 1 Gainesville Office	July 12th, 2016
	BMG	Seven	Georgia Transportation Management Center, Atlanta	July 19th, 2016
	IG	Five	Georgia One Center, Atlanta	August 1st, 2016

3.2.3 GDTA Methodology

This study employs the GDTA methodology to consider detailed information about human aspects of UAS operations, such as decision-makers, goals, and SA requirements. This section describes the GDTA methodology, goals and processes.

3.2.3.1 GDTA Goal and Process

The GDTA method was selected to identify the nature of goals of decision-makers for a specific task. The GDTA technique is usually employed for analyzing dynamic SA requirements for individuals where technology is used (M. R. Endsley & Garland, 2000). The reasons to use the GDTA include:

1) This method provides information about the goals and requirements for the successful integration of UAS;
2) This technique also provides information about how the data could be used in decision-making processes to attain the desired goals; and
3) The goals identified from the GDTA focus on the SA requirements supporting the SA of UAS operators (Bolstad, Riley, Jones, & Endsley, 2002).

According to M. Endsley, R et al. (2003), the GDTA has three main components: (1) decisions, (2) goals. and (3) SA requirements, and the GDTA process consists of four primary steps based on the interviews:

1) Identification of key decision-makers involved in the task;
2) Identification of overall or main goals;
3) Identification of the associated sub-goals and decision criteria of key decision-makers; and,
4) Identification of the SA requirements to support decision-making.

Figure 16 shows the process and the format of the GDTA methodology. In completing a GDTA, interviews with professionals should be conducted to identify the specific goals of the task. This study conducted the GDTA based on the FG interview results. The key roles were identified based on the FG interview results. Considering the common task scenario from the FG interview, the nature of the goals and SA requirements of the key decision-makers for UAS operation in the construction environment can be identified.

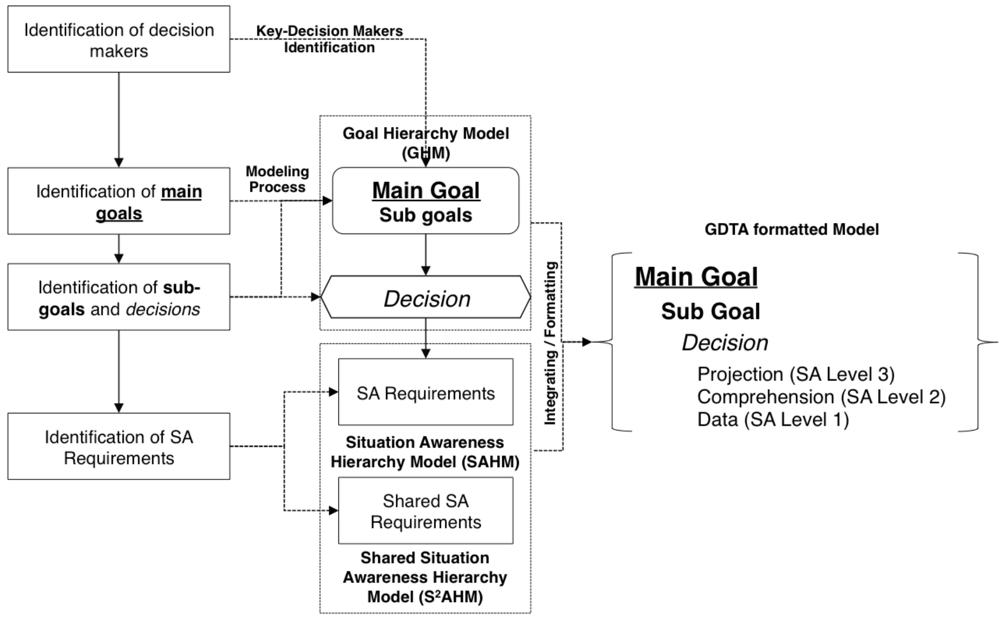


Figure 16 – GDTA Process

3.2.4 GDTA Result Address

The goal hierarchy model (GHM) is developed based on the information collected during the FG interviews. The detailed result of the FG interview will be described in Chapter 4.3. Moreover, the SA requirement model (SARM), consisting of three levels of SA: (1) perception of elements, (2) comprehension of the current situation, and (3) projection of future situation, is developed.

3.3 Field-Testing and Experiment

This section describes the field-testing protocol as well as the field experiment to evaluate the effectiveness of UAS integration in the infrastructure and construction environment. Figure17 shows the field-testing and experiment process.

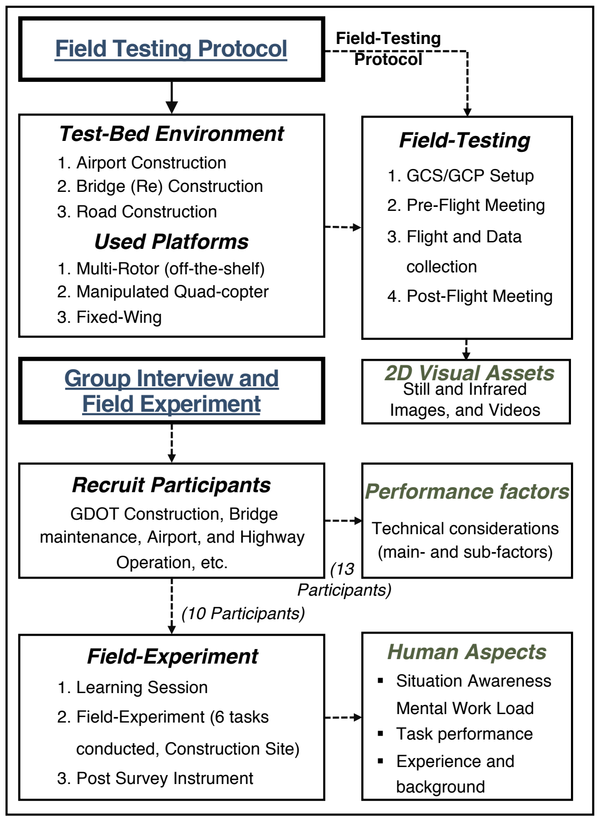


Figure 17 – Framework for UAS Field-Testing and Experiment

3.3.1 Field-Testing Protocol

Based on the results of the FG interviews with the GDOT personnel, the field-testing protocol was initially developed because the GDOT was collaborating with the Georgia Tech research team for the UAS research. At the level of dissertation proposal, this methodology was simply designed based on previous case studies and the flight experience of the research team. It was planned to deploy three different types of UAS platforms during the field tests: (1) an off-the-shelf multi-copter, (2) the UAS platform redesigned by the research team, and (3) a fixed-wing UAS platform,

According to the initial field-testing plan (as shown in Figure 18), the ground control station (GCS) should be set up as soon as the research team and GDOT field coordinators arrived at the jobsite (as shown in Figure 18), and all involved have a pre-flight meeting to establish the goals, share the goals, and develop the flight plan. During the flight, different types of visual data can be collected. In this chapter, the conceptual design of the field-testing is described; a full protocol is available in Chapter 5.

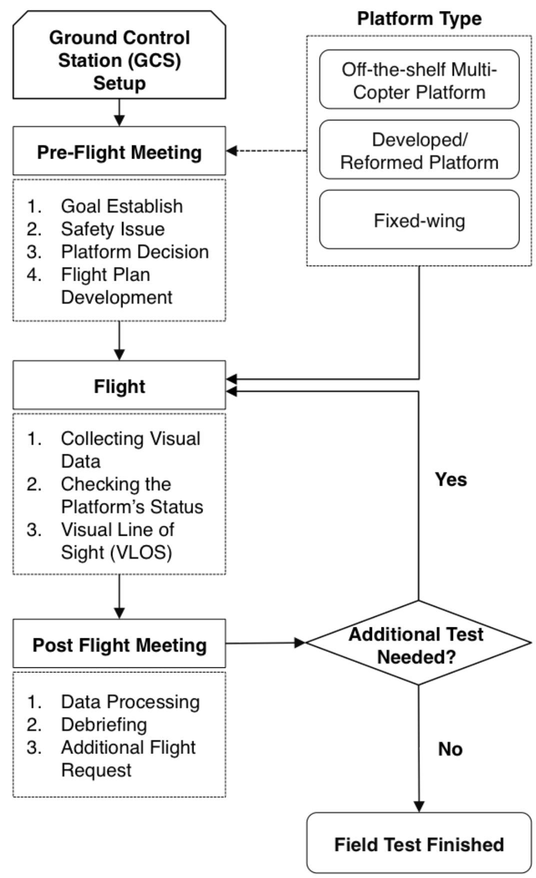


Figure 18 – Conceptual Field-Testing Design

3.3.2 Field-Testing Interview

During the field-testing, a group interview with the GDOT personnel was conducted to identify their perception changes as well as performance considerations for UAS integration. The result of this interview was used for the post-field-testing interview to identify the significance of the factors influencing the UAS' performance.

3.3.3 Field Experiment Design

The field experiment was also designed to measure the human operator's SA and MWL during the flight operation of the UAS. The field experiment consisted of three steps: (1) learning session, (2) field flight operation, and (3) survey questionnaire. Before starting the field experiment, the participants were asked for demographic information to identify their professional background and familiarity with UAS flight. A learning session was also provided to instruct the field experiment process. Figure 19 shows the field experiment protocol.

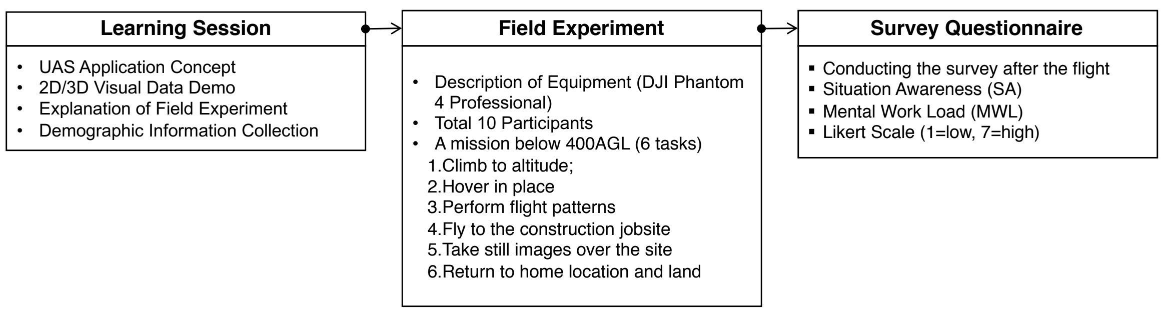


Figure 19 – Field Experiment Design

During the flight operation, the users were provided with a simple challenge consisting of a series of simple tasks: (1) climbing (below 400 feet), (2) hovering in place, (3) performing flight patterns, (4) flying to the construction jobsite (mission area), (5) taking still images of inspection items (areas), and (6) returning to land. The field experiment was located at Georgia Tech campus, and the jobsite to inspect and take still image was the Van Leer Building renovation and construction project site on campus. Two certified remote pilots were on hand during the experiment. Each flight experiment took approximately five minutes for each participant.

The post-subjective questionnaire is a self-rating technique that elicits the participants' subjective opinions. This survey has ten questions related to the user's SA ability and six questions about the human operator's mental work load (MWL) during the flight experiment, with scale-based responses. The scale is a seven-point rating scale (1=low, 7 = high) based on the participants' perceived performance of the task under analysis.

3.4 3D Data Processing and Analysis

A 3D model was developed through the UAS photogrammetry process, based on the 2D images collected during the field tests. The photogrammetry process encompassed three steps: (1) initial processing for aligning and matching images, (2) point cloud data (PCD) development, and (3) digital elevation model (DEM) development. With the developed 3D data and collected 2D images, the post field-testing interview and de-briefing session were conducted to analyze the effectiveness of the UAS and visual data for their current task, as well as to develop the UAS-integrated workflow in the construction environment.

The thematic analysis was based on the collected human performance data from the experiment. As one of the qualitative data analysis methods in psychology, thematic analysis searches for themes or patterns, as well as the relation to different components in an epistemological topic (Barun B. and Clarke V., 2006). In the process of this study, including the literature review, interviews, GDTA, and field-testing and experiment, three themes have emerged. Based on the components in each theme, the patterns or relationships are investigated and narratively described. Figure 20 shows the framework for 3D data processing, effectiveness analysis, and thematic analysis.

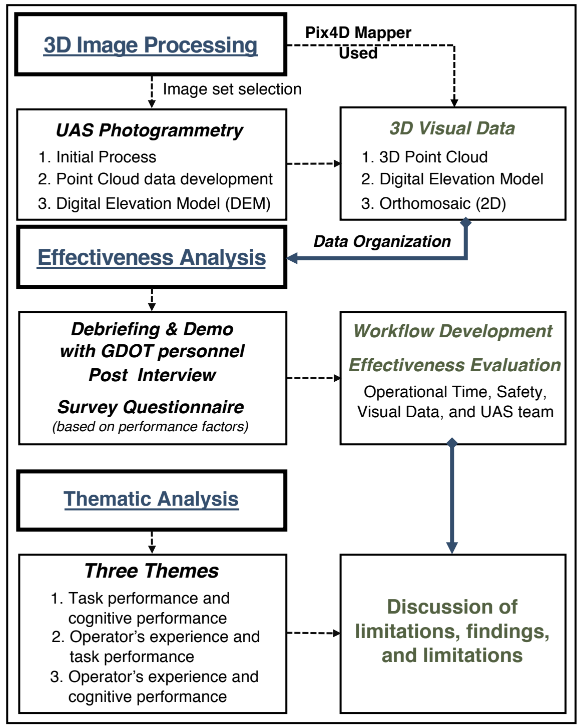


Figure 20 – Framework for Data Processing and Analysis

CHAPTER 4. INFORMATION REQUIREMENT ANAYLSIS

The U.S. Department of Transportation (DOT) is responsible for the infrastructure, construction, operation and maintenance of transportation systems in the United States. Each state DOT has several main groups, for example, Georgia DOT consists of a total of eight groups with varying major responsibilities: (1) administration, (2) construction, (3) engineering including bridge maintenance, (4) intermodal, (5) finance, (6) local grants and field services, (7) program delivery, and (8) permits and operations (Gheisari et al., 2015; Karan et al., 2014). Each group is related to one aspect of transportation and infrastructure concerns. Three of these groups, particularly the construction group (CG), bridge maintenance group (BMG) and intermodal group (IG), are directly in charge of field construction or management tasks, such as road construction, bridge inspection, and airport construction and inspection.

This chapter examines the focus group (FG) interview by conducting in-depth interviews with personnel from the three groups within the GDOT for the purpose of pre-field-testing data collection. The interviews seek to identify current operation workflows, the resources used by each group, organizational structure and decision-makers, and potential tasks that could be integrated with a unmanned aircraft system (UAS). Based on the interviews, a common potential task suited for UAS integration is identified. Another part of the information analysis is to identify specific goals, decision-making criteria, and situation awareness (SA) requirements through a goal-directed task analysis (GDTA). Since field-testing data collection and analysis will focus on the construction task environments, the GDTA will focus on the construction task environment.

4.1 Demographic Information

Based on the FG data collection plan (as shown Figure 15 in Chapter 3.2), a total of three interviews are conducted with each group based on the same process, including a brief presentation to explain the research objectives and concepts, demographic information collection, and the information collection based on the experience and perception of the staff. The script of the group conversation were generalized as qualitative data during the data coding process, because the FG may not provide the required degree of representativeness (Sim, 1998). The following sections in this chapter elaborate upon the demographic information and examine the qualitative results from the interviews. A total of 17 participants are recruited for a total of three FG interviews. The FG participants consist of 14 male (*82.4%*) and 3 female (*17.6%*) subjects, who have worked in the infrastructure and construction-related field for less than 10 years (*35.3%*), between 11 and 20 years (*29.4%*), or more than 21 years (*35.3%*). The participants' ages vary from below 30 (*5.9%*) to over 50 (*29.4%*) years of age. A total of eight has a high-school diploma (*47.0%*), seven have a bachelor's degree (*41.2%*), and two have a master's degree (*11.8%*).

All participants (*100%*) are familiar with the basic concept of UAS and the idea of integrating this technology with their tasks, however most of them do not have UAS flight experience. Only three out of 17 participants (*17.6%*) have UAS flight experience for either recreational or research purposes. Two persons from the construction group have engaged in UAS flying for recreational purposes, and one person from the intermodal group has used the UAS for urban and city planning research. Table 9 demonstrates the demographic information of all FG interview participants.

Table 9 – Demographic Information of FG Interview

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%

4.2 FG Interview Results

This section 4.3 describes the result of the FG interviews with three different groups from GDOT. The results include demographic information of each group, their current workflow, work team structure, required resources for current work, and potential tasks to be integrated with the UAS in their task environments.

4.2.1 Construction Group (CG)

4.2.1.1 Demographic Information of CG

A total of five experts (*N=5*) from CG participated in the FG interview The group comprised four males (*80%*) and one female (*20%*), two of them aged above 50 (*40%*) and the others between 41 and 50 (*60%*). Figure 31 shows the gender and age of the participants from the CG. All of them are responsible for managing the road construction projects in the District 1 Office of GDOT as project managers (*20%*) or project engineers (PE) (8*0%*). The participants in the CG have significant experience in their current positions or in related fields. Three participants (*60%*) have over 21 years' experience in the current group within GDOT. Four of them have over 21 years' experience (*80%*) in the construction-related field. One participant works for the largest department (more than 100 employees, *20%*); two of participants are involved in the large group (between 50 and 100, *40%*) and two in the medium group (fewer than 25, *40%*). With regard to academic background, four participants have a high-school diploma (80%), and one has a bachelor's degree in civil engineering. Table 10 summarizes the demographic information of CG.

Table 10 – Demographic Information of CG

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 of Current Position	Over 21 Years	Over 21 Years	Less Than 10 Years	Less Than 10 Years	11–20 Years
Experience of Related Field	Over 21 Years	Over 21 Years	Over 21 Years	11–20 Years	Over 21 Years
Size of Department (# of Employee)	Very Large (More than 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 use What			Recreational	Recreational	

4.2.1.2 Current Tasks of CG

According to the FG interview with CG, the main responsibility of the PE is to conduct field surveys, take linear and area measurements, and measure contractual items and materials in construction environments. The PEs usually record visual data, such as videos or photos of site logistics and project overviews to enhance their perception of the dynamic work environment. In particular, underground pipeline and ground utilities should be inspected from the roadside, in order to measure the items well and document them. However, this might cause traffic accidents, and is also limited to the access to safety signs to set up on the road.

One of the main tasks is to measure concrete and earthwork (earthmoving). The PE is in charge of verifying the volume of earthwork excavation when CG process payments to subcontractors. However, the problem is that the CG uses a simple calculation method to measure the volume of an excavation. The method involves multiplication of the height by the square footage of the excavation, or the number of dump trucks by the load capacity of each truck.

In addition, the PE is responsible for ensuring proper execution of erosion and soil control. PEs are required to control the project limits and work areas to manage erosion. They need to wear special boots and walk around the earthwork area in order to inspect erosion control measures using measuring devices. This work was regarded as one of the most important concerns of this group. Current additional responsibilities of PEs in the CG are to inspect and measure sidewalks for the safety of pedestrians and workers on the construction jobsite, as well as the speed of all traffic in order to avoid dangerous situations and accidents on the jobsite. Table 11 illustrates the identified current tasks for the CG.

Table 11 – Current Tasks of CG

Group	Current Tasks
CG	1. Site monitoring/inspection and assessment (photo or video) 2. Volume measurement (earthmoving) 3. Erosion control inspection 4. Traffic and heavy equipment control 5. Pipeline and sidewalk inspection (logistic)

4.2.1.3 UAS Potential Tasks for CG

This section discusses potential operations with UAS integration for the CG. The UAS integration could have significant potential for monitoring and documenting existing conditions and surveying site environments at the beginning of a construction project. In addition, this technology has the capacity to implement monitoring tasks of the working environment more frequently (on a daily or weekly basis).

Based on the current manual-based tasks, measurement and erosion control in particular could be integrated with a UAS (Irizarry et al., 2017). 3D model data developed through photogrammetry could be used for surveying and measuring to quantify the volume of excavation. A UAS has an equipped sensor, and it can capture photos with geo-referenced information and absolute geo-located points. Based on the geo-referenced data on three-dimensional (3D) model, the PEs can measure the volume and elevation of earthmoving. Using the UAS-based 3D model could be the PE's safety-driven method for erosion control tasks. This has significant improvements on erosion control in terms of efficiency and safety of project personnel.

According to the interviews, the UAS could assist in traffic control tasks in construction work zones. The real-time video can verify traffic speed, as well as the location and traffics of heavy equipment. Table 12 summarizes the identified current and potential operations with UAS integration for the CG.

Table 12 –Potential Operations with UAS Integration in CG

Group	Potential Operations with UAS Integration
CG	1. UAS-based 3D model through photogrammetry ▪ Erosion control ▪ Excavation measurement (quantification) 2. High-frequency site monitoring/inspection (daily or weekly inspection) 3. Traffic control in construction environments

4.2.2 Bridge Maintenance Group (BMG)

4.2.2.1 Demographic Information of BMG

Seven people (*N=7*) from the BMG attended the FG interview (*41.2%*). All participants were male (*100%*); the BMG comprises three seniors (aged over 50, *43%*) and four participants between 31 and 40 years of age (*57%*). One state manager (*14.3%*) is in charge of managing the BMG in the state of Georgia, two bridge inspection supervisors (*28.6%*) monitor all bridge inspection jobs, three bridge inspection specialists (*42.8%*), perform bridge inspection jobs, and one bridge inspection technician (*14.3%*), assists the bridge inspection supervisor during inspection and decision-making processes. This group mostly has less than 10 years' experience in the current position (*85.7%*), but one participant has 11-20 years' experience (*14.3%*). For the bridge maintenance related field, two have over 21 years' experience (*28.6%*), two 11-20 years' experience (*28.6%),* and three less than 10 years (*42.8%*). A total of five participants have been working in the large group (between 50 and 100 employees, *71.4%*) in the BMG group, and two came from small groups (fewer than 25, *28.6%*). Four have a high-school diploma (*57.1%*), three have a bachelor's degree (42.9%), including two in civil engineering. Table 13 summarizes the demographic information of BMG.

Table 13 – Demographic Information of BMG

	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 an Inspection	Perform an Inspection	Perform an Inspection	Supervise Inspections
Experience of Current	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 of 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			

4.2.2.2 <u>Work Organizational Structure (BMG)</u>

According to the BMG, the main responsibility of this group is to perform inspection tasks on the approximately 15,000 bridges in Georgia. This group consists of three teams with different inspection roles based on the bridge section to be inspected. Basically, a bridge has three main structural elements: (1) top-deck, (2) superstructure and substructure, and (3) underwater-Structure (as shown Figure 21).

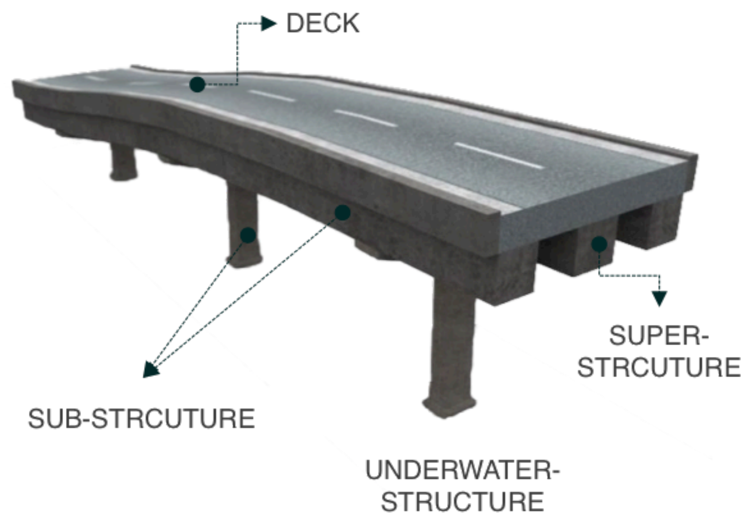


Figure 21 – Bridge Structure Components

The group develops and uses internal references as well as standard specifications, such as the Bridge Structure Maintenance and Rehabilitation Repair Manual (BMRM - checklist) (GDOT, 2012) based on the American Association of State Highway and Transportation Officials (AASHTO) guide manual for bridge element inspection and bridge maintenance unit (BMU) (AASHTO, 2010). Figure 22 presents the organizational structure of the three teams within the BMG.

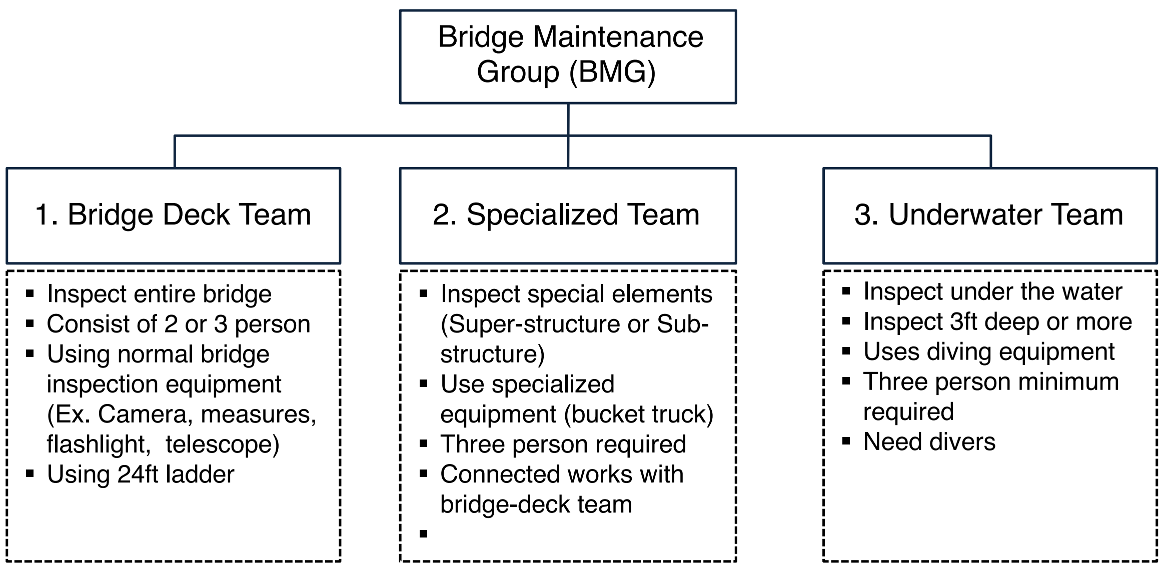


Figure 22 – Work Organizational Structure (BMG)

4.2.2.3 Current Tasks of BMG

The BMG performs visual observations when inspecting the various bridge elements. They consider performing more specific visual inspections with close-up views of the bridge deck, superstructure, substructure, and bearings, joint elements (bridge joint sealing or header joint), and curb/rail/pipes, etc. Depending on the type of bridge, structural elements, size and traffic on the bridge, the inspection may have a different sequence and frequency.

The team for the bridge deck inspection conducts regular inspections in two-year cycles per bridge. The specialized team has three different task cycles; three, six, and 48-month cycles depending on bridge size, location, and condition. The underwater team has a 60-month cycle to inspect the bridge elements located below the water surface. 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. GDOT BMG has been measuring vertical clearances and surveying permanent capacity as scheduled. In addition, the team has been using hammers to inspect connection points in hard to access locations. An infrared camera can sometimes be used to detect problems at the connections between the deck and superstructure by means of temperature differences. The temperature profile can be used to detect cracks on bridge elements. This group also has contingency plans to deal with accidents or problems during inspections to maintain the safety of its personnel. The inspection process typically involves the bridge deck inspection team or specialized structure inspection team, or both teams inspecting the points of interests on the bridge.

To control the traffic on the subject bridge, the group coordinates with authorities with jurisdiction over the bridge or third parties, such as traffic control companies or FHWA in charge of managing and controlling traffic on the road. It usually takes an average of 15 to 20 minutes to set up the equipment upon arrival at the site, and the team is able to start inspecting the points to be observed. Table 14 shows the current tasks of the BMG.

Table 14 – Current Tasks of BMG

Group	Current Tasks
BMG	1. Visual observation (sequence and frequency) ▪ Depending on bridge type, structure system, size and road traffic conditions ▪ Regular inspection (2 years), specialized team (3, 6, or 48 months), underwater team (60 months) 2. Vertical clearance measurement 3. Hammer sounds to inspect the points that are hard to access and inspect in person. 4. Accident or problem reaction plan (procedure) ▪ reported the problem to BMG ▪ Starts traffic control (takes about 30 minutes) ▪ Starts to setup equipment (15-20 minutes) ▪ Inspect the point of interest (ranging from 15 minutes to over 4 hours)

4.2.2.4 UAS Potential Tasks for BMG

The integration of UAS in bridge maintenance could save time, particularly on bridges with tall columns. In addition, an UAS is capable of performing inspections underneath bridges as well as underneath decks, including bearings, connections, column caps, and other structural elements. However, global positioning system (GPS) sensors would present a challenge since satellite signals are difficult to lock on to when the UAS is under a bridge. In addition, an UAS should be equipped with a special camera that is capable of looking up, and have a light to be able to capture images of the underside of the bridge. A UAS could assist to produce 3D model visualizations that could be used to measure cracks on the bridge as well as vertical clearances without interrupting traffic on the bridge. In addition, 3D models developed through UAS-based photogrammetry could be used to compare the accuracy of the original plans. If the 3D model has significant deviations from the original design, these could be addressed. When considering the use of UAS for bridge inspections, the GDOT BMG should consider the presence of power lines close the bridge for the safety of the operation.

Another potential task with UAS integration in bridge inspection and maintenance is to inspect the inside of box-beam structural elements in order to test the air quality and to detect cracks on the walls inside the element. Since the inside of the element does not have sufficient light to allow observation, and the detection of cracks is a manual process, this requires more time to conduct accurate inspections. However, this task still requires more complex and/or manual controls as well as sensors, such as vision sensors and lights to collect and process the visual data from confined space flights. A UAS equipped with a sonar sensor could be considered for use in underwater inspections. The sensor could measure depth when it comes into contact with the water surface, measure the distance from the deck to water surface, or from the water surface to the bottom of the underwater surface (river or lake bed). This would aim at reducing the use of human divers to perform inspections of submerged bridge elements, as well as the time needed to conduct measurements of water depth. Table 15 summarizes the identified potential operations with UAS integration for the BMG.

Table 15 – Potential Operations with UAS Integration in BMG

Group	Potential Operations with UAS Integration
BMG	1. Time-saving on bridges with tall columns (an upward looking camera and illumination is required) 2. UAS-based 3D model through photogrammetry ▪ Crack detection and measurement ▪ Vertical clearance assessment ▪ 3D steel beam model development for precision comparison of as built structure. 3. Inspection of underneath bridge and underside of deck using various sensors (i.e. infrared camera or thermal sensor)

4.2.3 Intermodal Group(IG)

4.2.3.1 <u>Demographic Information of IG</u>

This group consists of four departments: aviation, railway, freight transport syetm, and public transit. For the FG interview, only the airport and railway departments were selected because freight transport system and public transit are closely related to the transportation rather than construction environments. A total of five participants volunteered for this FG session (*N=5*). Three came from the airport department (*60%*) and two from the railway department (*40%*). This FG comprised three males (*60%*) and two females (*40%*). In this group, three participants are between 31 and 40 years of age (*60%*). Each person has a different role, i.e. one is a railway engineer (20%), one a railway planner (20%), one an airport project engineer, one an airport program manager (20%), and one an airport inspection/safety data manager (20%). All participants have less than 10 years' experience in the current position (*100%*). However, two participants have 11-20 years' experience (*40%)* in airport inspection-related jobs. Four participants are involved in small teams (fewer than 25 employees, *80%*) in the IG group, and only one is in the medium team (between 25 and 50, *20%*). Three have a bachelor's degree (*60%*) in civil engineering or aviation management, two have a master's degree (40%), in urban planning and aviation and safety management. Table 16 illustrates the demographic information of IG.

Table 16 – Demographic Information of IG

	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 of Current Position	Less than 10 years	Less than 10 years	Less than 10 years	Less than 10 years	Less than 10 years
Experience of Related Field	Less than 10 years	Less than 10 years	Less than 10 years	11-20 years	11-20 years
Size of Department	Small (Less than 25)	Medium (25-50)	Small (Less than 25)	Small (Less than 25)	Small (Less 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 use What	-	Research	-	-	-

4.2.3.2 Work Organizational Structure (IG)

The IG has four departments: (1) aviation, (2) railway, (3) freight transport, and (4) public transit in order to manage each facility and resource in the state of Georgia (as shown in Figure 23). Only the aviation and railway departments were considered in identifying the current tasks and potential tasks with UAS integration.

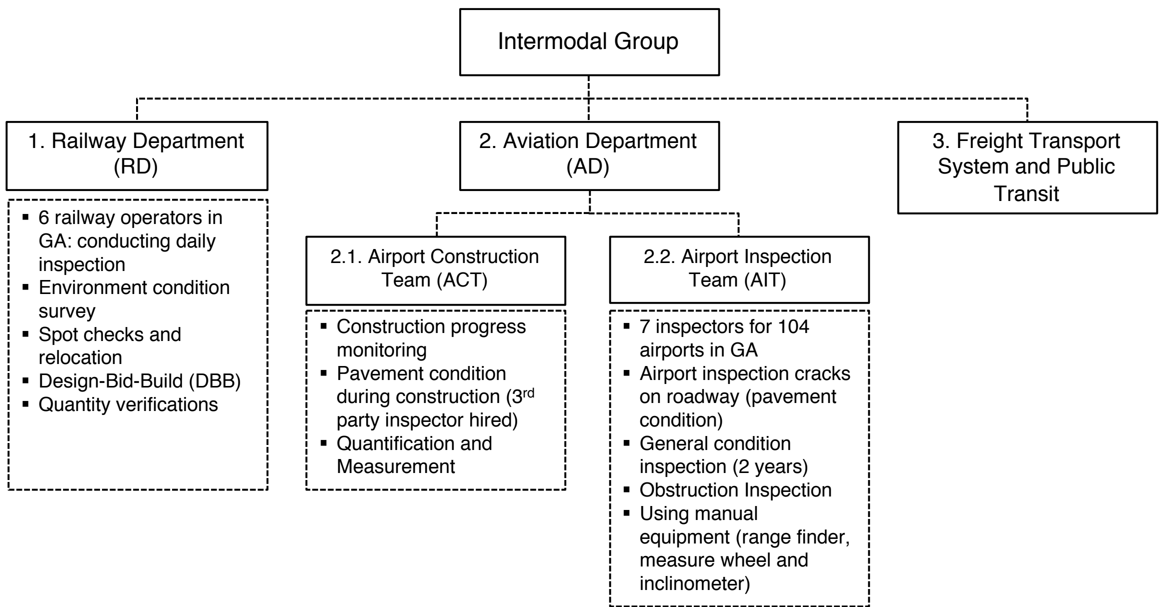


Figure 23 – Work Organizational Structure (IG)

The aviation department can be categorized in two specific teams: (1) airport inspection team and (2) airport construction team. The inspection team is mainly in charge of inspecting the pavement condition of airport runways, as well as observations of general conditions around the runway and the airport. A total of seven inspectors in this team are involved in working on a total of 104 registered airports in Georgia. The construction team in aviation department is involved in monitoring the construction progress of airport-related facilities. However, this team sometimes hires third-party inspectors to inspect pavement conditions. The railway department is contracted by six railway operators in the state in order to conduct daily inspections at the railway and its surrounding environment.

4.2.3.3 Current Tasks of IG

The railway department has contracts with six railway consultants in order to conduct inspections. The general inspection process has four steps: (1) walk through the railway, (2) check general conditions, (3) take pictures at the points of interest, and (4) address issues that have to be improved and document issues and solutions. The railway department has also been using a truck equipped with a camera for inspections. The truck can be operated to take videos of the rails and the surrounding environmental conditions at an average speed of 5 mph. This truck is used to inspect about 30 to 50 miles per day.

The aviation department is mainly in charge of inspecting the runways at airports. Inspectors or managers drive to the airport and onto the runway to perform visual inspections. This work requires human resources for conducting ground level inspection, and equipment such as range finder, inclinometer, and measuring wheel. The time required to inspect a runway is dependent on the size of the airport. Runway inspection includes the runway markings or signs, the height of trees located around the runway, and pavement conditions on the runway. In particular, the pavement inspection uses internal resources or hires external inspectors from time to time. All data collected from the inspection are processed and reported to the airport manager to compare the visual data before and after inspection, as well as when corrective measures are taken. For the safe operation of aircraft on the runway, obstacles or cracks on the runway should be precisely inspected. Table 17 illustrates the current tasks of each department in the IG.

Table 17 – Current Tasks of IG

Department of IG	Current Tasks
Railway department	1. Manual visual observation (once a month) ▪ Walking through the railway – check the condition – taking pictures – documenting ▪ Inspecting railway including wood ties, and the surrounding environment conditions 2. Special truck equipped with camera used (30-50 miles per day, average 5 mph speed)
Aviation department	1. Visual inspection (performed manually) ▪ Inspecting runway markings and signs (general condition) and pavement condition ▪ Inspecting tree heights and approach angle around runway ▪ Using equipment: range finder, inclinometer, and measure 2. Pavement condition inspection: external or internal inspector 3. Data processing and reporting to airport manager: pre-/post- visual data comparison

4.2.3.4 UAS Potential Tasks for IG

For the railway department's operation, a UAS with low altitude and long-distance flight capability has great potential to inspect track elements along the railway, according to the railway manager. In addition, a UAS equipped with a thermal camera could be able to generate a temperature profile of the railway in order to inspect for cracks, expansion, or contraction of the railway. Another possibility to integrate the UAS in the railway department is to inspect railway crossings from a different, clear, and effective perspective.

The UAS is capable of taking precise photographs of the obstacles and cracks at airports as well as observing the approach path to the runways, allowing the inspection of the tree line outside the airport. In addition, an UAS equipped with certain sensors could collect topographic data of the runway and/or airport construction areas with acceptable precision for management applications and thus reduce the man-hours required for this task. Aerial photography can provide pre- and post-survey comparisons of the runway and facilitate monitoring of construction work progress at airports. According to an aviation manager, UAS integration could overcome the cost issues associated with inspecting a total of 104 airports in the state of Georgia, which rely on outdated tools and human perception and judgment. Table 18 describes the identified potential operations with UAS integration for the IG.

Table 18 – Potential Operations with UAS Integration in IG

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

4.2.4 Summary of FG interview and common potential tasks

A potential task that can be integrated with the UAS has been identified as 3D engineered data, such as point cloud data, digital elevation model (DEM), or orthomosaic photo, to conduct progress measurement, site monitoring, or inspection tasks in each task environment. Table 19 shows the result of the information analysis that describes the 3D-based inspection or measurement tasks on each group's work environment.

Table 19 – Results of FG Interviews

Group	3D data-based Potential Tasks (for UAS integration)
CG	1. Progress monitoring 2. Site condition inspection 3. Progress measurement (earthwork excavation or embankment measurement or quantification)
BMG	1. Bridge structure condition inspection. Detecting and measuring cracks on the bridge structures 2. Vertical clearance assessment 3. Development of 3D steel beam model for precision comparison
IG - railway	1. Railway condition inspection – expansion, contraction, and cracks on the railway 2. Railway intersection condition
IG - aviation	1. Runway pavement condition inspection (detecting and measuring cracks) 2. Obstruction inspection (trees around the airport) 3. Topography development (around the airport area) 4. Runway construction progress monitoring/measurement 5. Pre- and post-survey comparisons of runway

4.3 Goal-Directed Task Analysis (GDTA)

Based on the result of the FG interview, one potential task for the construction work environment has been identified as 3D-data-based progress inspection and measurement. To investigate the key decision-makers, goals, decision criteria, and SA requirements of the UAS operation for this task, GDTA analysis was conducted in this section. Based on the Federal Aviation Administration (FAA) regulations and the FG interview result, the decision-makers of UAS operations in the construction environment were identified. The role of each decision-maker was described. In addition, their goals and situation awareness (SA) have been identified.

4.3.1 Decision-Makers of the UAS Operation

The FAA outlines the required and recommended crews for commercial UAS operations within the U.S. National Airspace System (USNAS) in their related rule FAA 14 CFR PART 107. According to this regulation, UAS operations require a certified pilot-in-command (PIC) and highly recommend the use of a visual observer (VO) or person manipulated control (PMC), and other crew that could directly or indirectly participate in the UAS operation (FAA, 2016b). The PIC, who must have a remote pilot certificate issued by the FAA, is the person in charge of actual UAS controls. This member has final authority and responsibility for the safe operations of UAS under Part 107. A PIC is also responsible for balancing the team environment as well as maximizing team performance during the operations. A PMC should also meet all of the requirements of PART 107 with the PIC. The PMC can help a PIC to have a quick response to any dangerous situation before any accident occurs. One or more VOs are highly recommended to join the flight team since they can interact with the PIC to maintain visual line of sight (VLOS) of the platform, as well as to avoid the loss of control (LOC). The VO is responsible for scanning the airspace where the UAS is flying in order to recognize potential obstructions or traffic and keep track of the position of the UAS by direct visual observation. Table 20 presents the responsibilities of each UAS operation decision-maker recommended by the FAA.

Table 20 – UAS Operation Decision-Makers

Roles	Responsibilities	Required
PIC	▪ Responsibility for tele-operating the UAS within VLOS ▪ High degree of training needed ▪ A key decision-maker for flight operation ▪ On-demand computer mediation to see outputs ▪ Mixed perspective (switching between exocentric and egocentric perspective) of the UAS operation	Required (Only one PIC per UAS operation)
PMC	▪ Responsibility for assisting the PIC in terms of sensor installation and flight planning ▪ Data collection about UAS operation and communication with the PIC ▪ Egocentric perspective (through the UA's eyes) of the UAS operation	Not Required (Highly Recommended)
VO	▪ Responsibility for helping the PIC keep the UAS platform with VLOS ▪ Exocentric (external view) perspective of the UAS operation	Not Required (Highly Recommended)

A construction project requires various organizations with different fields of expertise, such as owner, general contractors (GCs), construction managers (CMers), architect engineers (AE), and subcontractors (SCs). The GC is mainly in charge of managing the whole work sequence, resources, and performance during the construction phase. The DOT can deploy a number of PEs on the construction worksite. The PE is involved in the management process on the jobsite. The potential UAS integration in the operational tasks of a dynamic construction environment were identified in the previous chapter. A UAS includes three main elements: (1) the ground control station (GCS) and human operators, (2) a platform, and (3) the sensors. UAS operations in the construction environment comprise two different roles – construction PEs and UAS flight crews (by FAA) – should work together in an interdisciplinary setting in order to share their expertise, knowledge, and skills.

The PE has a high-level professional role for communicating with other PEs, flight operators, and SCs or other work crews, and to administer all contracts on the construction project. The main duties of the PE range from project administration, construction inspections, and human resource control, to documentation or correspondence (Mastronardi, 2014). The first priority of the PE is to ensure the safety of all workers involved in the construction project, including managers, SCs, and laborers. The second duty of the PE is to implement the traffic control plan and erosion control plan on the jobsite. In addition, the PE is in charge of all construction administration tasks, communication with the personnel from other organizations, and documentation of all projects. The roles of the PE are described as following:

1) managing work sequence, resource, and performance;
2) communicating with other personnel from the other contractors or workers;
3) administrating all contracts on the construction project;
4) inspecting project progress and safety;
5) conducting measurements and payments;
6) implementing traffic control and erosion control plans; and
7) documenting all records and project correspondence.

4.3.1.1 Action-control model (ACM): interactions of decision-makers

This section explains the ACM for individuals performing dynamic tasks, because it is important to know how individuals process their objectives and information, and how individuals process information is one component within the whole decision-maker interaction model (Hinsz, Wallace, & Ladbury, 2009). The action of an individual in the specific task environment can have an impact on the other's task outcomes. Figure 24 shows the ACM for individuals in the general task environment.

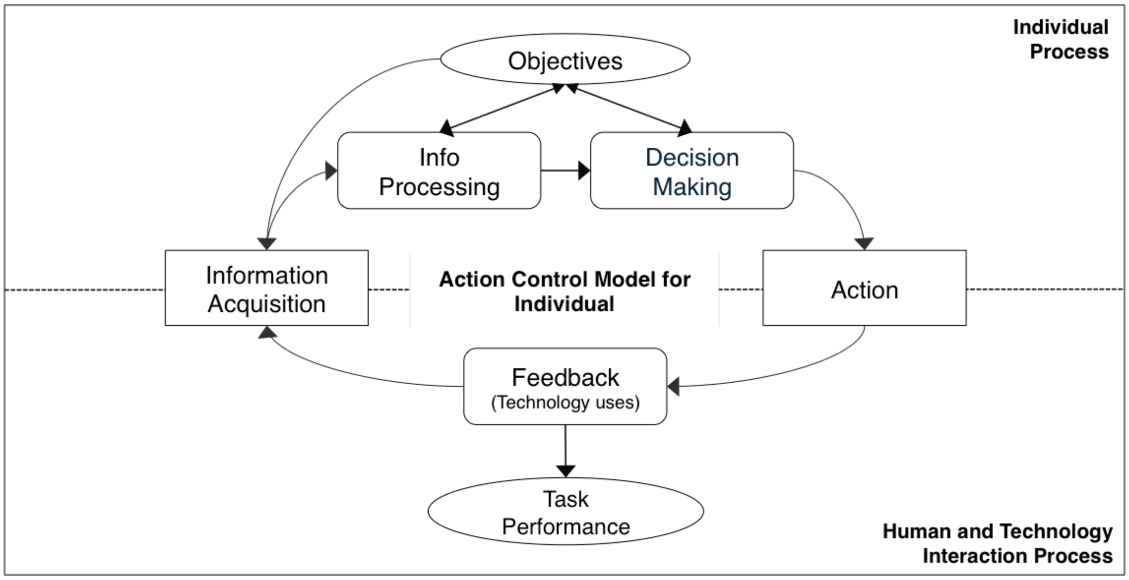


Figure 24 – ACM Applied from Hinsz's Model (Hinsz et al., 2009)

Each decision-maker can have task goals and follow the ACM information process. For example, the PIC may attempt to operate and manage the UAS platform safely and effectively, and the PE may attempt to monitor how the data are collected and to analyze the data in the construction environment. Therefore, the function of each member could be represented by an ACM.

One or more PICs establish the task objectives related to the flight plan development and acquire the specific task-related data or project parameters from the PE or the personnel in charge of the project. Based on the acquired information, the PIC can progress to develop the flight plan during the pre-flight process. After the decision-making process in the pre-flight meeting, the PIC can deploy the UAS platform to the point of interest in order to collect the data. While the UAS completes the flight mission, this person can evaluate whether the action was successful, or whether other actions are required to collect the appropriate data in the environment. Figure 25 presents the ACM of the PIC.

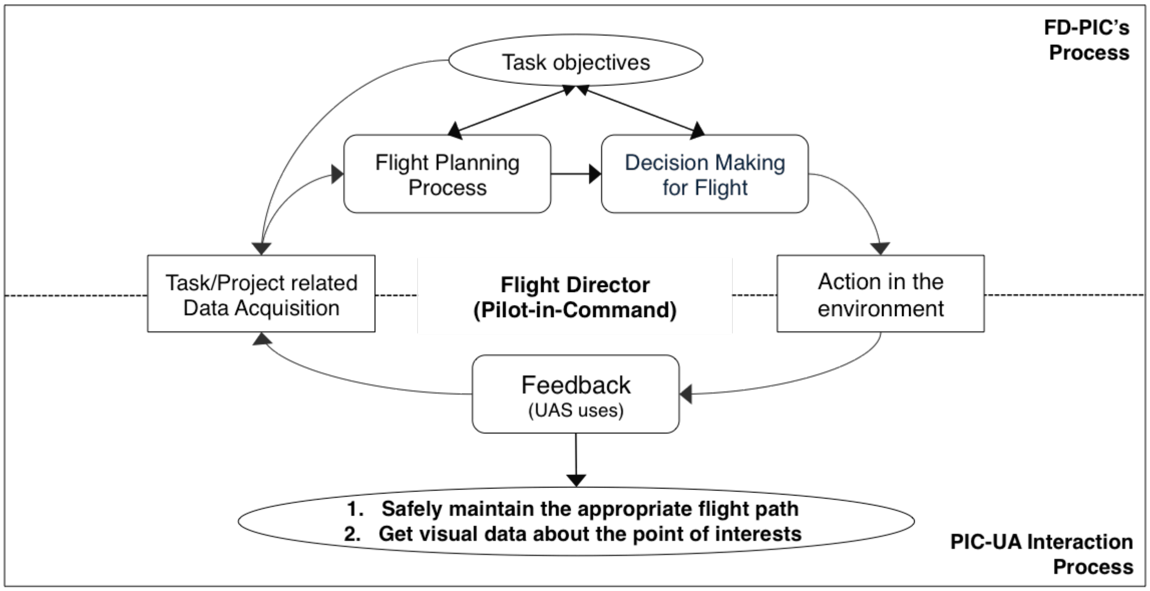


Figure 25 – ACM of PIC

The PMC or VO are responsible for assisting the PIC to develop the flight plan during the pre-flight process, and for keeping the VLOS of the platform during the flight. During flight, the PIC is in charge of communicating and exchanging flight information with the PMC or VO which can be defined as flight coordinators (FC). The FC and PIC would be separated spatially during the flight, and can communicate using a two-way radio. The FC and PE may communicate during the pre-flight process, in order to exchange flight and project information and to develop the flight plan, however, the FC mainly communicates with the PIC during the flight. Figure 26 presents the ACM of the FC.

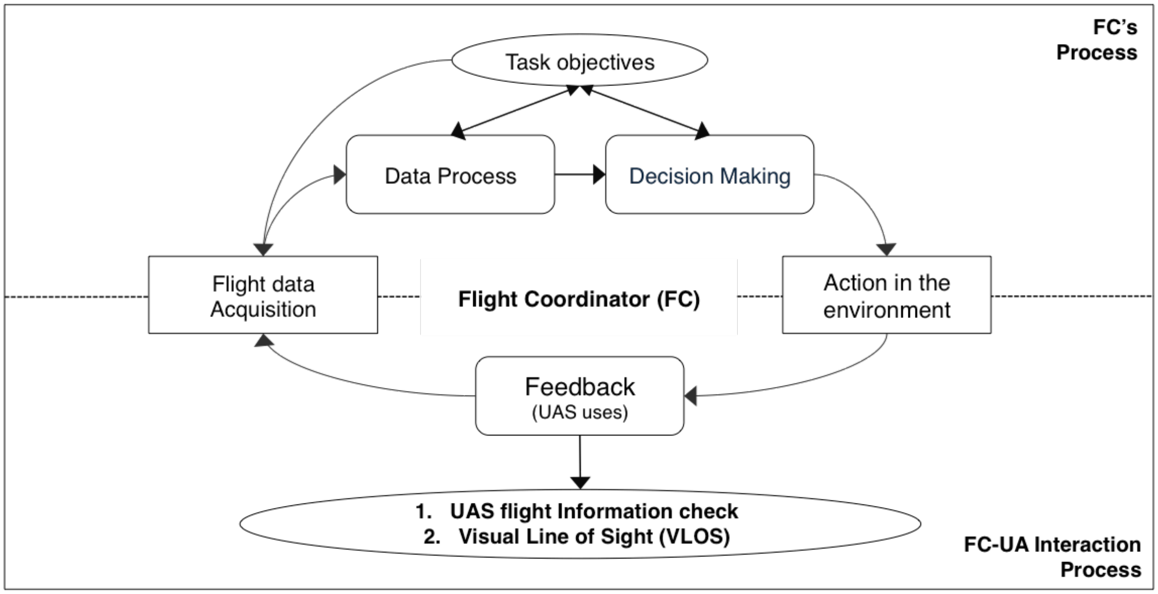


Figure 26 – ACM of FIC

The PE is a required role for operating an UAS in a dynamic construction environment. The primary role of the PE is to manage the construction project. For the progress measurement in this study, the PE establishes the objectives of the work in order to comply with the contracted schedule or payment. The PE can go out to measure and quantify the work progress as usual. With the UAS integration into the construction task environment, the PE should deliver the project data or parameters to the PIC or the FC during the pre-flight phase. The PE and PIC can communicate to monitor all data collection processes while the UAS covers the dynamic construction environment. Based on the collected and processed visual data, the PE can get the work performance, which means the 3D-model based construction progress measurement and quantification results. Figure 27 illustrates the ACM of the PE.

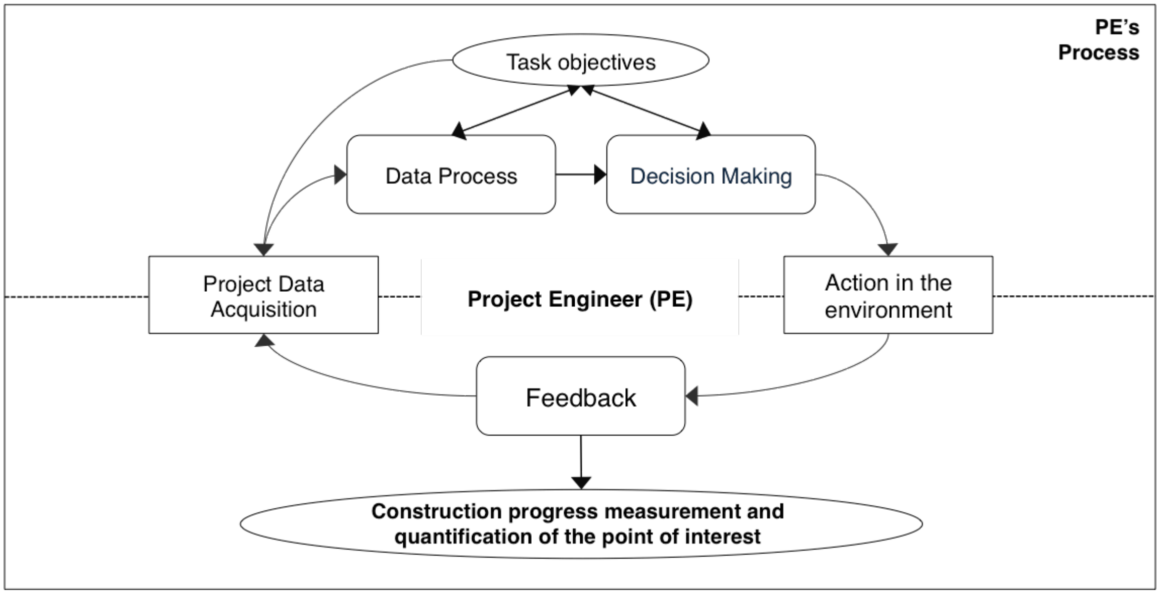


Figure 27 – ACM of PE

4.3.1.2 UAS Operation Decision-Makers' Interaction Model

Figure 28 shows the interaction model of UAS operations' decision-makers based on their task goals, their information processing and action, and their task performance. All interdependent individuals interact with each other in the dynamic construction environment. The hexagon is divided into three diamonds that each describe individual actions and feedback loops, and all diamonds interact with each other. This model demonstrates the interrelationship between the activity of one individual and the information acquisitions of other members. This means that the action of individuals could be important information for the others in pursuing their task goals. Consequently, the result of feedback within the individual ACM is directly relevant to the team's common objectives.

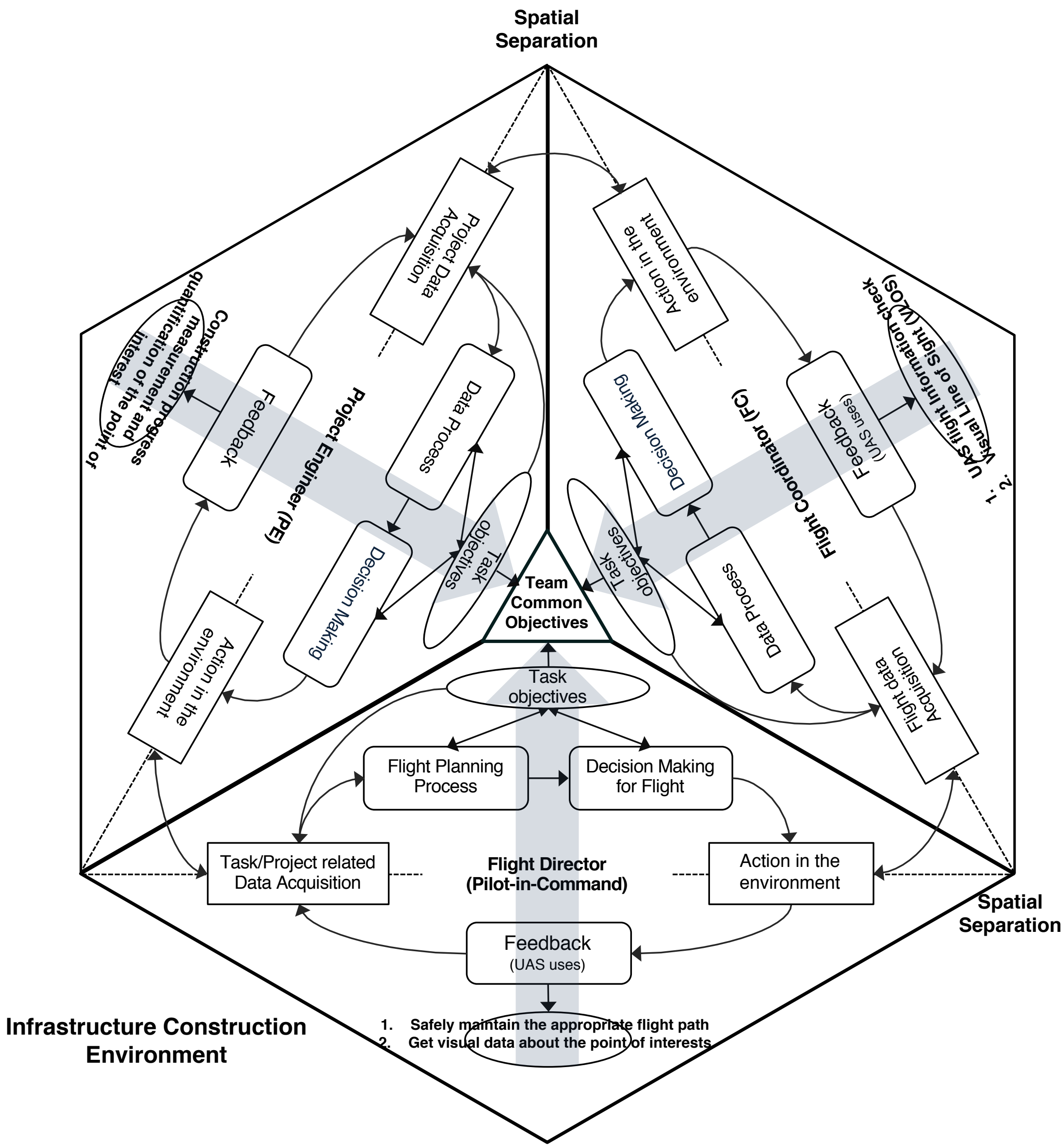


Figure 28 – Decision-Maker Interaction Model

4.3.2 Nature of Knowledge

This chapter identified the FG interview results and the key decision-makers. This section demonstrates the nature of the decision-makers' knowledge to investigate the nature of goals based on the GHM, as well as the SA requirement model (SARM). Figure 29 illustrates the nature of knowledge, goals, and SA requirements of key decision-makers.

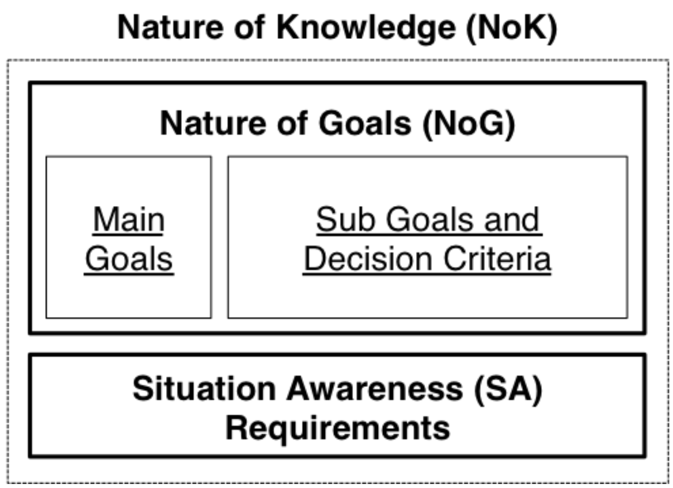


Figure 29 – Nature of Knowledge and Goal

4.3.2.1 GHM – Nature of Goals

Based on the analyzed information in this chapter, this section develops the GHM, a unique hierarchy of goals for key decision-makers. Considering the tasks integrated with the UAS, the main goals of the UAS operation decision-makers are to gather visual data during the UAS flight, analyze the collected data, and document the results. All key decision-makers should collaborate to achieve the goals during the flight process. In this study, the main goal of the PIC is identified as "managing all flight processes and collecting visual data of points of interest". The PIC has sub-goals to manage each stage during the entire flight, including the pre-flight, flight, and post-flight phase. The PIC is responsible for developing the flight plan on the construction site, and for organizing any resources needed for the flight during pre-flight process. This person is also required to check the flight status and to keep the UAS platform safe during the flight. This includes monitoring air traffic or obstructions during flights as well as checking landing location status. After completing the flight, the PIC should collaborate with the PE to process the collected data and report the flight result. Figure 30 shows the PIC's hierarchy goals and decisions.

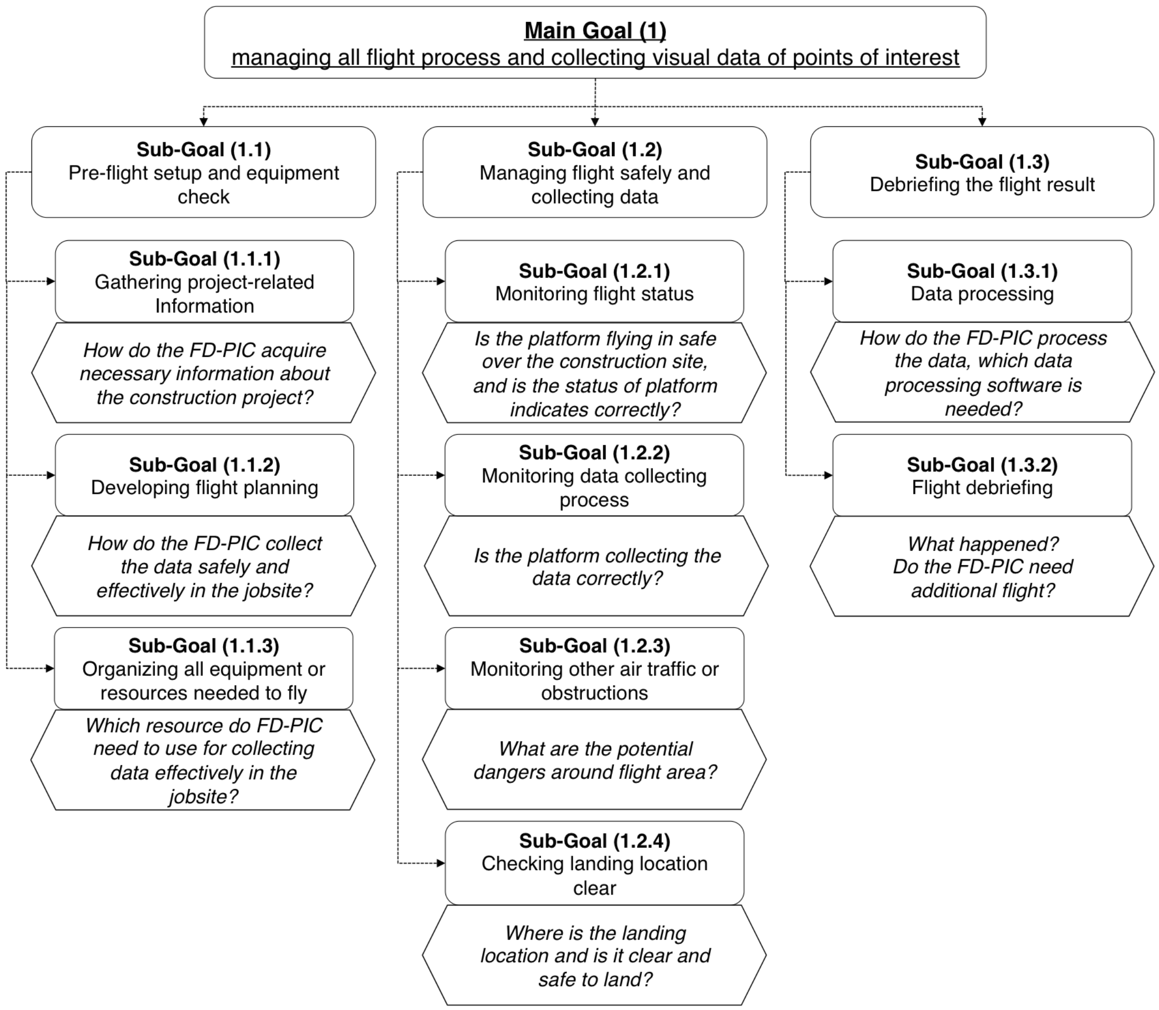


Figure 30 – Nature of PIC Goals

Based on the goal of the PIC as illustrated in Figure 30, the role should answer nine questions from each third-tier goal:

1) How do I acquire necessary information about the construction project?
2) How do I collect the data safely and effectively from the construction site?
3) Which resource do I need to use for collecting data effectively from the jobsite?

4) Is the platform flying in safe over the construction site, and is the status of the platform indicated correctly?
5) Is the platform collecting the data correctly?
6) What are the potential dangers around the flight area?
7) Where is the landing location and is it clear and safe to land?
8) How do I process the data, and which data processing software is needed?
9) What happened, and do I need additional flights?

These questions show the decisions that the PE should make to accomplish each sub-goal. If the PIC can answer all questions on all third-tier goals (i.e., 1.1.1 or 1.2.1), the PIC can achieve all second-tier goals (1.1 or 1.2). For the PE, the main goal is identified as "communicating with the PIC and FC, analyzing the data, and documenting the result". In the pre-flight process, the PE should give the construction project information or parameters to develop the flight plan to the PIC and FC. The PE should communicate with the PIC in order to check the data collecting status. The PE is mainly involved in the data analysis phase by analyzing the data processed and making decisions based on the analysis. Moreover, the PE is responsible for documenting the result. Figure 31 presents the hierarchy of goals and decisions of the PE.

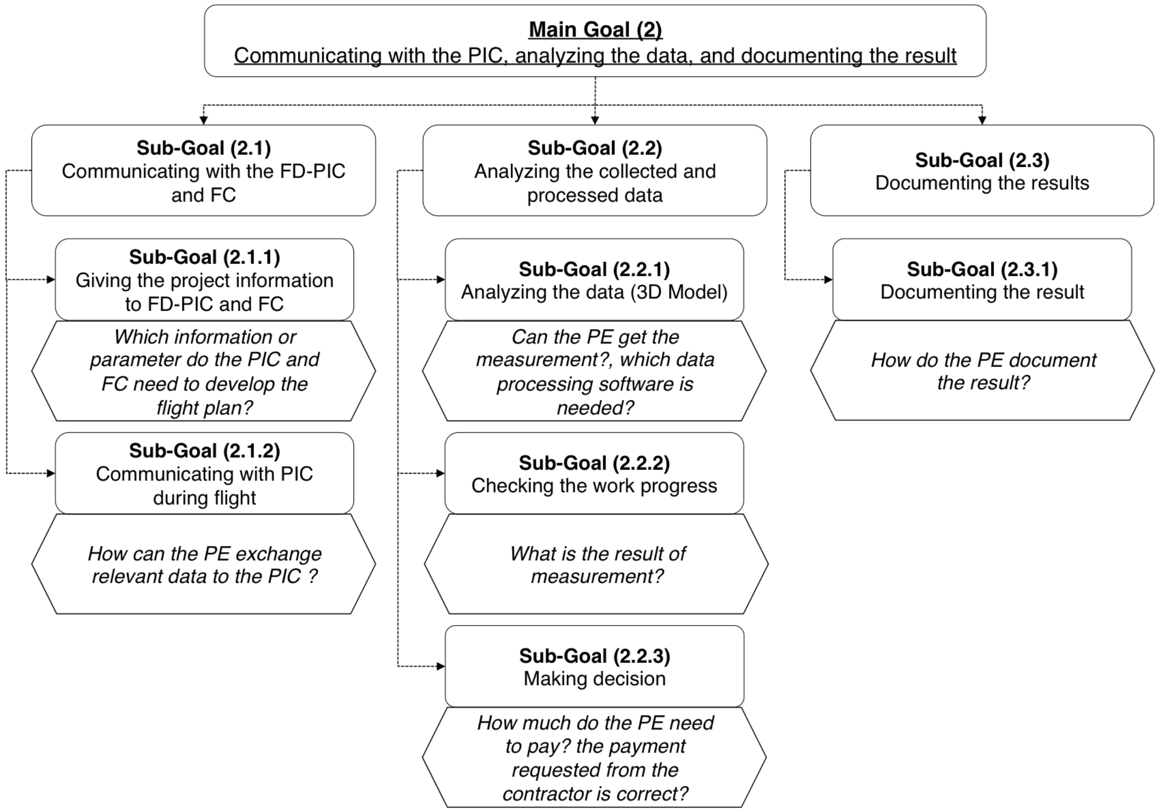


Figure 31 – Nature of PE Goals

Based on the goal of the PE as illustrated in Figure 31, the role should answer six questions from each third-tier goal:

1) Which information/parameters do the PIC/FC need to develop the flight plan?
2) How can the PE exchange relevant data with the PIC?
3) Can the PE get the measurements from the data, and which data processing software is needed?
4) What is the result of the measurement?
5) How much does the PE need to pay, and is the contractor's request correct?
6) How does the PE document the result and outcome?

The main goal of the FC is "Supporting flight setup, communicating with the PIC, and observing the flight status during the flight". The FC shares much information with the PIC. They should communicate to share information during the entire process. Figure 32 illustrates the hierarchy of goals and decisions of the FC. Based on the goals of the FC as illustrated in Figure 32, the role should answer seven questions from each third-tier goal:

1) How does the FC acquire necessary information about the construction project?
2) How does the FC collect the data safely and effectively from the jobsite?
3) Which resources does the FC need to use to effectively collect data from the site?
4) How can the FC exchange relevant data with the PIC?
5) Is the platform safe in flying over the construction site, or is the status of platform safe?
6) What are the potential dangers around the flight area?
7) Is the UAS platform within the VLOS?

These questions show the decisions that the FC should make to accomplish each sub goal. If the FC can answer all questions on all third-tier goals, the FC can achieve all second-tier goals (1.1 or 1.2).

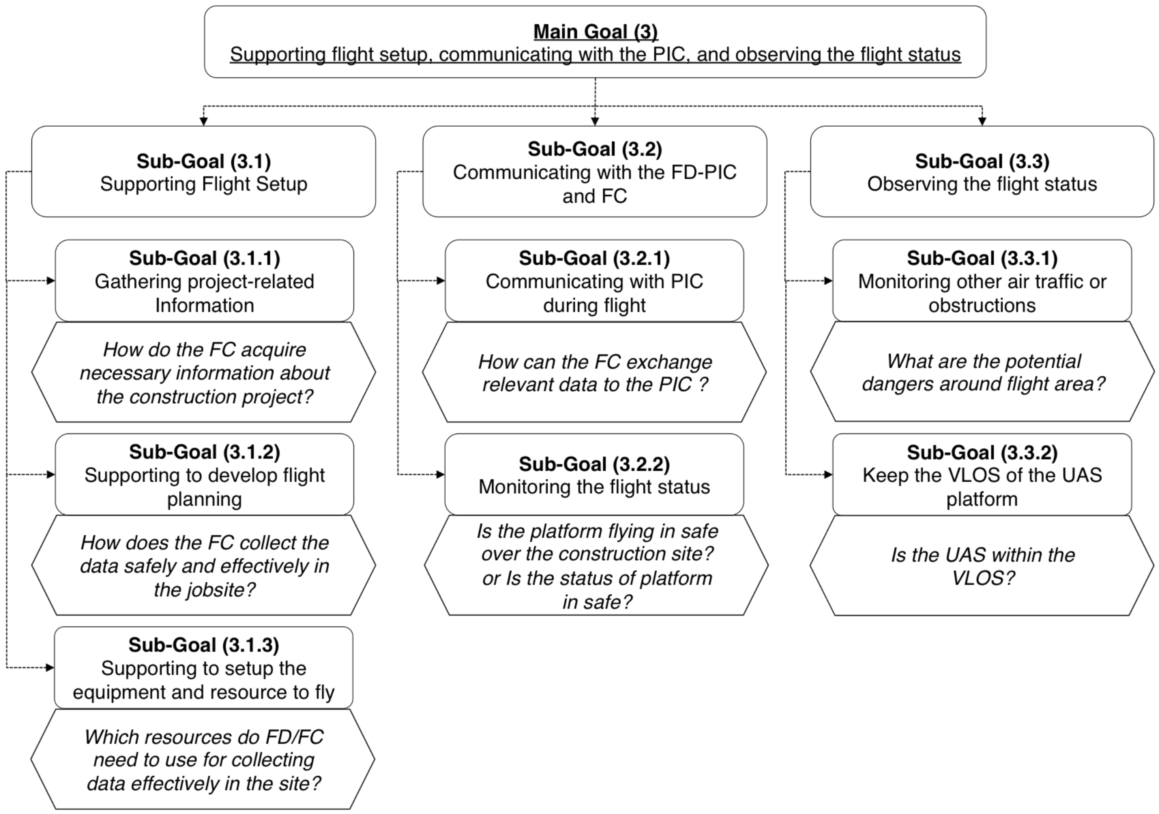


Figure 32 – Nature of FC Goals

Figure 33 demonstrates the GHM describing the nature of goals of each decision-maker in the dynamic construction task environment.

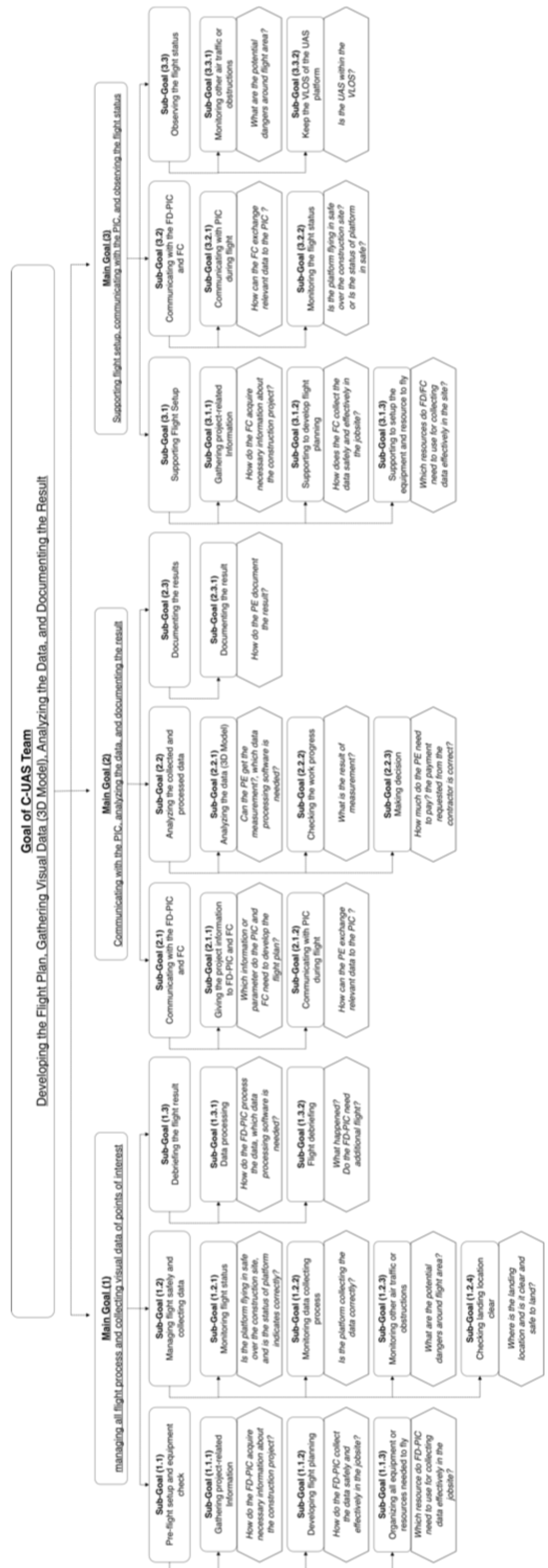


Figure 33 – GHM of Decision Makers

4.3.2.2 SA Requirement Model (SARM) of Decision-Makers

The individual goals of decision-makers was defined as the GHM (as shown in Figure 33). For example, the PE and FC are required to communicate with the PIC during the post-flight as well as the flight process. However, the level of detail of the information they require, the SA requirements, and the way in which they use the information vary among the roles. Based on the GHM, the SARM could be developed to describe the SA requirements by the various levels and roles. Table 21 shows the SARM. Each column in the SARM indicates the key decision-makers of the UAS, and the rows describe the SA requirements for each role.

As can be expected, the PIC is required to perform the tasks with the highest level of detail and the highest goals in terms of the UAS flight process. This position involves obtaining information about the construction project, monitoring the UAS flight status and obstacles for safety, and following FAA regulations. The majority of the differences in SA requirements appear in how the decision-makers understands (Level2) and forecasts (Level 3) by using the same information (Level 1) during flight. The PE is primarily concerned with how the construction-related visual data are collected, processed, and analyzed to make decisions. The FC is primarily concerned with the constant communication between the FC and the PIC to exchange flight or obstacle information during a flight. By understanding not only what information each key decision-maker needs but also how the information will be used by them, they can generate the level of detail for a particular role without unnecessary additional information.

Table 21 – SARM of the Decision-Makers

SA Level	PIC	PE	FC
SA Level 1 (Perception)	▪ Map of flight area • Project area • Point of interests ▪ Features • Jobsite condition • Site parameters ▪ Obstacles • Equipment • Traffic/Vehicles • People • Power-line/Tree • Private property	▪ Map of flight area • Project area • Point of interests ▪ Features • Jobsite condition • Site parameters • Work progress and schedule (Contract) ▪ Obstacles • Equipment • Traffic/Vehicles • People • Power-line/Tree • Private property	▪ Map of flight area • Project area • Point of interests ▪ Features • Jobsite condition • Site parameters ▪ Obstacles • Equipment • Traffic/Vehicles • People • Power-line/Tree • Private property
SA Level 2 (Comprehension)	▪ Flight plan and Communication • Applicability and safety of flight plan • Communication capability effects • Effect of potential equipment or vehicle traffic • Comprehension of the current platform status • Effect of visibility of the site • Obstacle information	▪ Communication • Project information • Effect of potential equipment or vehicle traffic • Effect of work schedule • Effect of labor's work • Communication capability effects • Effect of visibility of the site • Comprehension of current platform status	▪ Flight Plan and Communication • Effect of potential equipment or vehicle traffic • Obstacle information • Comprehension of current platform status • Comprehension of the VLOS flight • Effect of visibility of the site

SA Level 3 (Projection)	▪ Flight plan and data collecting • Predicted the flight route of the platform • Predicted the effect of the current status of the platform • Predicted the effect of the equipment or vehicle traffic • Predicted potential obstacles and their effects • Projected flight plan	▪ Communication • Predicted the effect of the equipment or vehicle traffic • Predicted the effect of labor's work or reaction • Predicted the flight route of the platform • Projected flight plan	▪ Communication • Predicted potential obstacles and their effects • Predicted the potential route of the platform and VLOS • Predicted the flight route of the platform • Projected flight plan

CHAPTER 5. UAS FIELD-TESTING AND DATA COLLECTION

In this chapter the field-testing protocol is developed based on the result of the focus group (FG) interviews with Georgia Department of Transportation (GDOT). The GDOT provided several test-bed environments: road construction, bridge inspection and construction, and airport construction and inspection in the state of Georgia. All group-related personnel participated in all field-testing processes . The main objective of this field-testing was to collect the geo-referenced still images as well as to develop the unmanned aircraft system (UAS)-integrated workflows. This chapter also describes the ongoing interviews with potential end-users to identify performance factors affecting the UAS integration, such as technical and human or team-related factors.

This chapter will describe the test-bed environments, the field-testing process, the platforms used, and the type of data collected. For this dissertation three test-bed environments were selected: road construction, bridge reconstruction and airport construction. A total of six platforms, including a fixed-wing and five different multi-rotors, were deployed to collect still images, videos, and infrared images. Based on the collected images and geo-referenced information, three-dimensional (3D) data were generated through the UAS photogrammetry process. This chapter will also describe the UAS photogrammetry process as well as the outcomes produced through that process.

5.1 Field-Testing Protocol

The field-testing protocol describes the field-testing process, the type of platforms to be used, the participants, and the type of data to be collected during the field-testing. The process includes (1) ground control station (GCS) setup, (2) pre-flight meeting, (3) ground control point (GCP) installation, (4) pilot flights (for collecting flight parameters, such as communication range, altitude, and distance) before conducting actual flights, (5) data collection (flight), (6) post-fight meeting, and (7) GCS removal. All participants GDOT personnel and the industry partner (SkySight Imaging Inc.) collaborated during all the test processes. Three types of UAS platforms were deployed, including (1) off-the-shelf Multi-Copters, (2) a modified UAS platform, and (3) fixed-wing from a third-party service. A total of three construction environments were selected, (1) road construction (US 129), (2) bridge construction (I-85 reconstruction), and (3) airport runway construction (Habersham county airport). Identification codes were distributed to the resources, such as test bed environments, participants, and platforms used (as shown in Table 22). Figure 34 shows the field test protocol.

Table 22 – Field-Testing Code Distribution

Resource	Type of resource	ID
Test-bed environments	Road construction (US 129)	TC_R
	Bridge construction (I-85)	TC_B
	Airport construction (Habersham airport)	TC_A
Participants	Georgia Tech research team	P1_#
	GDOT Project Engineer (PE)	P2_R/B/A
	Industry partner (3rd party)	P3_#
UAS Platforms	Off-the-shelf multi-copter	UP1_#
	Manipulated multi-copter	UP2_#
	Fixed-wing	UP3_#

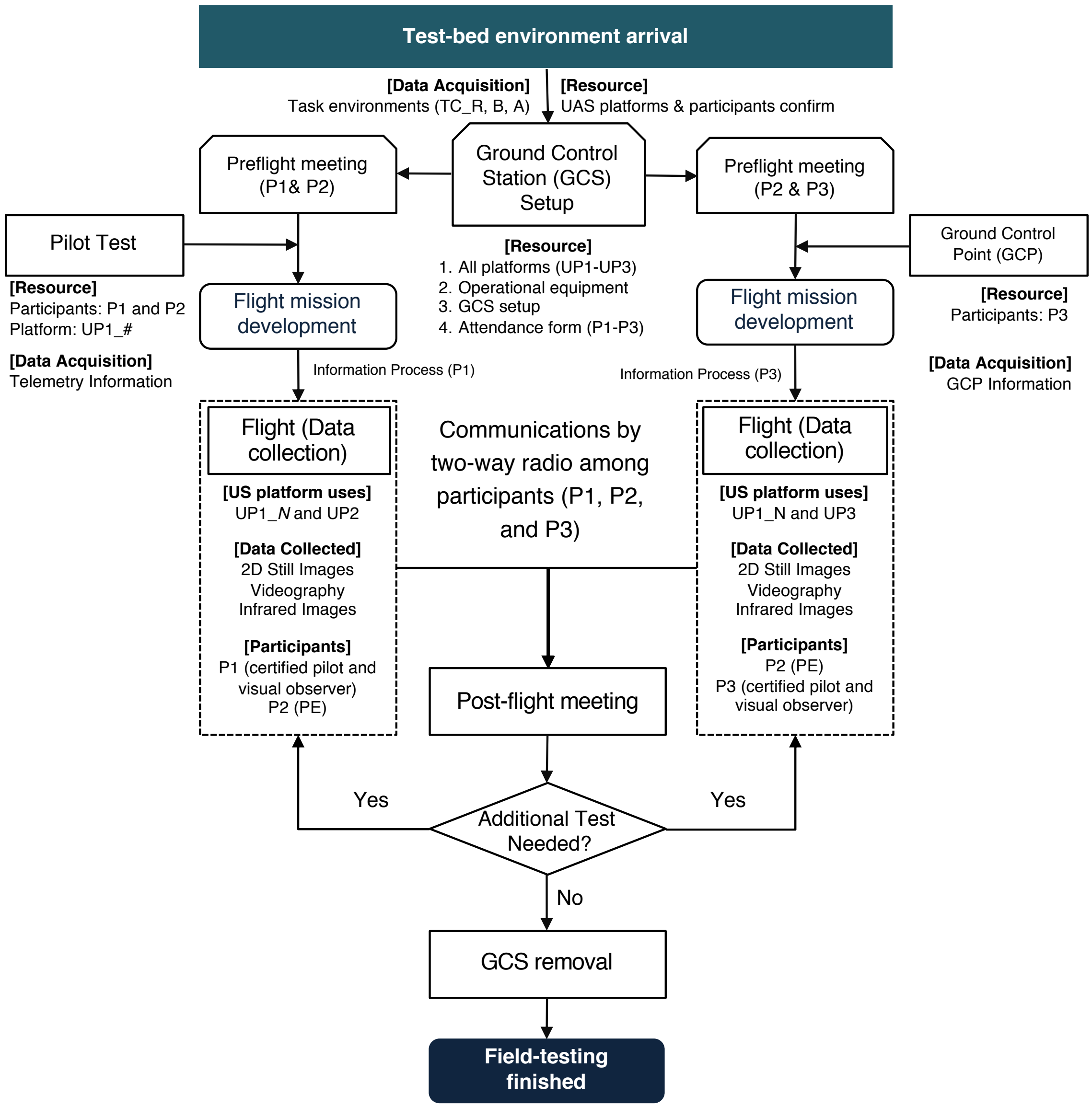


Figure 34 – Field-Testing Protocol

5.2 Test-Bed Environments

GDOT recommended six project sites for the field-testing, including two airports, three bridges, and one road projects. From these projects, one construction project for each task environment (three in total) was selected as test-bed environments to focus on the UAS integration in the construction environments particulary.

A section of the I-85 bridge structure collapsed on March 30th, 2017 due to fire damage on the steel beneath the deck. Since this re-construction project involves GDOT bridge maintenance and inspection tasks, the UAS flights were periodically conducted to collect visual data in order to check and monitor the progress of the re-construction. A total of eight visits were made from March 31st to May 12th, 2017. The GDOT bridge maintenance group (BMG) and a 3rd party collaborator collaborated to conduct project progress checks and site monitoring tasks during UAS flight data collection, specifically quad-copters. Figure 35 shows the location of the project.

The GDOT recommended four candidate sites for airport construction and inspection. Pre site visits were conducted to observe the prevailing site conditions in more detail. As a result, Habersham County Airport was selected because it was the most appropriate for the field-testing that this study required. Table 23 shows the available information on the airport. The field-testing on this site was conducted on May 18th and November 6th, 2017. Figure 37 and Figure 38 show the site conditions at Habersham County Airport.

Figure 35 – Location of I-85 Bridge Construction

Table 23 – Detail of the Habersham Airport

Airport site	Operational Controls	Field-testing schedule issue
Habersham County Airport (Cornelia)	▪ Handheld radio control – advisory frequency ▪ No Air Traffic Control (ATC) tower ▪ Operation depends on weather conditions (strong winds)	Need to schedule in advance (Heavy traffic on weekends)

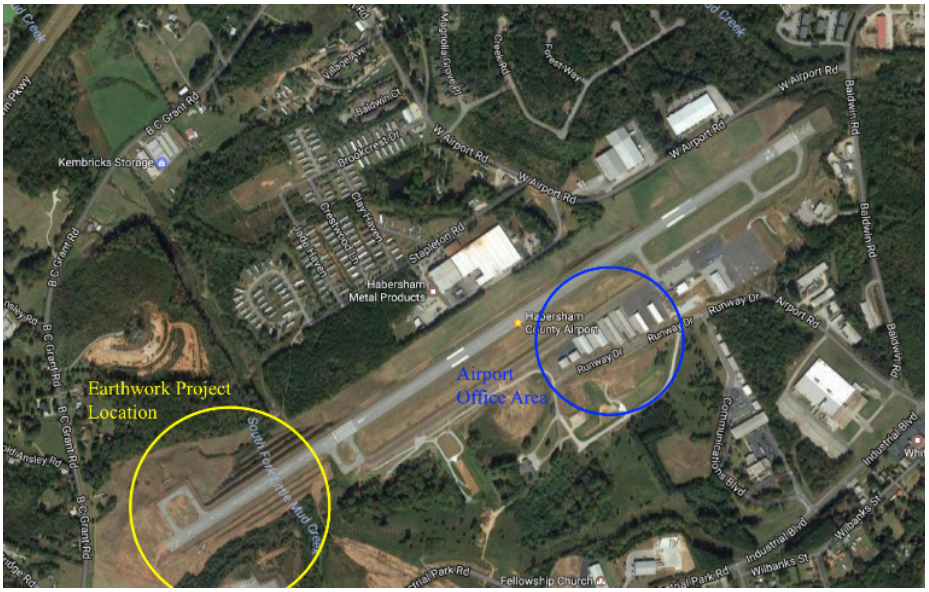


Figure 36 – Logistic of the Airport Test-bed Environment

Figure 37 – Site Condition of the Airport Test-bed Environment

For UAS field-testing in a road construction environment, the GDOT recommended a construction project on road US 129. A total three visits were made on August 16th and September 8th, 2017 to collect the visual data. The construction group (CG) helped to decide the point of interests and to develop flight mission plan to collect the visual data. A 3rd party of UAS photographers deployed a fixed-wing platform during the field-testing. Figure 38 shows the location of the project. Table 24 shows the description of the test-bed environment.

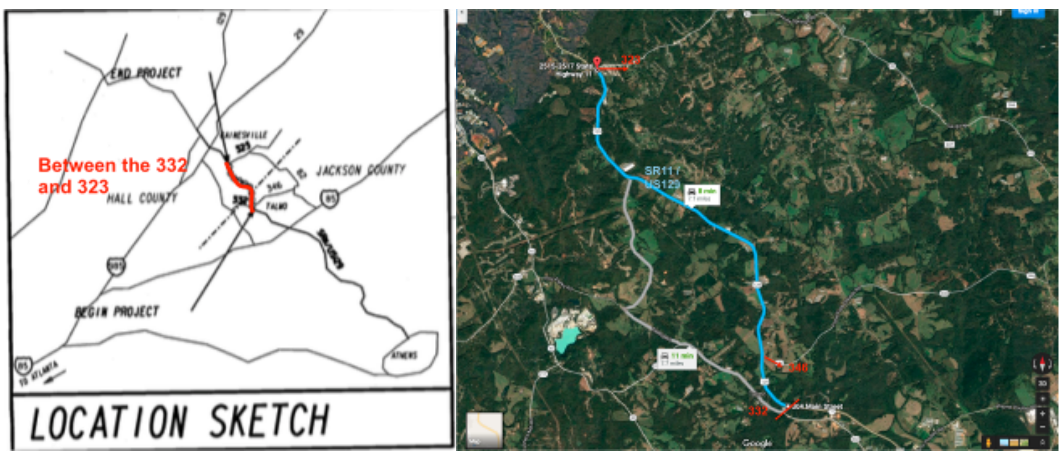


Figure 38 – Location of US 129 Road Construction Project

Table 24 – Overview of Field-Testing

Environment	Tasks	Platforms	Participants	Field Visit
Bridge (I-85)	Construction site monitoring, progress check, and measurement	UP1	P1, P2_B, and P3	March 2017 ~May 2017
Airport (Habersham Airport)		UP1, 2 and UP3	P1, P2_A, and P3	May 18th and Nov 6th 2017
Road (US 129)		UP1 and UP3	P1, P2_R, and P3	Aug 16th, Sept 8th and Oct 18th, 2017

5.3 Equipment: UAS Platforms

A total of three different platforms were used: (1) UP1 (the ID of the UAS platforms): off-the-shelf multi-rotors; (2) UP2: modified multi-rotors (quad-copter); and (3) UP3: fixed-wing. More specifically, two different quad-copters, DJI Mavic Pro and DJI Phantom 4 were used for monitoring the bridge construction progress. For the airport construction, different platforms were used, including DJI Mavic Pro, DJI Phantom 4, Sensefly Albris, one hexa-copter (Yuneec Typhoon H), DJI Matrice 100 (modified, UP2), and TOPCON Sirius (fixed-wing, UP3). Lastly, UP1 and UP3 were used for the road construction project, particularly DJI Phantom 3, DJI Mavic Pro, Yuneec Typhoon H as UP1, and TOPCON Sirius as UP3.

All used platforms are registered with the FAA in compliance with the PART 107 regulation. The minimum weight of the platforms is 734g; the largest platform weighs 2,700g. The overall average maximum flight time of the platforms is about 30 minutes. The camera pixels range from 12.4M to 16M. Yuneec Typhoon H is able to take both 2D and infrared images since it is equipped with an infrared camera sensor. The maximum resolution for video records is 4K (4096×2160 24P), and the cost range of platforms is from the $500 to over $25,000. Table25 shows a short specification of each piece of equipment used for field-testing. Figure 39 illustrates the platform used by the research team and the industry partner. In addition, the GCS was setup as soon as all related participants arrived at the project location. Figure 40 shows the installed GCS on the site.

Table 25 – UAS Platform Information

UAS Platform (code)	Test-Bed (code)	Weight (g)	Max flight time (mins)	Camera resolution (video record Capability)	Cost
DJI Mavic Pro (UA1_1)	TC_A, B, and R	734	27	12.35 M (C4K: 4096×2160 24p)	$999 (DJI, 2018a)
DJI Phantom 3 Professional (UA1_2)	TC_R	1,236	25	12M (C4K: 4096×2160 24p)	$1,259
DJI Phantom 4 (UA1_3)	TC_A and R	1,388	28	20M (C4K: 4096×2160 24p)	$1,499 (DJI, 2018b)
Yuneec Typhoon H (UA1_4)	TC_A and R	1,695	25	12.4 M (HD 720P)	$1,299 (body) $1,999 (Infrared Camera)
Sensefly Albris (UA1_5)	TC_A	1,800	22	38M (HD 720P)	$35,000 (Christ, G., 2016)
DJI Matrice 100 (UA2)	TC_A	2,908 (gimbal camera)	23	12 M	$3,299 (DJI, 2018c)
TOPCON Sirius (UA3)	TC_A and R	2,700	50	16 M	$53,000 (Equipment World, 2015)

DJI Mavic pro and Phantom 4

DJI Phantom 3 Professional

SenseFly Albris

Yuneek Typhoon H

Matrice 100

TOPCON Sirius

Figure 39 – UAS Platforms

Ground Control Station (GCS) Setup

Pre-Flight Meeting Developed Flight Mission

Figure 40 – GCS Setup for UAS Operations

5.4 Field-Testing Results

Three different types of 2D data were collected during the field-testing. Mostly, the UAS platforms in the test-bed environments collected still images. The still images contained geo-referenced information, including the absolute coordinate points based on the world-coordinate system (WCS), since the UAS platforms are equipped with GPS. Infrared images were collected by the hexa-copter (UP1_4). This platform is equipped with an infrared camera, and the operator can take both infrared and still images at the same time. In addition, videos were recorded during flights. The following section summarizes the result of the 2D data collection in the I-85 bridge construction environment (TC_B as shown in Table 26), at Habersham Airport (TC_A, Table 27), and in the road US-129 construction environment (TC_R, Table 28).

Table 26 – Result of Data Collection (Bridge Construction)

Site Visit	Used Platform	Collected Data
March 31st, 2017	UP1_1	47 photos 5 videos (4min 26sec)
April 2nd, 2017		11 photos 2 videos (2min 2sec)
April 10th, 2017		46 photos 3 videos (5min 38sec)
April 11st, 2017	UP1_3	61 Photos
April 18th, 2017		14 photos 2 videos (2min 38sec) 61 photos
April 25th, 2017	UP1_1	8 photos 2 videos (2min 20sec)
May 7th, 2017		69 photos 3 videos (3min)
May 12th, 2017		38 photos 3 videos (3min 33sec)

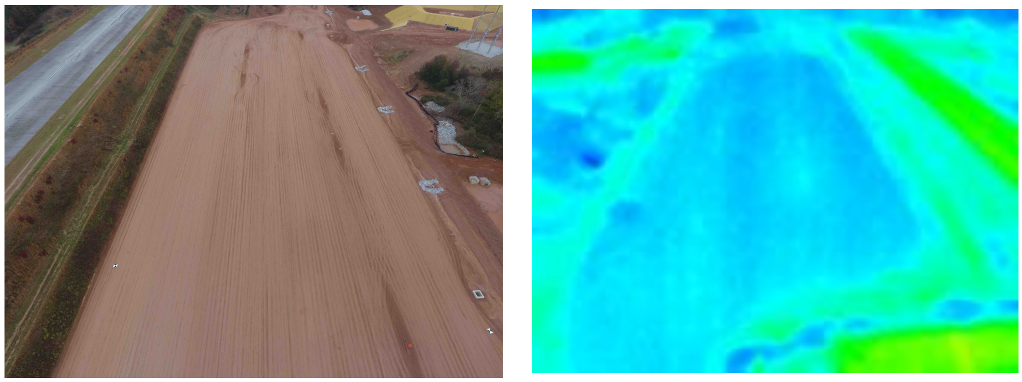
Table 27 – Result of Data Collection (Airport Construction)

Site Visit	Used Platform	Collected Data
May 18th, 2017	UP1_3	101 photos 2 videos (4min 54 sec)
	UP1_5	29 photos
	UP2	660 photos
	UP3	1533 photos
October 6th, 2017	UP1_1	371
	UP1_3	65
	UP1_4	231
	UP1_5	19 19 (Infrared Images)

Table 28 – Result of Data Collection (Road Construction)

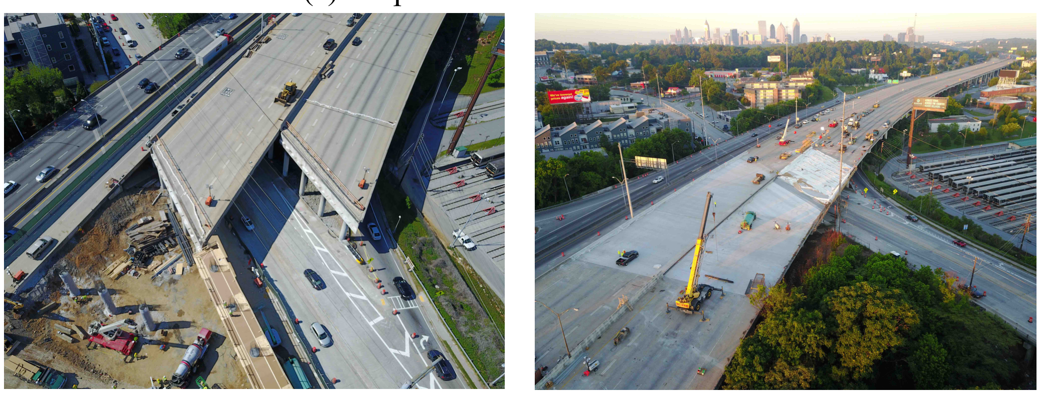
Site Visit	Used Platform	Collected Data
Aug 16th, 2017	UP1_1	160
	UP1_2	387
	UP1_5	21 21 (Infrared Images)
Sep 8th, 2017	UP1_1	332
	UP1_2	749
Oct 18th, 2017	UP3	610

Figure 42 shows an example of the collected 2D data from the (a) airport construction, (b) bridge construction, and (c) road construction.

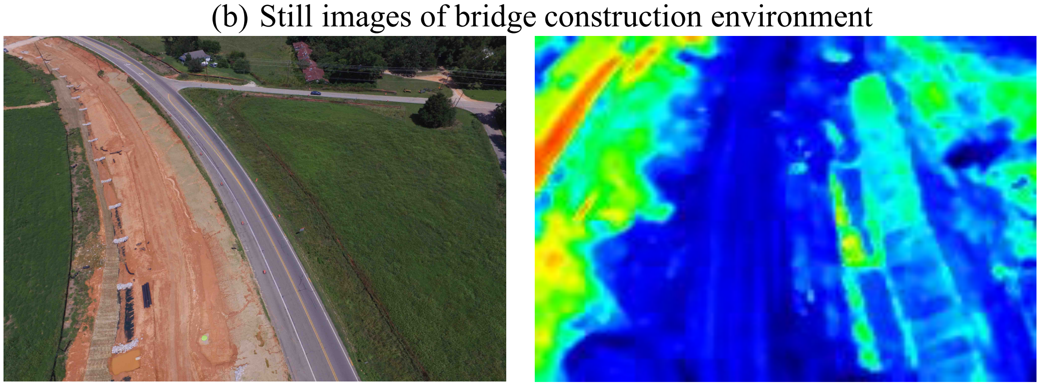


Still Image Infrared Image

(a) Airport construction environment



(b) Still images of bridge construction environment



Still Image Infrared Image

(c) Road construction environment

Figure 41 – 2D Visual Data collected by UAS

5.5 Field-Testing Interview

5.5.1 Description of Interview

To identify the technical considerations to integrate the UAS, a group interview was conducted during workshop session for GDOT on July 2017. A total of 13 GDOT personnel participated in the interview sessions. Their ages ranged between 20 to above 51; 11 were male and two female, and they were professional bridge inspectors, airport inspectors, construction project engineers (PE), highway emergency response operator (HERO), and others. They were also asked about their educational background and their familiarity with UAS operations. Only one of them had high-level familiarity with UAS operations (2 -5 years' experience). Only ten of them participated in the field experiment. For this experiment, one of the participants was very familiar with UAS operations, two had average-level familiarity (between 1-2 years' experience), and seven had less than 1 year or no experience (low familiarity). On average, the participants in the field activities had 11 years of construction and infrastructure management-related work experience. Table 29 presents the demographic information.

During the interview, open-ended and structured interview questions were used to collect the professionals' knowledge and perception about the technological and cognitive considerations of UAS applications. All interviews were recorded, and all questions were evaluated and approved by the Georgia Tech Institutional Review Board (IRB), charged with the protection of human research subjects.

Table 29 – Demographic Information of Group Interview

Attribute		Participants (*N=13*)
Gender		
	Male	84.6%
	Female	15.4%
Age		
	Under 30 years	7.7%
	31-40 years	38.5%
	41-50 years	30.8%
	Over 51 years	23.1%
Role		
	Bridge Inspector	30.8%
	Aviation Manager	15.4%
	Project Engineer	23.1%
	Emergency Operator	15.4%
	Others	15.4%
Work experience		
	Less than 10 years	61.5%
	11-20 years	30.8%
	Over 21 years	7.7%
Educational Attainment		
	High-school level	38.5%
	Undergraduate level	46.2%
	Graduate level	15.4%
Familiarity with UAS		
	High level (3)	7.7%
	Average level (2)	15.4%
	Low level (10)	76.9%

5.5.2 *Result of Interview*

The interviewees were asked to indicate an appropriate UAS platform (multi-rotor or fixed-wing) to use for their tasks in Table 30. The construction managers and airport inspectors indicated both platforms would be used for their tasks, such as runway inspection or road construction inspection. For example, road construction environments have large sites over two miles in length, and a fixed-wing platform can assist in monitoring weekly or bi-weekly work progress by taking videos or still images. Multi-rotors can also capture 2D images on a road bridge or culvert construction site. Bridge inspections and highway emergency operations or traffic monitoring can only use multi-rotor platforms. Those task environments cannot deploy the fixed-wing platforms, as they require sufficient space for takeoff and landing. In addition, bridge inspections require the platform to collect very close-up images from the bridge elements, such as a deck, under-deck, and super- or sub-structures. The use of fixed-wing platform has a challenge to approach the bridge structures in order to collect a detailed view.

5.5.2.1 UAS Sensors

Almost 80% of the interviewees answered that an infrared camera is very helpful to improve the work performance in their task environments. A light detection and ranging (LiDAR) sensor has the potential to inspect bridge components by using the light reflection. The interviewees also indicated that the UAS platform equipped with a thermal sensor that collects thermal photos to identify the runway marking conditions or light operations on the airport. The most useful material is the 3D data from the photogrammetry process. To improve the accuracy of the data, the GPS sensor's capability would be considered.

5.5.2.2 Data Process and Management System

Along with UAS integration, which could change the current work process, a system for data processing, documentation, and management as outlined in Table 30 should be considered to assist the works in the different task environments. The collected and processed data should be properly managed on a secure server. In addition, the interview participants discussed the necessity of a UAS-based data processing and management system. The log files of the UAS flight should be recorded.

Table 30 – Data Process and Management System Considerations

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

5.5.2.3 UAS Operation Team Composition

UAS operations require a human operator called a PIC and a person who need to support the PIC. The interviewees indicated that the UAS operation team, when composed of proper roles, should interact during the flight. During the interview, the four basic roles were descriebed in Table 31. They include pilot-in-command (PIC), person manipulating control (PMC), visual observer (VO) and project specialists. Each team member performs multiple roles depending on the capabilities, training, or knowledge. According to the responses, the PIC should be the person who is familiar with the knowledge of flight controls and airspace. This role should have a PART 107 Remote Pilot Certificate issued by the FAA. The person in charge of the project management or inspection can be in charge of the UAS operations instead of the PIC, if the person is properly trained to control the UAS. According to the FAA regulation, the PMC is the person who is responsible for manipulating or handling the sensors, platforms, missions, or other elements during the entire operation (FAA 2016). The VO is responsible for ensuring the visual line of sight (VLOS) of the aircraft platform. However, the VO should be familiar with the work environment and sequence of UAS flights. All team members involved in the UAS operation should have two-way radios or hand signals for remote communication during the flight. As an outcome of the interview, Table 31 shows the UAS operational team and roles to be considered.

Table 31 – UAS Operational Team Considerations

Roles	Considerations
PIC	▪ Requires the highest level of operational training ▪ Needs certification (FAA PART 107 Remote Pilot Certificate) ▪ Needs continuous communication with other collaborators
PMC	▪ Assists the PIC in operating the hardware or software of UAS ▪ Not required under the FAA PART 107 ▪ Crew resource management, UAS operation, air traffic, or flight mission
VO	▪ Platform's line of sight ▪ Would be familiar with the DOT groups' field tasks, their equipment, and safety issues of the work environment ▪ The roles of VO and PMC could be held by one person alone
PE	▪ With proper training and certification, PE can be in charge of the roles of the PIC ▪ This role should be involved in all flight operations with the PIC

5.5.2.4 Privacy, Safety, and Legal Issues

The interview participants indicated the FAA's regulation environment is main concern to be considered to use UAS applications. The UAS operational policy should be compatible with the FAA rules. The interviewees indicated that privacy issues, emergency response, and insurance standards should be described in the policy or operational procedure. All operations should consider private property, pedestrians, and traffic near the flight area. Moreover, an emergency response needs to be established in case of accidents or loss of communication between the operator and the UAS platform. The interviewees noted that insurance for the UAS damage liability is required at least at the minimum coverage level. Table 32 describes the legal issues in terms of privacy, emergency response, and insurance.

Table 32 – UAS Legal Issue Considerations

Legal Issues	Considerations
Privacy	▪ Don't fly over private properties or person ▪ Follow the current FAA guidelines ▪ Consider Health Insurance Portability and Accountability Act (HIPAA) to protect the personal information of the victim
Emergency Response	▪ Need a procedure to respond in case of emergency ▪ Need a specific classification of emergency situations and associated response systems
Insurance	▪ Minimum level of coverage is needed ▪ State equipment coverage system

5.5.2.5 Others Technical issues

The interviewees also emphasized the pre-process of UAS flight operations, which includes (1) establishing the pre-flight inspection system or checklist, and (2) setting up GCS. Another note they made is third-party employment to use UAS. Professional operators can bring their certified PIC, UAS equipment, and insurance to cover their equipment and liability. They also suggested that employers and contractors should have a legal agreement with the management level's authority about data access and management. Table 33 shows the summary of the interviews.

Table 33 – Summary of Group Interview Result

	UAS Platform	Sensors required	Data Management System	TEAM	Legal Issues
Construction	Fixed Wing & Multi-Rotor (both)	High-accuracy telemetry sensors	3D Data processing system, automated earthwork measurement payment calculation system, and cloud-based documentation system	PIC, PE, and VO	Common Issues: certified PIC needed, privacy issues, emergency response, procedure insurance (at least minimum coverage)
Bridge Inspection	Multi-Rotor only	Infrared camera and light	3D-data processing system and documentation system	PIC, Bridge Inspector and VO	
Airport Inspection	Fixed Wing & Multi-Rotor (Both)	Infrared camera, LiDAR, and high-accuracy telemetry sensors	Cloud-based documentation system	PIC, Airport Inspector and VO	
HERO	Multi-Rotor Only	Infrared camera and visual sensor	3D-data processing system and cloud-based documentation system	PIC and VO	
Others	Fixed Wing & Multi-Rotor (Both)	Infrared camera, LiDAR, and high-accuracy telemetry sensors	Documentation system compatible with current system	PIC and VO	

CHAPTER 6. WORKFLOW DEVELOPMENT AND EFFECTIVENESS ANALYSIS

This chapter will describe three main parts: (1) Three-Dimensional (3D)-data processing through UAS photogrammetry; (2) debriefing interview as a post-field testing interview (3) unmanned aircraft system (UAS)-integrated workflow determination and effectiveness analysis. Based on the collected still images from the field-testing, a 3D model was generated through UAS photogrammetry process. Since the images have geo-referenced information, the key-points that overlap in the photos can be matched, then the 3D model can be developed. The Pix4D mapper was used for the data processing.

The main goals of this chapter are to (1) identify the performance factors and (2) evaluate them based on the potential users' perspectives and experience. Based on the processed 3D-data, a post field-testing interview (debriefing) was conducted with Georgia Department of Transportation (GDOT) professionals who participated in both of the previous interviews, focus group (FG) interview before the field-testing (Ch.4.2) and the group interview during the workshop with the GDOT (Ch. 5.5). During the last interview in this chapter, the potential end-users had demo sessions showing how the 3D model was processed, developed, and manipulated for their tasks. After the demo, they were asked about the significance of the factors, and the effectiveness of the identified factors based on the proposed workflow.

6.1 3D Data Processing

The UAS photogrammetry-based 3D data can support surveying tasks, quality control processes, and progress control and measurement in the AEC domain according to previous studies (Ham, Han, Lin, & Golparvar-Fard, 2016; Kim, Irizarry, Costa, et al., 2016; Siebert & Teizer, 2014; Wortel, 2009). This section will describe the photogrammetry program, Pix4D Mapper, as well as the UAS photogrammetry process based on the Pix4D. At the end, the 3D data products generated through the process will be demonstrated.

6.1.1 Pix4D Software

To process and develop 3D data based on the 2D images collected during the field-testing, Pix4D Mapper software was used. As a “plug-and-play” program, this software has a user-friendly interface as well as strong compatibility with the DJI platform for autonomous flight and data collection. This is commercially available both for desktop and cloud-based applications. The other advantages of Pix4D Mapper are as follows. By using machine-learning techniques, it automatically classifies the dense point cloud data (PCD) into five groups: ground, road surfaces, buildings, high vegetation, and human-made objects. In addition, the Pix4D development team has improved the processing speed of generating 3D textured mesh, especially the tiled level of detail (LoD) mesh. According to the 24 projects they tested, generating a tiled LoD mesh is now 680% faster and saves 89% of the processing time (Pix4D, 2017). The other advantage is that Pix4Dmapper is pre-calibrated to support all the latest UAS cameras. The Pix4D capture, which is the flight mission planning application, can be complied with Pix4D Mapper, and also provides ease of use to collect 2D data automatically for a 3D data mapping mission.

6.1.2 UAS Photogrammetry Process

To acquire a highly accurate 3D model, it is very important to design an image acquisition plan before the flight. This is discussed during the pre-flight meeting. Based on the field-testing, the following aspects need to be taken into consideration:

1) Type of project: it has different task performance and goals to use the UAS;
2) Type of terrain: it requires different flight mission range depending on the visual line of sight (VLOS) (e.g., steep, hill, mountain, or forest);
3) Type of camera: digital camera or infrared camera;
4) Purpose of the image collection: monitoring overall condition or inspection details on the point of interests;
5) Flight distance, angle, and height: different flight mission plans have different flight parameter data; and
6) Flight path: different flight mission plans have different flight paths.

After collecting the 2D data, the UAS photogrammetry process involves three main steps (as shown in Figure 42): (1) matching key-points from geo-referenced 2D images, (2) generating point cloud data, (3) developing digital elevation model (DEM) or orthomosaic. The key-point extraction is automatically processed through software. Image geolocation sets the coordination system. In this step, the coordinates can be imported or exported, and the orientation of the images and/or the accuracy of the coordinates can be determined. Ground control points can be added to improve the quality and accuracy of the result. Extracted key-points on each group of images will be matched and overlapped in order to generate a PCD. Once initial processing is completed, point densification and filtering is performed. 3D points can be computed where there is visual content. If some objects have little visual content, the 3D point may have less accuracy. Once the dense PCD is developed, filtering is performed in order to reduce "noise" and improve image quality by removing redundant points.

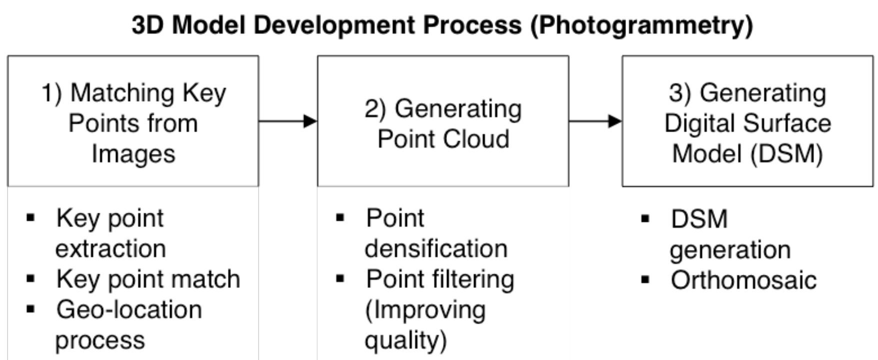


Figure 42 – UAS Photogrammetry Process

Figure 43 shows the PCDs of the road construction and the bridge reconstruction projects, and Figure 44 and Figure 45 describes the DEM and orthomosaic of the airport construction environment.

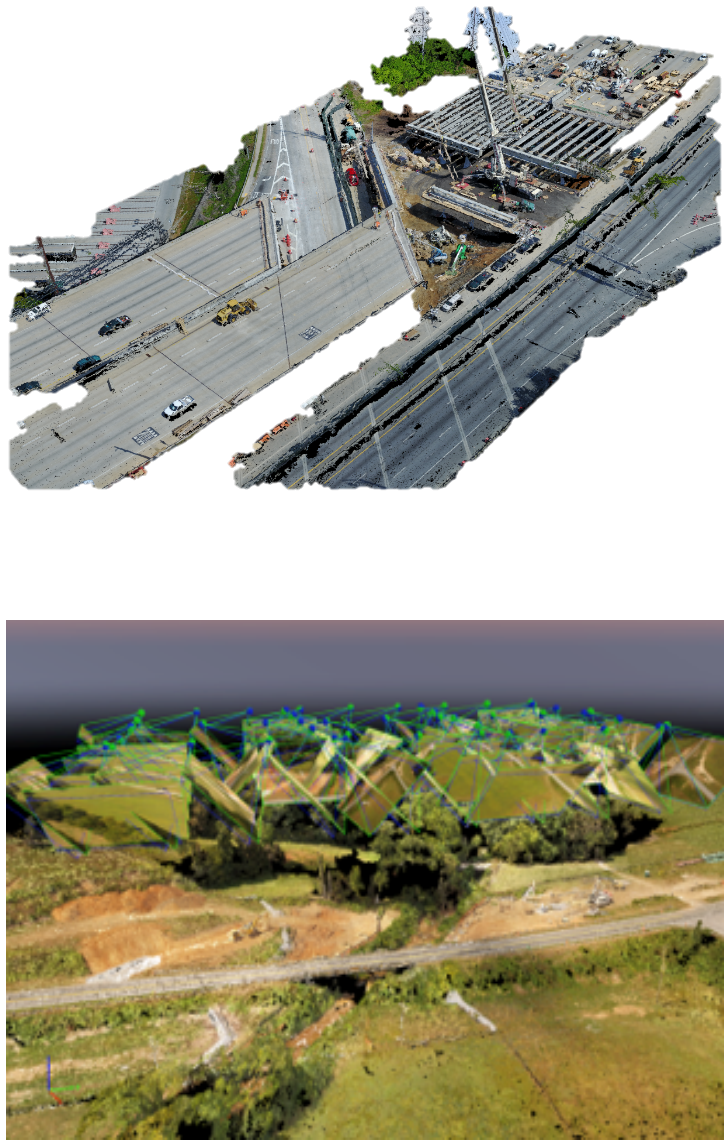


Figure 43 – PCD model (Bridge Construction above, Road Construction below)

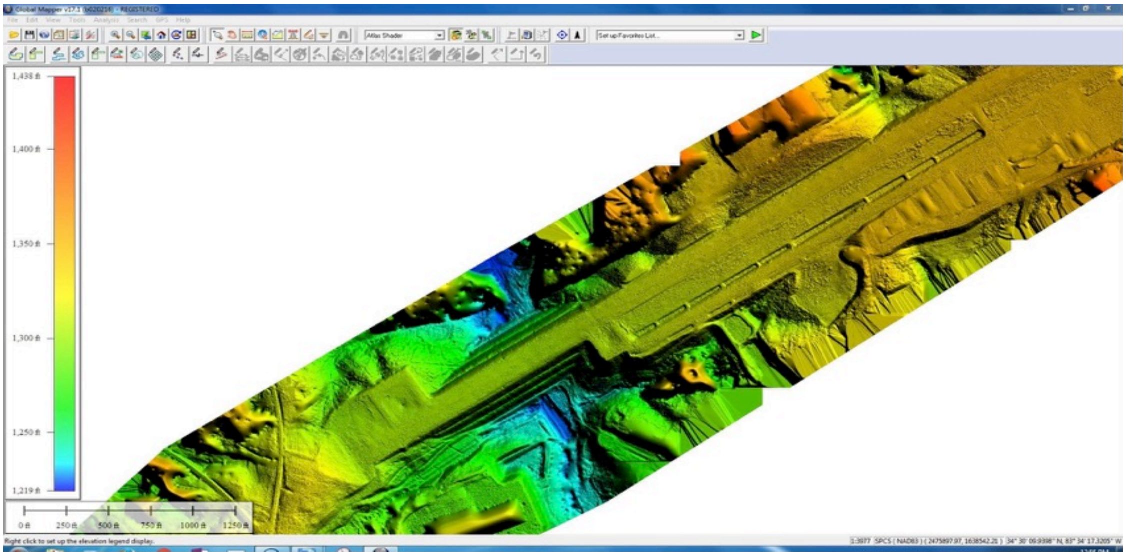


Figure 44 – DEM Model of Airport Construction

Figure 45 – Orthomosaic Photo of Road Construction

6.2 De-briefing Interview

After completing the field-testing and 3D data processing, post field-testing interviews were conducted as debriefing interviews with the GDOT personnel who participated in the FG interview, the field-testing, and the interview during the field-testing. This interview session was conducted on December 11th and 15th 2017.

The last interview session consisted of three steps (as shown in Figure 46):

1) a short description and debriefing about the field-testing result;
2) 2D and 3D data demo; and
3) follow-up interview (post field-testing interview) and survey with the potential-users from the GDOT.

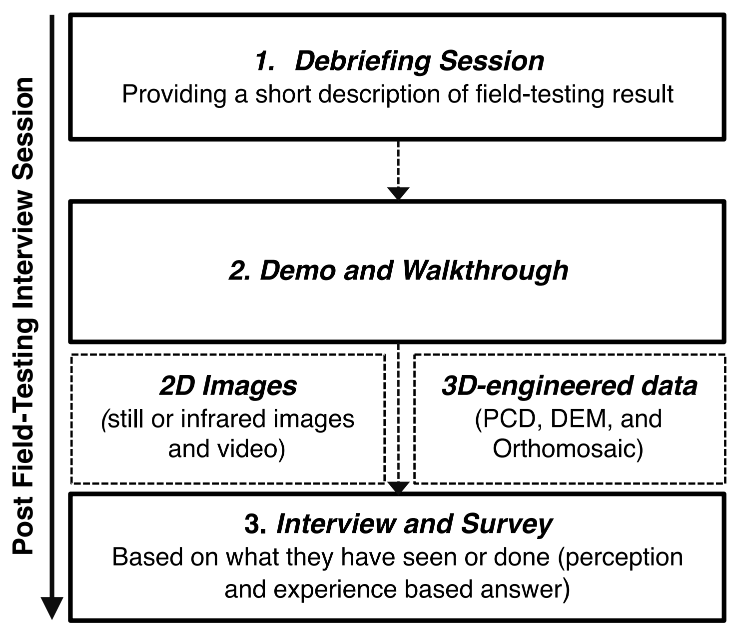


Figure 46 – De-briefing Interview Process

During the debriefing interview session, all of the field-testing participants, including the Georgia Tech research team, GDOT PEs, and industry partners, discussed the result of the field-testing (as shown in Figure 47). A total of nine GDOT professional participated in thi interview. Based on their experience during the field-testing, they are asked about their familiarity with UAS. Seven out of nine indicated low familiarity (*77.8%*) and two indicated high familiarity with the UAS (*22.2%*). In regard to 3D familiarity, only one had average familiarity (*11.1%*), six had low (*66.7%*), and two had no experience with 3D data use (*22.2%*). Table 34 describes the demographic information of the participants. The main goals of this session included:

1) To provide the potential end users with the insights into how the UAS and 3D data can meet their task objectives;
2) To identify important factors affecting the UAS integration;
3) To collect their experience and perception-based data in terms of effectiveness of the factors; and
4) To determine the UAS-integrated workflow based on the field-testing.

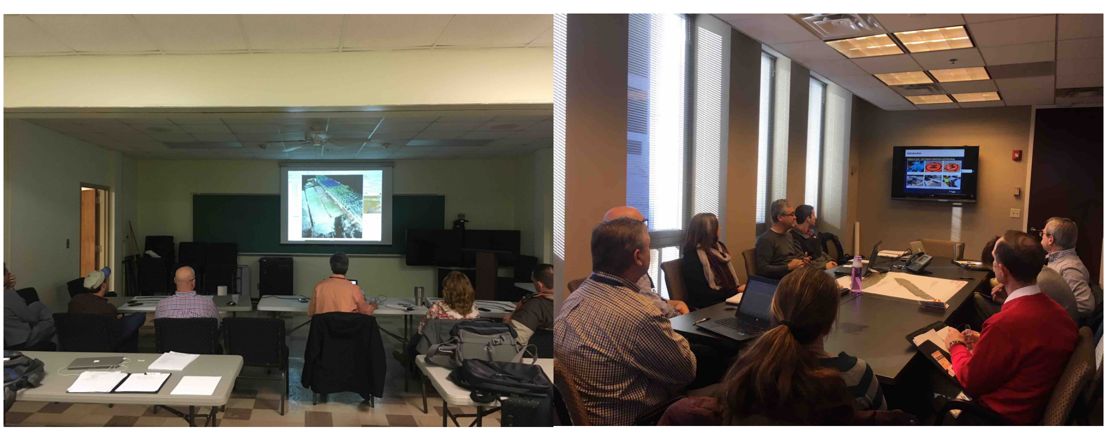


Figure 47 – De-briefing and Demo Session

Table 34 – Demographic Information of De-briefing Interview

Attribute		**Participants (*N=9*)**
Gender		
	Male	77.8%
	Female	22.2%
Age		
	Under 30 years	11.1%
	31-40 years	33.3%
	41-50 years	33.3%
	Over 51 years	22.2%
Role		
	Construction Group (PE)	55.6%
	Airport Group (PE)	11.1%
	Airport Group (Inspector)	33.3%
Work experience		
	Less than 10 years	55.6%
	11-20 years	22.2%
	Over 21 years	22.2%
Educational Attainment		
	High-school level	33.3%
	Undergraduate level	55.6%
	Graduate level	11.1%
Familiarity with UAS		
	High level	22.2%
	Average level	00.0%
	Low level	77.8%
Familiarity with 3D		
	High level	11.1%
	Average level	00.0%
	Low level	88.9%

6.3 Significance of Performance Factors

Based on what the potential end-users experienced, they were asked about the significance of the factors affecting the effectiveness or performance of the integration and operation of UAS in the construction environment. From the field-testing interview, the main factors and sub factors were defined as follows:

1) Hardware – capability of UAS platform and computational workstation;
2) Usability – ease of use (UAS and software);
3) Time – operational time;
4) Cost – total operational cost for using the UAS;
5) Human and team – capability of UAS operator, communication and interaction; UAS team composition, and the use of 3rd party;
6) Data quality – 2D image quality and 3D data accuracy (quality); and
7) Legal issues – safety management, emergency response, or privacy

Based on the identified factors, a conceptual factor model was developed as shown in Figure 48. A survey was developed to identify important factors to use UAS effectively in the construction environment. In this survey, the interview participants were asked to indicate whether the listed factors would influence the effectiveness or efficiency of the UAS integration into the construction environment. Based on indications from all respondents, the importance of each factor was determined with a likert scale from 1 = not significant to 5 = very significant. The collected data are described and computed as the mean.

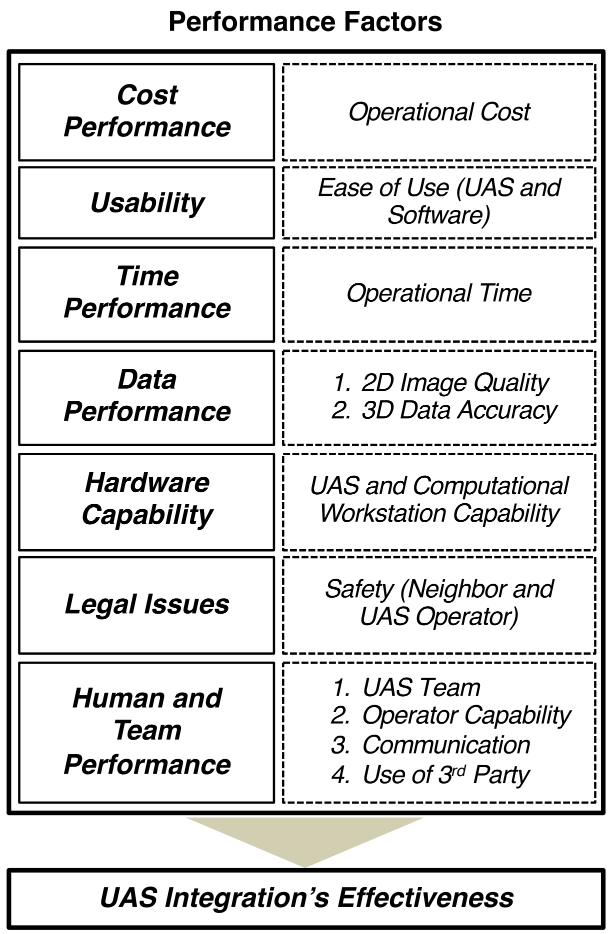


Figure 48 – Conceptual UAS Performance Factor Model

The most significant factor was identified as "Safety (*avg. = 5.000*)" because all operations should consider the safety of both UAS operators and neighbors including traffic and pedestrians according to the FAA PART 107 (FAA, 2016b). The respondents also indicated that 2D image quality (*avg. = 4.875*) and 3D data accuracy (*avg. = 4.750*) are very important. The quality of 2D images could have an impact on the progress monitoring or site condition inspection tasks on a construction worksite. In addition, 2D images have an impact on the quality of the 3D model.

In regards to human and team factors, the UAS operational team (*avg. = 4.625*) should be considered and developed within the appropriate department or division. The other important issue is the capability of the UAS operators (*avg. = 4.125*), which should include the task as well as the cognitive performance. The cognitive performance should include the situation awareness (SA) or mental work load (MWL). The operator's communication (*avg. = 3.125*) is also considered to avoid any accidents and maintain the VLOS of the platform. The operational cost (*avg.* = 4.500) and capability of the UAS platform (*avg.* = 4.375) are other factors that influence the performance of the UAS-integrated application. In addition, the ease of use (*avg.* = 3.375) and operational time (*avg.* = 3.000) should be considered for effective and efficient use of the UAS.

This study still faces the challenge to conclude the derived importance of the factors because of the limited number of samples in the survey. However, it can provide initial implications of the significance of UAS implementation for further studies, since the data were collected after several field tests and demos, and based on the experience and perception of a focus group with significant industry experience. Figure 49 shows the importance of the factors.

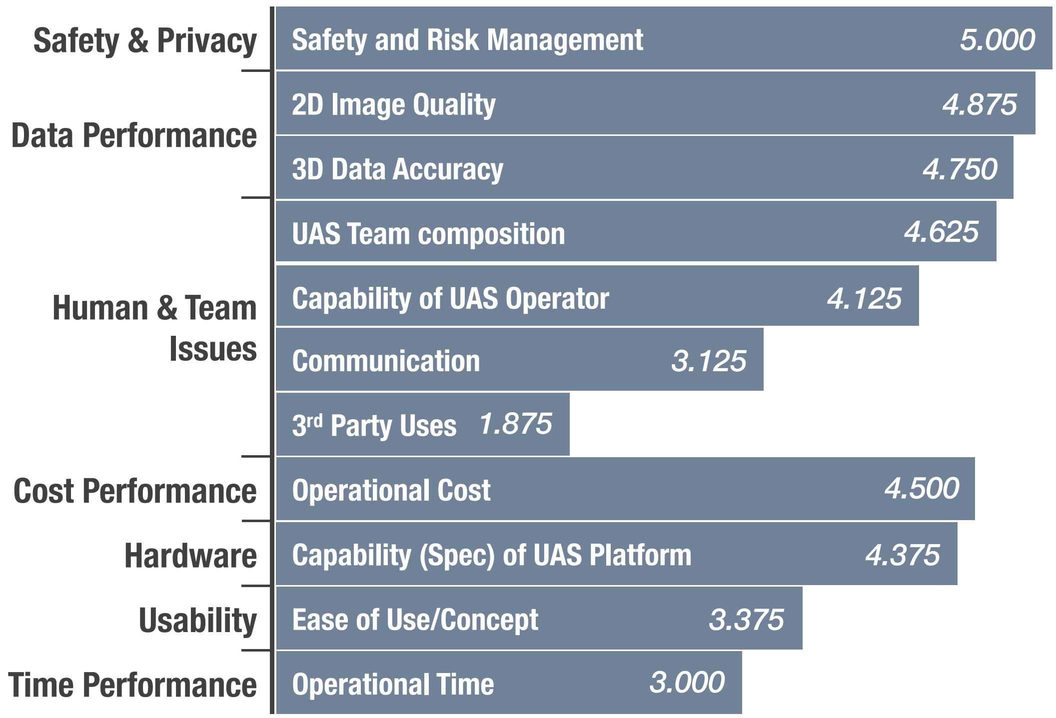


Figure 49 – Important UAS Performance Factors

6.4 UAS-Integrated Workflow Development

Based on field-testing, a UAS-integrated workflow was developed, particularly for construction inspection and measurement. To analyze the operational time efficiency of the UAS for each step in this newly developed workflow, the survey respondents estimated the time based on their experience during the field-testing. In this section, the UAS-integrated workflow will be described and recommended, and the operational time for each step will be estimated and analyzed by comparing it to the current manually-based workflow.

6.4.1 UAS-Integrated workflow

The UAS-integrated workflow on the construction site mainly consists of three steps: (1) pre-flight, (2) flight, and (3) post-flight (as shown in Figure 50). More specifically, the pre-flight stage comprises GCS setup for UAS operation, GCP setup, onsite meeting for data collection plan or flight mission plans, and equipment check. During the flight, the UAS can collect the data. The post-flight step consists of data processing to develop the 3D model, debriefing meeting, GCP removal, data analysis and decision-making and data documentation.

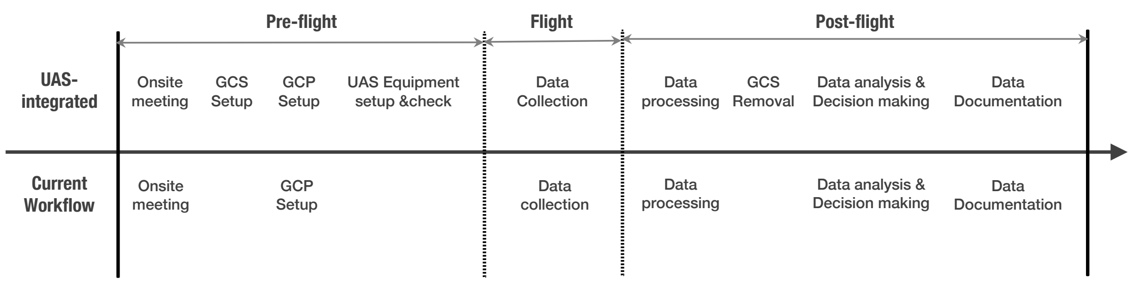


Figure 50 – UAS-based and Current Workflow

6.4.1.1 <u>Pre-Flight Stage</u>

Based on the field-testing, the pre-flight stage consists of four main steps: (1) onsite meeting, (2) GCS setup, (3) GCP setup, and (4) equipment inspection. The main objective of the pre-flight stage is to establish clear goals for the UAS flight including deciding on the point of interests (entire site or specific location), making a flight mission plan associated with the point determined, equipment or GCS setup, and flight preparation.

The main goal of the onsite meeting is to decide on specific flight plans, including takeoff and landing locations, potential obstructions, and point of interests. The outcome of the meeting is the detailed flight plan. The participants of this meeting should include the PE and UAS operators. It is very important to coordinate between all stakeholders of the construction projects. The GCS should be appropriately and safely located and established around the location of the construction project. This includes UAS control systems, the operator's communication system, backup batteries, and other equipment. These requirements vary, depending on the location of the site or type of project. During field-testing, the UAS and supplementary equipment are inspected to check for the UAS platform is ready to fly. This stage can be included in the GCS setup process. The UAS operators, including the PIC and VO, must be able to maintain direct communication during the pre-takeoff check before starting the flight. This can be accomplished through the use of a two-way radio. Performing the pre-takeoff check can help to avoid flight accidents or lost connections during the flight. This is one of the most important steps to avoid non-compliance with any important mission parameters required for a safe flight. For example, if the pilot misses checking the available battery power, the mission could be affected by sudden power failure. The checklist items include very specific and simple tasks, ranging from checking the charge of the UAS battery, checking the condition of the camera, etc. Figure 51 shows the pre-flight stage.

(a) Pre-flight meeting

(b) GCS setup

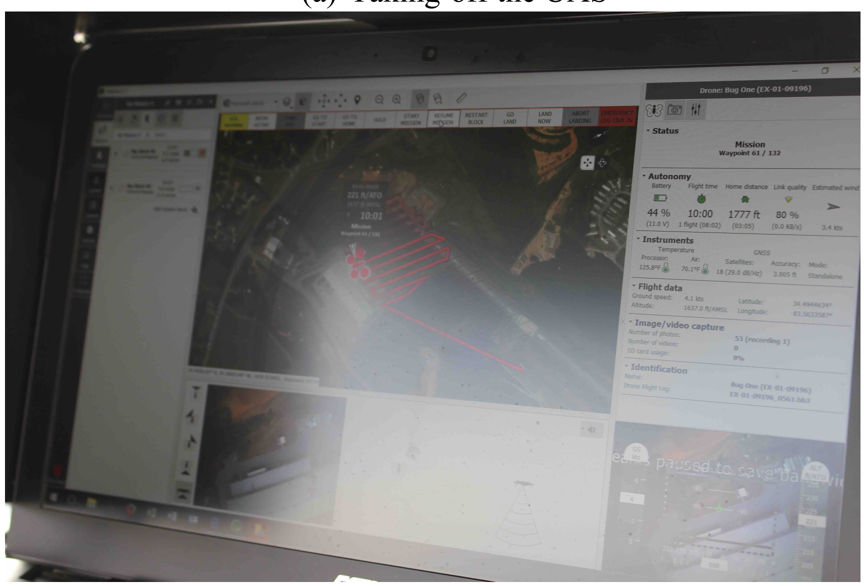
(c) GCP Setup

Figure 51 – Pre-flight Step: (a) Pre-flight Meeting, (b) GCS Setup, and (c) GCP Installation

6.4.1.2 Flight Stage (Data Collection)

During flight, the VO tracks the UAS location to allow the pilot to focus on flight control and on collecting the visual assets useful to the PE. At the same time, observers check the UAS flight conditions with the mission checklist. Three issues should be checked during flight: (1) hover approximately 10 feet above ground to confirm UAS is under pilot control and GPS has engaged, (2) verify that all control sticks operate correctly while in hover, and (3) battery charge levels are safe for flight. UAS, router (if used), and transmitter are at adequate % of charge (above 50%) to avoid the loss of communication during the flight. Flights should be kept to 15-20 minutes, depending on the UAS platform and battery capacity. When the UAS pilot determines the mission has been completed, a signal is made by VOs to prepare for UAS landing. The VO then checks the landing location conditions. The landing location should be the same as the takeoff location determined during the pre-flight planning meeting. If the location is clear and safe for landing, the VO indicates to the PIC to verify that the camera provides a view of the landing location for the PIC. Figure 52 shows the UAS flight stage in the construction task environment.

(a) Taking-off the UAS



(b) Data collection based on the flight mission

Figure 52 – Flight Step: (a) Taking-off and (b) Data Collection

6.4.1.3 Post-Flight Stage

After finishing the data collection, the collected 2D images should be processed to 3D data. This requires a high-capacity computational work station. The time needed for data processing depends on the number of the images collected, the resolution (quality) of the images, and the setting of the software. The data could be directly downloaded to local storage media or web-hosted storage, a process that can take a few minutes or several hours with the web-storage method. As with other digital data transfers, the time required depends on the bandwidth of communication networks as well as read-write speeds of the devices used. The most efficient method for the tests conducted in the project studies was local storage data transfer. It is recommended that web-hosted storage is used for backup purposes and for none time-critical data sharing needs. Once data are downloaded, processing involves cataloging the visual assets by location, work task observed, and type of potential hazard observed. This step may require the longest operational time. Once the 3D model has been generated and processed, the stakeholders can discuss the progress of construction work, condition of the overall site, and even the volume of the earthwork in a road construction project. They can view visual data through a large screen if available, discuss identified issues to make a decision. In addition, if another flight should be required, proper takeoff and landing locations can be determined as well as issues that should be inspected again during the next flight.

6.4.2 Estimated Operational Time

Based on the proposed workflow integrated with the UAS, the interviewees estimated the operational time of each step of the new workflow as well as of their traditional methods. The longest times for the UAS-integrated work process were identified as the post-flight data processing step and the GCS/equipment setup. Based on the interviewees' estimates, the GCS and equipment setup averages five hours, and the 3D data processing was estimated at three hours. The data processing step can be executed after business hours, and the project personnel can leave the computer and software to conduct the UAS photogrammetry process by itself during the night. In contrast, the longest time for the traditional method is to setup the GCP around the construction worksite. This work is usually conducted during the design as well as construction stage. The GDOT personnel indicated that this step takes 10 hours, but it can be left during the construction phase. The UAS-integrated workflow can refer to an already installed GCP or may require a new GCP. Therefore, the total operational times are highly reliant on the GCP needs for the UAS flight.

The UAS-based workflow has significant benefits in terms of the data collection and analysis steps. Based on the estimate of the UAS-based inspection on the whole construction site it takes an average of 0.42 hours, whereas the current method takes 1.83 hours to collect the visual data. For the analysis, the stakeholders can have a discussion for an average of 0.5 hours to discuss the conditions and progress, as well as to make a decision. In contrast, the current method takes an average of 3.53 hours. Based on the total operational time, an average of 11.92 hours is estimated for the UAS integration (assuming the GCP is not required or already installed) and an average of 18.075 hours for the current method. However, if the new GCP first needs to be setup for UAS operation on the jobsite, the total time would increase and the UAS-based inspection take longer than the traditional method. Table 35 and Figure 53 show the estimated time by work process.

Table 35 – Estimated Time of Workflows

Workflow	UAS-integrated method (hour)	Manual method (hour)
1. Onsite meeting (pre-data collection, flight mission plan development)	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 (manual equipment as well as UAS)	4.000	0.000
5. Data collection (inspection/monitoring) or UAS flight	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 (reporting)	1.000	0.917
Total estimated operational time	**11.920**	**18.075**

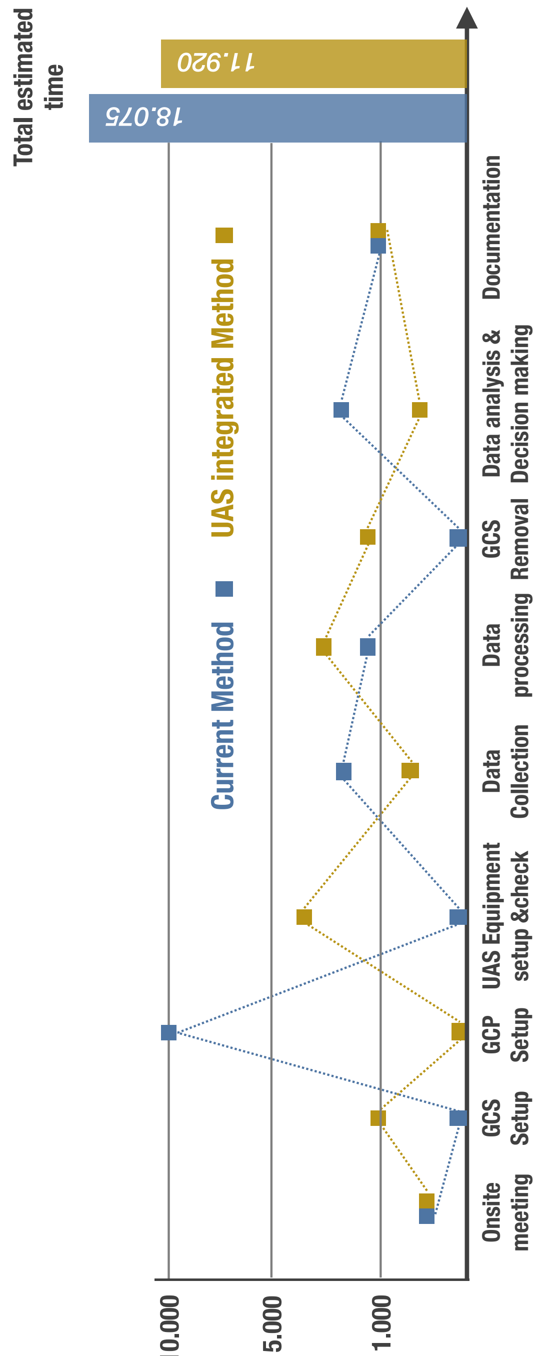


Figure 53 – Estimated Operational Time of Workflows

6.5 Effectiveness and Efficiency Analysis

This study conducted three field tests and interviews to collect the visual data as well as the users' perceptions of the UAS operations in the construction environment. During the 3rd interview, the participants were asked about the effectiveness of the UAS-integrated tasks in terms of the identified factors. Then they were asked about the effectiveness of the factors. The survey asked the interview participants to indicate their perception about the effectiveness of the factors on the each step of new workflow. Based on indications from all respondents, the importance of each factor was determined with a Likert Scale from 1 = not effective or efficient, to 5 = very effective or efficient. The collected data are described and computed as the mean.

6.5.1 Effectiveness of Visual Data (2D and 3D)

After the demo session, the participants as the potential end-users indicated the effectiveness of the UAS-based visual images including 2D images, infrared, video, and 3D data. Their evaluation was based on what they perceived and experienced during the demo and field-testing. As to 3D data use, the participants indicated the 3D data have significant influence on the effectiveness (*avg. = 4.500*) of the construction progress and site inspection, however the 3D data for surveys (*avg. = 3.333*) requires more accuracy. 2D still images are also very effective for construction progress inspection (*avg. = 4.833*), overall site inspection (*avg. = 4.833*), and survey (*avg. = 4.667*). Infrared images were not effective in any construction task environment in this study (*1.000*). Figure 54 shows the effectiveness of the visual data.

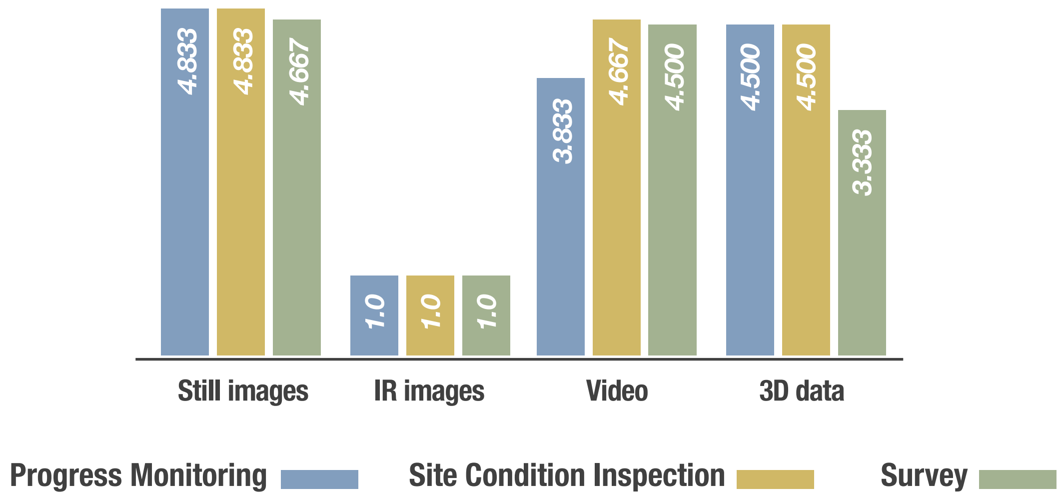


Figure 54 – Effectiveness of Data Quality

In addition, the participants were also asked about the effective location of the UAS or the required view to get more effective visual data. A total of three views were provided to the participants, such as detailed close-up view, medium altitude view, and high-altitude overview. The close-up view has better effectiveness for progress monitoring or measurement (*avg. = 5.000*) or survey tasks (*avg. = 4.833*); however, the site condition monitoring tasks need just a high-altitude overview (*avg. = 4.333*). Depending on the task objective and scope, the flight mission should be adjusted to collect better quality of visual data. Figure 55 shows the effective views by distance.

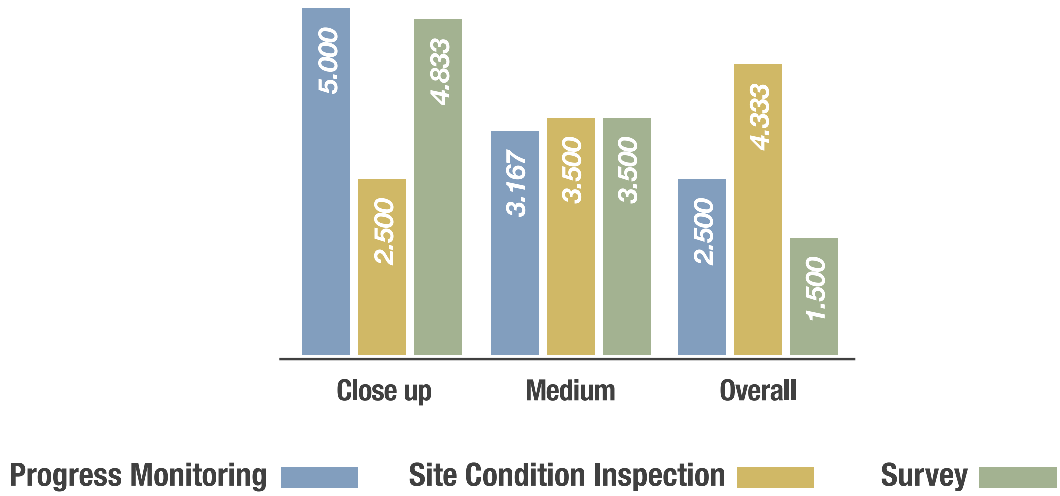


Figure 55 – Effective Distance of UAS for Data Collection

6.5.2 Effectiveness of Team

Based on the result of the information analysis in the previous chapter, the UAS operators can comprise PIC, FC, and PE. During the field-testing, all of participants collaborated as one team. The GDOT personnel was asked about the most effective team composition for the UAS operation based on their experience during the flight. They indicated the UAS team was not fully effective in developing the flight mission (*1.375*), data collection (*avg. = 1.500*), and the data process (*avg. = 1.375*). However, the developed team consisting of different stakeholders was very effective in analyzing the data and making a decision (*avg. = 4.625*) in the post-flight stage. Surprisingly, the GDOT personnel overall implied the overall team composition and the communication with each other to be very effective (*avg. = 4.500*) since the most important issue for the PE is the result of the analysis, decision-making, and data management system. Figure 56 shows the effectiveness of the team composition by the work process.

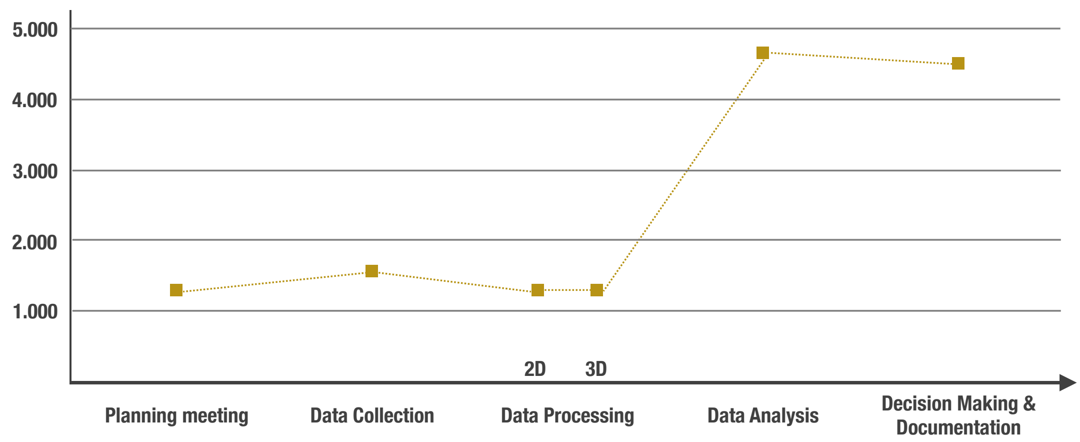


Figure 56 – Effectiveness of Team Composition

6.5.3 Usability

The GDOT personnel indicated the usability of the UAS and 3D model uses based on what they had experienced in terms of flight planning development during the pre-flight meeting, UAS operation, demo session, and debriefing. The most difficult part for the end-users is to control the UAS (*avg. = 2.857*) since this requires significant experience and depends on the capabilities of the PIC. The survey participants indicated the UAS visual data-based analysis and decision-making process are very efficient for them (*avg. = 4.857*). This result implies that improvement of the usability would involve an improvement of the human operator's performance and capabilities during the data collection process. Figure 57 shows the usability based on this experience.

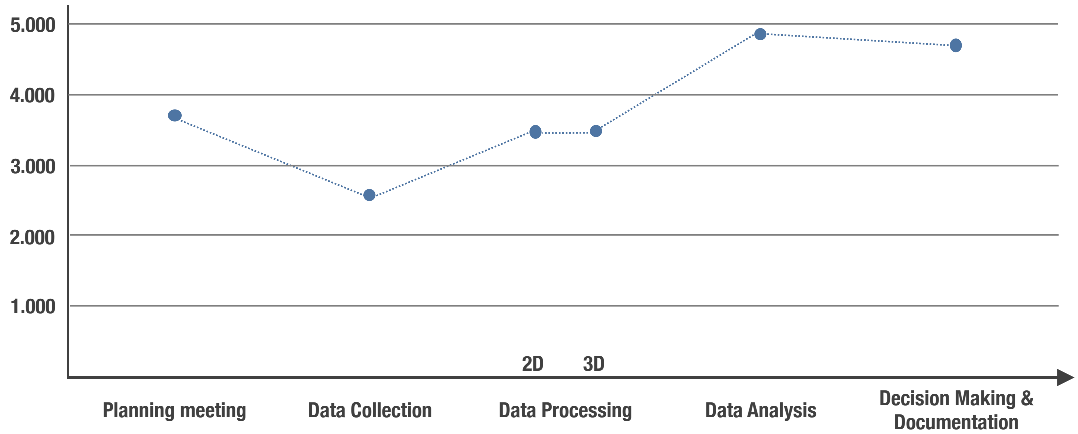


Figure 57 – Effectiveness of the Usability

6.5.4 Efficiency of Work Procedure

Based on the proposed work procedure with UAS integration, the GDOT personnel indicated the efficiency of the developed workflow as shown in Figure 58. The GDOT personnel agreed that the proposed workflow improves the efficiency of the data collection, analysis, and documentation step (*avg. = 5.000*). However, the data processing step is inefficient (*avg. = 1.500*) because it takes longer than the manual method.

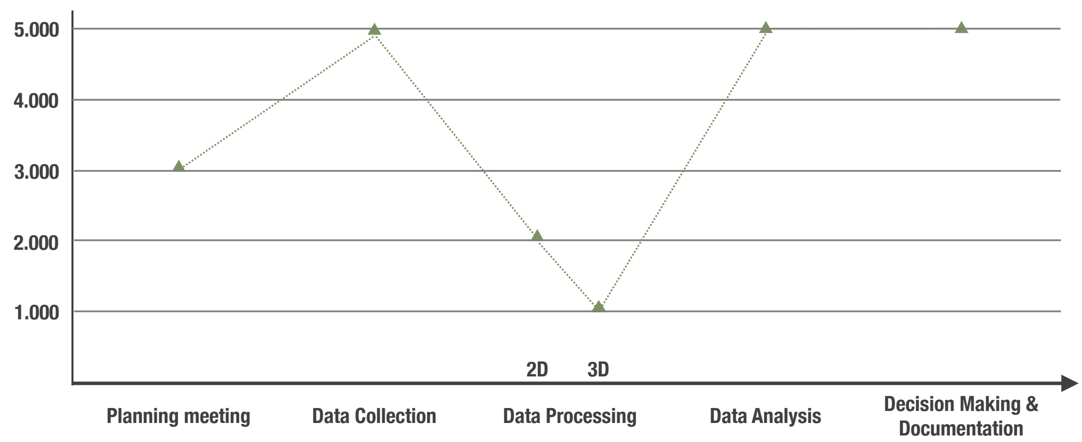


Figure 58 – Efficiency of Work Procedure

6.5.5 *Effectiveness of Safety*

As it is very difficult to evaluate the safety of the operators as well as the public, this study implements a user perception- and experience-based study. The respondent from the GDOT indicated that the most important stages for safety are the pre-flight and flight stages. In special cases, pilot flights during the pre-flight stage are required in order to collect the pre-flight data, such as the required altitude or distance. As a result of the GDOT response, the safety of both the public (*avg. = 1.778*) and the operators (*avg. = 1.889*) should be carefully considered. The physical data from the pilot flights enable the team to develop a specific flight plan considering the safety of the team and the public, as well as private property. As a result, GDOT personnel indicated that safety on the actual flight would be better than the pilot flight to collect the flight parameter data (*avg. = 4.000*). Figure 59 shows the safety performance and effectiveness of the foreseen flights.

Figure 59 – Effectiveness of Safety (public and UAS Team)

6.6 Summary of the Effectiveness Analysis

The potential end-users also indicated the effectiveness of safety procedures (*avg. = 3.278*) and of the team (*avg. = 4.500*), as well as the efficiency of the work procedures (*avg. = 4.000*), and the overall usability (*avg. = 4.000*). The overall result implies that UAS operations within the construction environment requires a team composition suitable for analyzing visual data and effective decision-making. However, further studies are required to improve the team's effectiveness during the flight mission development and data collection. With improved team composition and communication, the team would be able improve the data quality as well as the efficiency of the work procedures. Figure 60 shows the overall effectiveness or efficiency of the UAS operation in terms of performance factors.

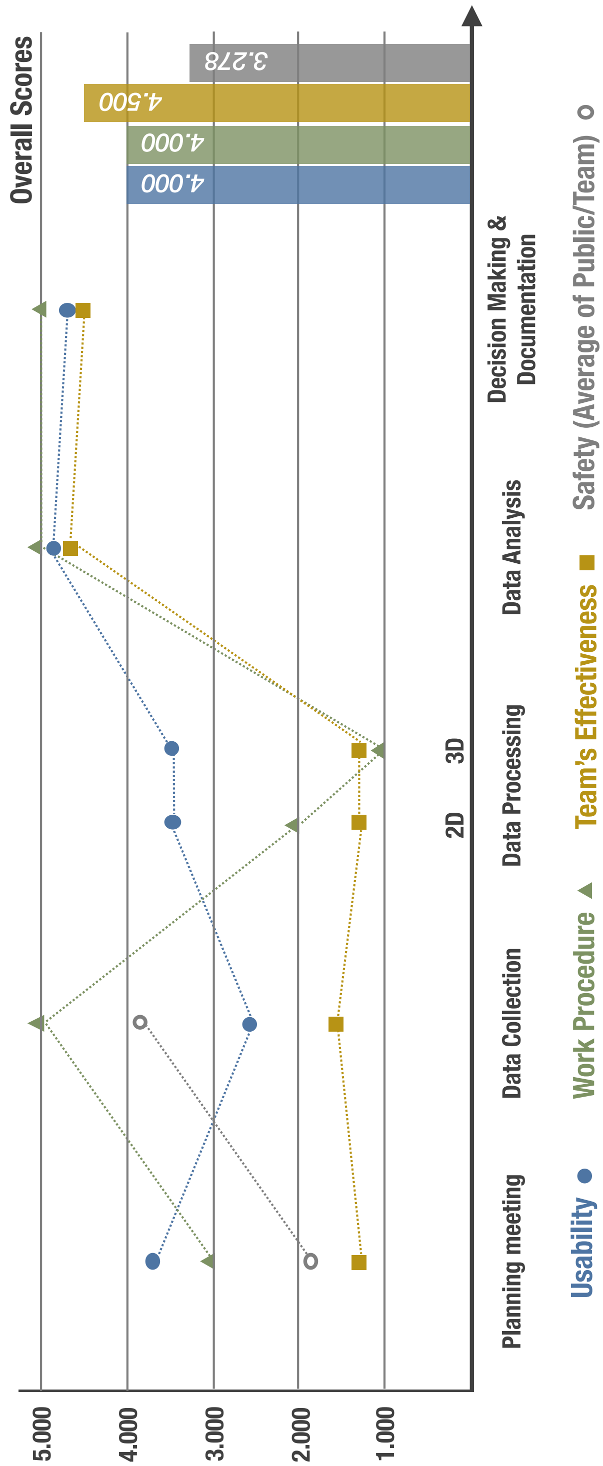


Figure 60 – Summary of Effectiveness Analysis

CHAPTER 7. HUMAN PERFORMANCE ANALYSIS AND IMPLICATIONS

The goal-directed task analysis (GDTA) model was developed based on the information analysis. The unmanned aircraft system (UAS) operation considers human cognitive task performance, including situation awareness (SA) and mental work load (MWL). This chapter describes a participatory user field experiment to measure the SA and the MWL, i.e. the performance of the human operator during the UAS operation. From the experiment, three themes were observed from the GDTA analysis and field-testing that served to analyze the cognitive performance, capabilities, and experience of human UAS operators. A total of ten participants from the Georgia Department of Transportation (GDOT) participated in the field experiment. The experiment was conducted after the workshop with the GDOT on July 18th, 2017. The participants performed the UAS flight around a construction jobsite on the Georgia Tech campus.

This field experiment had three main challenges: (1) all processes or environments had to follow the FAA and campus police department regulations (for the safety of equipment, participants, pedestrians, or traffic) (2) small number of participants from the GDOT; and (3) the human cognitive performance was evaluated by the survey questionnaire. Because of these limitations, this chapter conducts a thematic-based qualitative case study to investigate the pattern between the human aspects of UAS applications, such as human task performance, cognitive performance, and experience. Thematic Analysis can help to the relationship or patterns between the set of data (Barun B. and Clarke V., 2006). Further quantitative studies with enough samples or a data-driven simulation model will be conducted to verify the main findings from this qualitative analysis.

7.1 Participatory User Field Experiment

The field experiment was designed to evaluate the users' task performance and cognitive performance, as well as to find out the relationship between those performance and the user experience. First a learning session was held during the workshop for the GDOT, providing them with the description of the UAS application for construction, a demo of 2D and three-dimensional (3D) visual data, instructions on UAS control, and an explanation of the field experiment process. The participants were also asked about their background during the survey questionnaire in Appendix A.5.

During the field experiment the participants conducted an actual UAS flight on a construction site in the Georgia Tech campus. They were asked to perform six tasks, including (1) taking off and to set altitude ; (2) hovering; (3) performing flight patterns; (4) flying to the construction site (point of interest); (5) taking still images; and (6) returning and landing. While they conducted the flight, their performance was evaluated by tracking the time they required to complete the tasks. In addition, each participant was asked to fill out the post-subjective survey to evaluate their SA and MWL immediately after finishing the flight.

Three main themes were observed from the information analysis during the FG interview, the GDTA, and the field-testing data collection. In the last step the patterns or relationship between the components in each theme were analyzed. Figure 61 shows the design of the experiment.

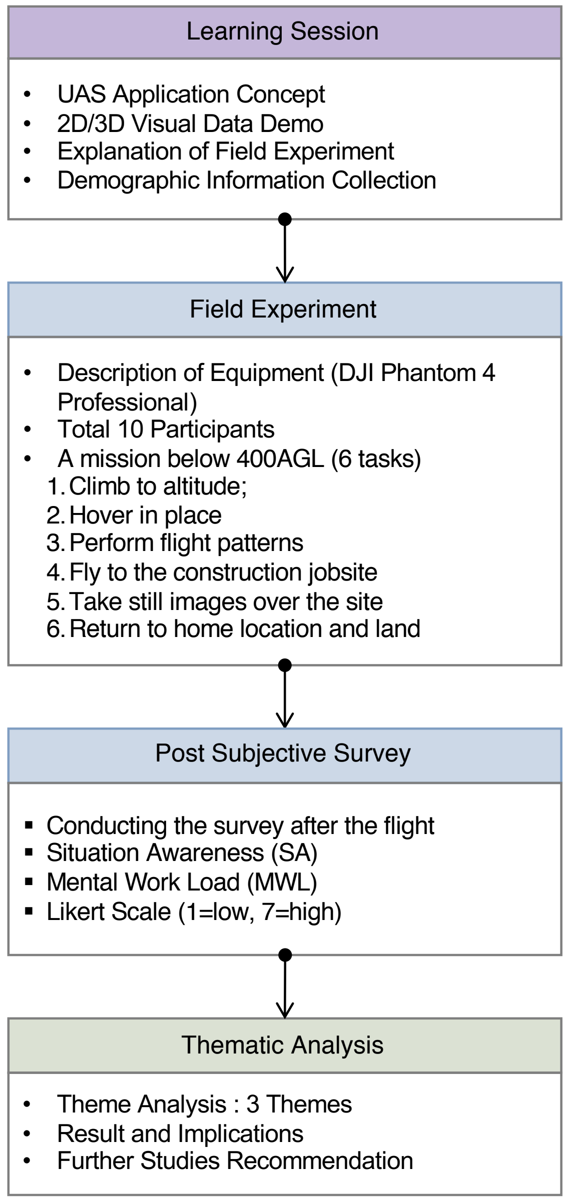


Figure 61 – Field Experiment Process

7.1.1 Participants

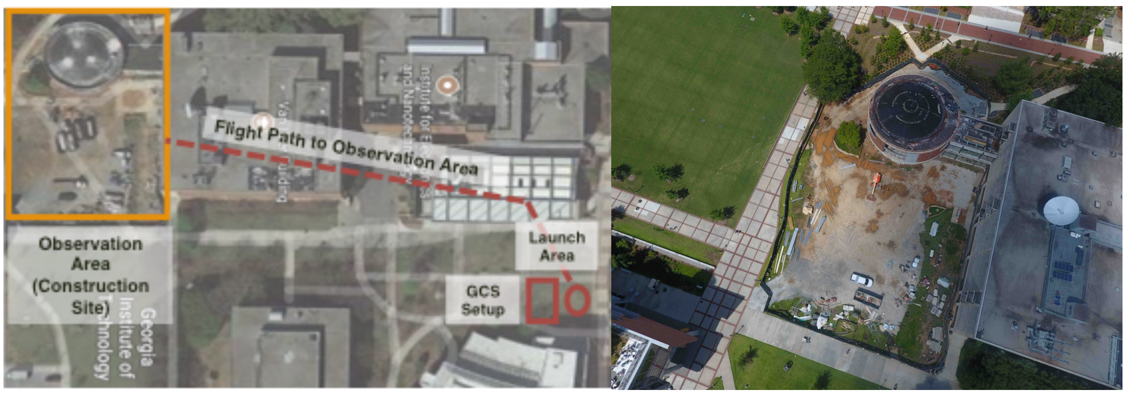
A total of ten GDOT professionals participated in the field experiment (*N=10*). The participants of this study comprised ten industry professionals from the Georgia Department of Transportation. They ranged from 30 to over 51 years of age; eight were male and two female. On average the participants had 11 years of transportation or construction-related experience. One participant reported more than 21 years of experience; four had 11 to 20 years of experience, and five had less than 10 years of work experience. Their professions mainly comprised four groups: three bridge inspectors, three project engineers (PE), one highway emergency response operator (HERO), and others (*30%*). They were also asked about their educational background and their familiarity with UAS operation. Only one of them had high-level familiarity with UAS operation; two had an average level and seven had rarely or never used UAS. Table 36 shows the variables of all participants.

Table 36 – Demographic Information of Field-Experiment

Attribute		Participants (*N=10*)
Gender		
	Male	80%
	Female	20%
Age		
	31-40 years	40%
	41-50 years	40%
	Over 51 years	20%
Role		
	Bridge Inspector	30%
	Project Engineer	30%
	Emergency Operator	10%
	Others	30%
Work experience		
	Less than 10 years	50%
	11-20 years	40%
	Over 21 years	10%
Educational Attainment		
	High-school level	40%
	Undergraduate level	40%
	Graduate level	20%
Familiarity with UAS		
	High level	10%
	Average level	20%
	Low level	70%

7.1.2 Equipment

The field observation was undertaken within the Van Leer Building construction worksite on the campus of Georgia Institute of Technology presented in Figure 62. For this experiment, the GCS and power generation was set up around the construction jobsite as shown in Figure 63. Two certified PICs were involved in the experiment, which used a DJI Phantom 4 (Figure 63). This UAS has a 12.4 megapixel camera with 4K-resolution video recording capability. This platform is registered with the Federal Aviation Administration (FAA) according to the PART 107 regulation. The maximum flight time of this platform is approximately 25 minutes. Upon completion of the experiment, all participants were asked to complete the situation awareness rating technique (SART) form (Taylor, 1990) and the NASA task load index (TLX) questionnaire shown in Figure 64 (S. G. Hart & Staveland, 1988).



(a) Field Experiment Logistic (b) Building Construction Site

Figure 62 – Field Experiment Location

(a) DJI Phantom 4 b) GCS Setup

Figure 63 – UAS Platforms and GCS

\

Domains	Elements	Indicates (1 = Low, 7 = High)						
		1	2	3	4	5	6	7
Attentional Demand	Instability of Situation							
	Variability of Situation							
	Complexity of Situation							
Attentional Supply	Arousal							
	Spare Mental Capacity							
	Concentration							
	Division of Attention							
Understanding	Information Quantity							
	Information Quality							
	Familiarity							

(a) Situation Awareness Rating Technique (SART) (Taylor, 1990)

Elements	Questions	Indicates						
		1	2	3	4	5	6	7
Mental Demand (1:Low – 7:High)	How much mental and perceptual activity (thinking, deciding, calculating, remembering, looking, searching, etc) was required? Was the task easy or demanding, simple or complex, exacting or forgiving?							
Physical Demand (1:Low – 7:High)	How much physical activity was required (Pushing, Pulling, controlling, activating, etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?							
Temporal Demand (1:Low – 7:High)	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?							
Performance (1:Good – 7:Poor)	How successful do you think you were in accomplishing the goals of the task set by yourself? How satisfied wer you with your performance in accomplishing these goals?							
Effort (1:Low – 7:High)	How hard did you have to work (mentally or physically) to accomplish your level of performance?							
Frustration Level (1:Low – 7:High)	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?							

(b) NASA Task Load Index (TLX) (S. G. Hart & Staveland, 1988)

Figure 64 – Post Survey Questionnaire

7.1.3 Task Scenarios

The experiment mainly consisted of three steps: (1) learning session; (2) field operation; and (3) post-subjective survey. The subject survey was based on the SART questions (Taylor, 1990) and NASA TLX (S. G. Hart & Staveland, 1988) that were used to measure the SA and MWL of the human operator. The learning session was provided to all participants. After a short briefing, participants were given the survey instrument to be completed immediately after the experiment. They also participated in an educational session to clarify how the UAS can be controlled, as well as which tasks should be performed during the experiment. One certified pilot controlled a short trial, which involved operating the UAS by performing the planned tasks. Figure 65 shows the learning session and field experiment session, in which one user performed six tasks as follows:

1) taking off and climbing to altitude about 100feet (below 400feet);
2) hovering in place;
3) performing flight patterns;
4) flying over the construction jobsite;
5) taking still images of the construction environment; and
6) returning to the home location and landing.

Figure 65 – Learning Session and Participatory User Field Experiment

7.1.4 Experiment Results

7.1.4.1 <u>Situation Awareness (SA)</u>

The overall SA score has been derived using Equation 1 below. Equation 1 describes the SA calculation based on the understanding (US) score, attentional demand (AD), and attentional supply (AS).

$$SA = US - (AD - AS) \tag{1}$$

The mean overall SART score is computed as 25.5(*SD = 8.370*). The highest SART score is indicated as 38. The lowest overall SART score is 15. All participants' scores were calculated for each SART dimension, such as Supply, Demand, and Understanding. The mean score for the Demand is 14 (*SD = 3.055*). The mean score for Supply is 22.4 (*SD=3.373*), and the mean score for Understanding is 17.1 (*SD = 3.381*).

7.1.4.2 Mental Work Load (MWL)

The participants were asked to fill out the rating of each attribute based on NASA TLX rating package. An overall MWL score of 3.967 (*SD=0.666*) was computed based on averaged ratings.

7.1.4.3 Task Performance

During the field experiment, each participant's performance was measured. The mean score of performance was 229. Since this value indicates the total time to perform the tasks, a lower value indicates a higher performance. Table 37 shows the descriptive statistic of the post-subjective survey.

Table 37 – Descriptive Statistics

Variables	Min	Med	Max	Mean	Std.D (SD)
Attentional demand	11	12	20	13.000	3.055
Attentional supply	18	22	28	22.400	3.373
Understanding	13	17.5	21	17.100	3.338
Overall SA score	15	26.5	38	25.500	8.370
Overall MWL score	3	3.75	5	3.967	.666
Performance time (seconds)	124	248	311	229.000	58.589

7.1.4.4 Theme Selection

The main purpose of the thematic analysis was to examine how operators' cognitive performance and user experience can enable efficient and safe UAS operations in construction and civil environments. During the information analysis and field-testing the participants had trials to operate the UAS and perform the described tasks; moreover, their experience, demographics, and cognitive performance were analyzed and evaluated. The time to complete all listed tasks was measured by an visual observer (VO) during the observation. Based on the research questions and the experiment, three themes emerged shown in Figure 66:

1) To what extent does the UAS operator's cognitive performance have an impact on the UAS operation (task performance)?
2) To what extent does the user experience have an impact on the UAS operation (task performance)?
3) To what extent does the user experience have an impact on the UAS operator's cognitive performance?

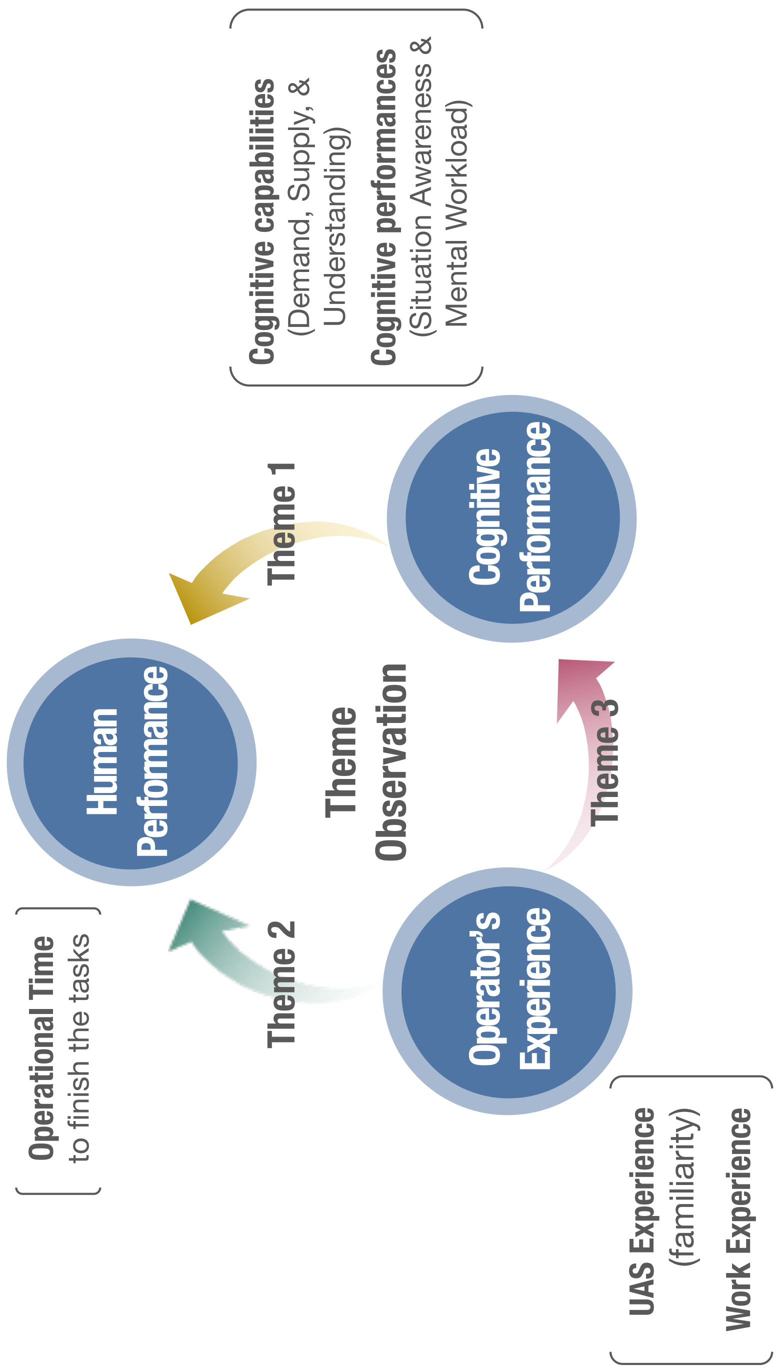


Figure 66 – Themes Observations

7.2 Thematic and Narrative Analysis

This section presents the thematic and narrative analysis (Barun B. and Clarke V., 2006) based on the data collected from the field experiment. As the sample is too small, this study was conducted with a qualitative-based method, which is a thematic analysis.

7.2.1 Theme 1. To what extent does the UAS operator's cognitive performance have an impact on the UAS operation (task performance)?

The main goal of Theme 1 is to clarify the pattern between the participants' task performance and their cognitive capabilities. The participants' demographics comprised gender, age, and job. Based on these demographics, the narrative analysis can identify patterns to show how and which cognitive capabilities facilitate better performance. This theme can be discussed in two main parts: (1) SA, and (2) MWL. The SA is further divided into three components based on the SART: (1) Demand, (2) Supply, and (3) Understanding. The following section describes the result of the thematic and narrative analysis, including the evidence, as well as further implications for using UAS in the construction environment.

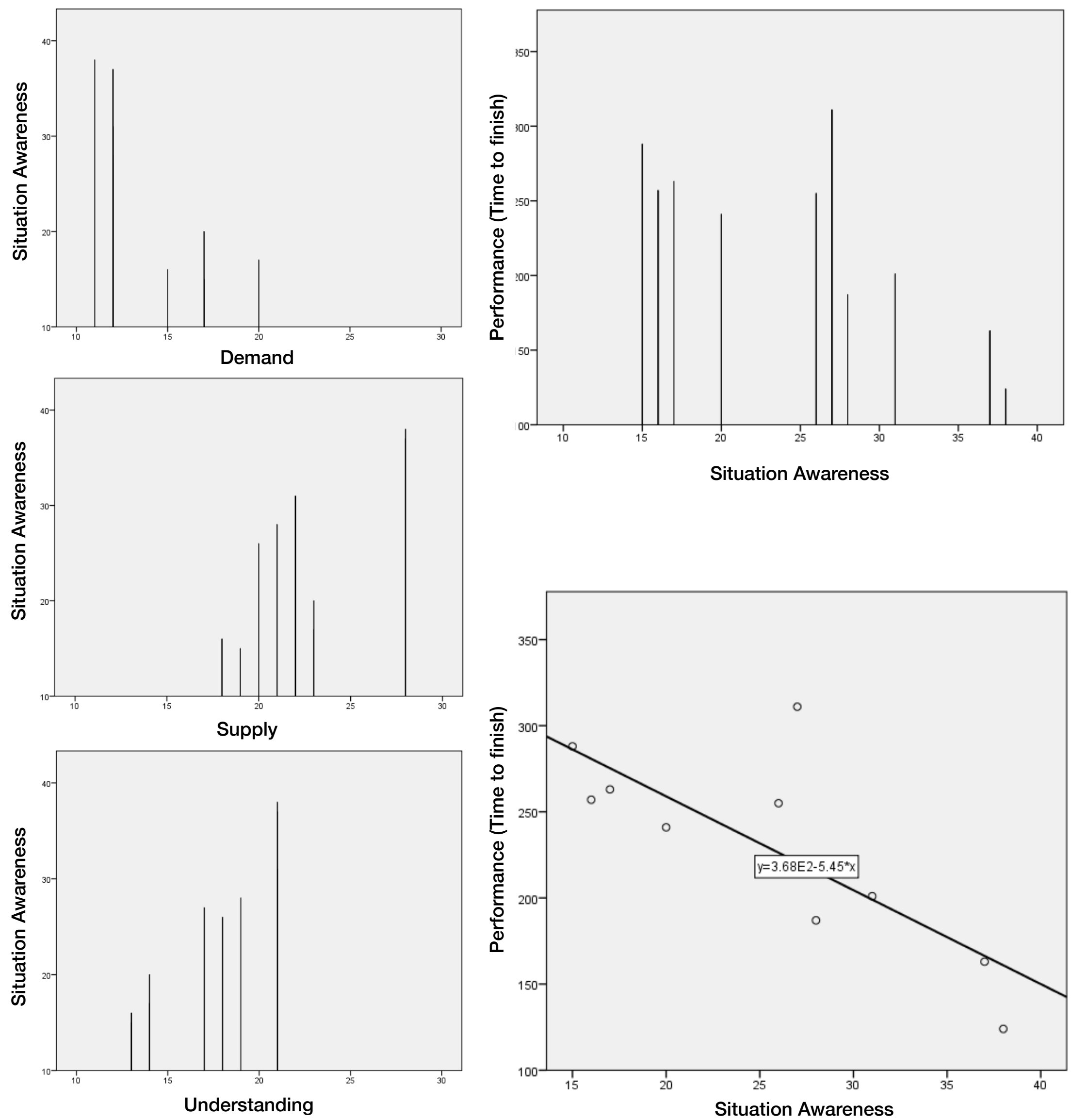
7.2.1.1 Situation Awareness (SA)

The maximum SA score is the 39 according to the SART and Equation 1 in section 7.1.3. The average SA score of male participants (*avg. = 27*) were higher than the female participants' mean scores (*avg.* = 22). Male participants aged between 31-40 had the highest SA scores (*avg. = 31*). The 41-50-year old female participants had higher SA scores than the males; in contrast, the male participants had higher SA scores in the over-51 age group. Since there were no females in the group of 31-40 year-olds, the comparison of the SA scores by age level was only conducted on the other levels. In the age group of 41-50-year-olds the female participants had higher SA scores (*avg. = 26*) than the males (*avg. = 21*). The participants in the younger group (31-40 years old, *avg. = 31*) had much higher SA scores than the other two older groups (41-50 and over 51, *avg. = 22*). for the three components of the cognitive capabilities, the AD of male participants (*avg. = 14*) was lower than that of females (*avg. = 16*). The AD score of the younger group (31-40 years old, *avg. = 13*) was the lowest among all age levels (*avg. = 14 and 16*). The AS scores did not show significant patterns related to age or gender. However, the US score of the younger group (31-40 years old, avg. = *19*) was higher than among the older groups (41-50 or over 51 years old, avg. = *16*).

The operators in the range of 41-50 years old had higher SA scores (*avg. = 24*) than the scores of the PEs over 51 (*avg. = 17*). Male PEs had higher SA scores (*avg.=24*) than female PEs (*avg. = 17*). The female participants recorded higher SA scores (*avg. = 26*) than the males (*avg. = 21*), when they were involved in other DOT-related jobs. Based on the jobs, the HERO had the highest SA scores (*avg. = 38*) among other jobs; however, it is very difficult to explain that there are no remarkable patterns between the different jobs and SA scores, and the sample was too small to investigate relationships or patterns. As to the gender, age, and job of the participants, they do not have any relationship with the SA of the UAS operators.

Figure 67-(a) describes the relationship between the cognitive capability components and the SA scores of the participants during the field experiment. The participants with lower scores of AD obtained relatively higher SA scores; however the AS

and SA scores had moderately positive relationships. The US scores showed positive relationship between the UAS and SA scores. In this study, the performance of the participants was measured by the time needed to perform the tasks during the experiment. This means the lower value shows the better performance. The participants who acquired high scores of SA showed better performance, for example one who recorded 38 points in SA finished all tasks within 130 seconds, while another who obtained 15 points of SA needed more than 250 seconds to finish the same tasks (Figure 67-b). Since seven points are very close to the linear trend line in Figure 67-b, the relationship between the SA scores and performance was negative (*r: -0.782, p-value: 0.008 < 0.05 significant*).



(a) Situation Awareness and Demand, Supply, and Understanding

(b) Performance (Time to finish) and Situation Awareness

Figure 67 – Cognitive Capabilities, SA, and Task Performance

The trend between age, SA scores and performance of the participants was very clear in Figure 68. The overall time to finish the tasks was generally much lower in the age group of 31-40 (*avg.=178.75*) rather than in the 41-50 (*avg.=250.25*) or over 51 year-olds (*avg.=287.00*). Within the same group, participants with higher SA scores finished the tasks earlier than those with lower SA scores, except the group of over 51s. It is very difficult to find any pattern between the performance and AD score, or between the performance and AS score from this study. However, the participants with higher US performed better (finished in a shorter time) than those with lower US scores.

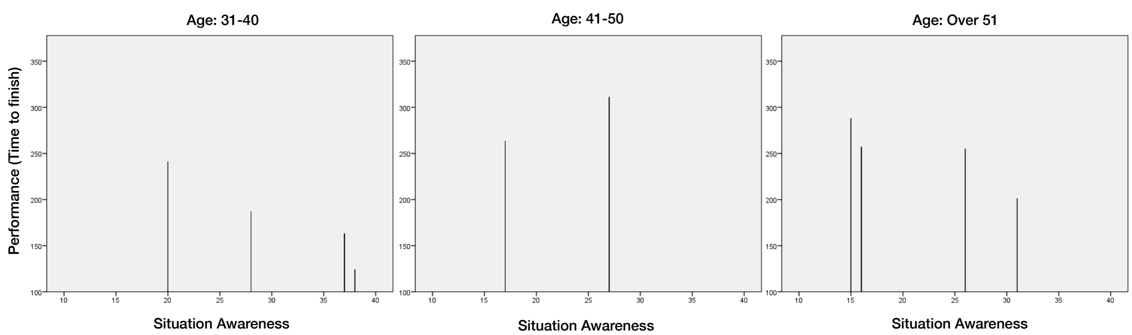


Figure 68 – SA and Task Performance by Age Level

Overall, the ages of the participants were related to the SA scores, but not to a highly significant level. However, age can have a direct impact on the performance of a participant. The gender and job positions did not show any relationships with the SA components and scores. All SA components (AD, AS and US) had linear patterns with the SA scores. The AD and SA both had a negative relationship; in contrast there were positive relationships between the AS and SA scores, as well as between the US and SA. This implies the UAS operators can obtain better SA capabilities when they have (1) a better understanding of the information around the site environment, (2) a greater supply of information from the surrounding environment, or (3) less need for information to be considered around the worksite. Based on the comparison of the performance and each of the components, only the US scores may have a close linear relationship (negative correlation) with the performance of the participants. Lastly, the SA capabilities had a pattern with the performance in terms of time to complete the tasks.

7.2.2 Mental Work Load (MWL)

The MWL score was also measured during the field experiment and survey. Here the results revealed that the MWL scores were lower in the older groups, and that the male participants had higher MWL scores than the females at the same age level. For the female participants the recorded MWL scores were higher in the older group, in contrast to the males, where the older group had lower scores. The higher MWL score indicates that the human operators are subject to higher mental, physical and temporal demand, or higher frustration levels There is no relationship between the three capabilities, AD, SD, and US, and the MWL scores in this analysis. Based on age, the AD and the score of MWL have a negative relationship, and the US and the MWL scores have a positive relationship. That indicates that the operator with higher AD has less MWL, or the worker with higher US has more MWL. The AS did not show any patterns with the MWL. There is no relationship between the MWL and the demographics of the participants in this thematic analysis.

Figure 69-a shows that the completion time was relatively longer (lower performance) when the MWL scores were higher in the older groups (aged 41-50 or over

51). However, there is no linear relationship between the MWL scores and the performance of the participants, as there are no clear patterns between the MWL scores and the performance of the participants depicted in Figure 69-b. Overall, there are no patterns between the demographic, such as age, gender, and job and MWL, or the MWL and task performance (*r: -.292, not significant*).

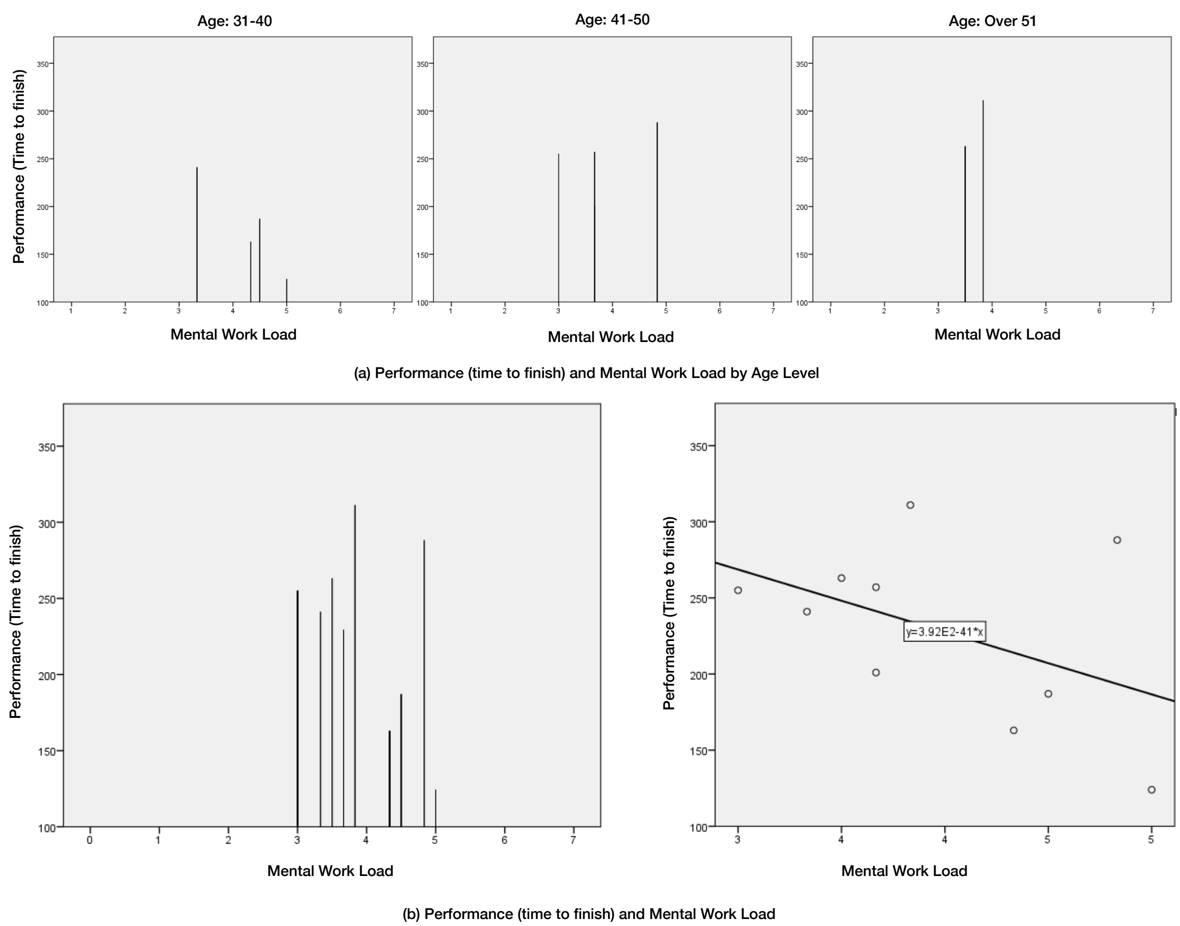


Figure 69 – MWL and Task Performance

7.2.3 SA and MWL

The MWL and SA are primary components of the cognitive capabilities in this study. However, there were no patterns or relationships between the two components in Figure 70. Based on the results from the previous section, on the one hand SA affected performance, on the other hand, it did not show a strong relationship between MWL and performance. Thus, all factors in this study are independent. The main challenge of this case study is the number of participants, therefore the effects of SA or MWL on performance, as well as the relationships between two variables, require further significant quantitative studies with more experiment participants. Figure 70 shows the relationship between SA and MWL.

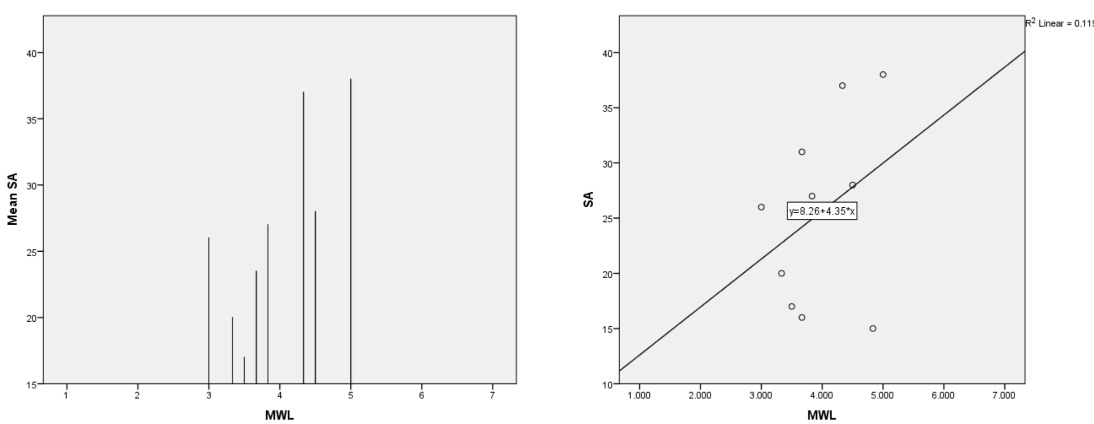


Figure 70 – SA and MWL

7.2.3.1 Implications for UAS Uses in Construction

The result of the Theme 1 analysis is summarized in Table 38 below. The SA scores have significant effects on the performance of UAS operations. The participant with the highest SA capabilities completed the tasks in the shortest time. In addition, three SA components, AD, AS, and US were also closely related to the performance of the operations. Alone the age of the operators could be an important variable, and could impact UAS operations and performance according to the analysis of Theme 1. Other demographics are not related to SA or MWL capabilities.

Table 38 – Result of Thematic Analysis (Theme 1)

Theme 1 Element	Result
SA	▪ Gender, age, or job is not significantly related to SA capabilities. ▪ The AD, AS, and US are related to the SA capabilities of participants. ▪ The AD has a negative, and AS and US a positive relationship with SA capabilities. ▪ The US score is related to the task performance of the participants. ▪ The SA score is related to the task performance of the participants. ▪ US and SA capabilities are negatively related to the time to complete the tasks.
MWL	▪ There are no clear patterns or relationship between the MWL capabilities and other variables at all in Theme 1.

UAS operations in the construction and infrastructure environment may need an operation team consisting of the pilot-in-command (PIC) and other project-related persons. The PIC should have enough cognitive capabilities in terms of SA and its three components. Therefore, public sectors (e.g. DOT or Federal Highway Administration-FHWA), or other commercial contractors should have trained the PIC well to use UAS in their projects. Based on the result of this study, the cognitive capabilities required of UAS operators are low AD and high AS and US, as well as high SA capacities, in order to effectively, efficiently, and safely use UAS on the construction site. This indicates that UAS operators should have more attentional information (e.g. instability, variability or situation complexity) from the surrounding environment; (2) a high number of cognitive capabilities (e.g. arousal, mental capability, concentration, or attention) by themselves; and (3) better understanding of information obtained (e.g. quality, quantity, or familiarity of information) from the outside.

7.2.4 Theme 2: To what extent does the user experience have an impact on UAS operation (task performance)?

The main goal of Theme 2 is to clarify the pattern between the participants' experience and their performance. In this context, experience related to UAS (familiarity with UAS) and work experience. The narrative analysis investigated how and which experience shows a pattern to improve the performance. This theme can be discussed in two main parts: (1) UAS experience, and (2) work experience. The following section describes the results of the thematic and narrative analyses with the evidence, as well as further implications for using UAS in the construction environment.

7.2.4.1 UAS Experience (Familiarity)

In this study the participants were asked to indicate their experience and familiarity with UAS flying and the concepts of the UAS applications. The relationship between UAS experience and task performance (represented by the time to complete the tasks) is shown in Figure 71. The UAS experience (familiarity) has a very clear linear pattern with the performance of the participants. The experiment participants, who have more familiarity with UAS, completed the given tasks much earlier than those with little or average UAS experience, regardless of age or gender. Age also has a clear relationship with UAS performance (as shown in Figure 72); however, there are still challenges with the size of the sample. It was very difficult to find and recruit anyone with any UAS flight experience in GDOT.

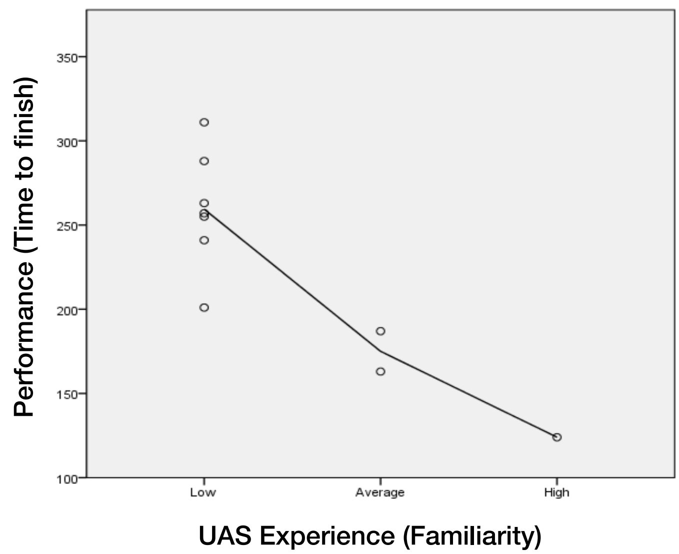


Figure 71 – Task Performance and UAS Experience

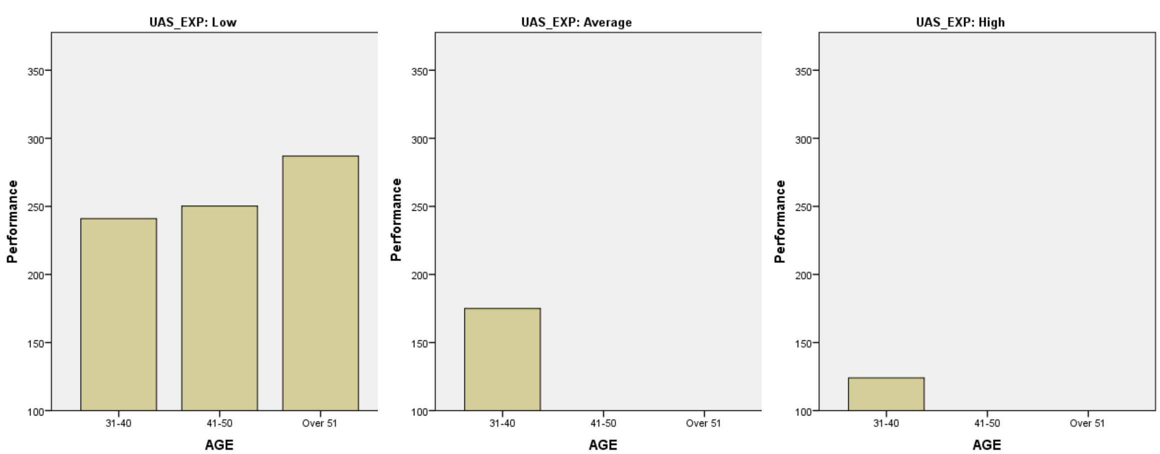


Figure 72 – Task Performance and Age of User (by UAS Experience)

7.2.4.2 Work Experience

The demographic information of this study supports the relationship between age and work experience. The participants with more work experience had lower performance compared to the participants with less work experience. The result for the age group of 41-50 differed from the results of other age groups (as shown in Figure 73). On the same work experience level, the older group needed significantly more time to finish than the younger group. This implies that the work experience of participants does not have a strong effect on the performance. In addition, there is no relationship between work experience and performance in this controlled environment.

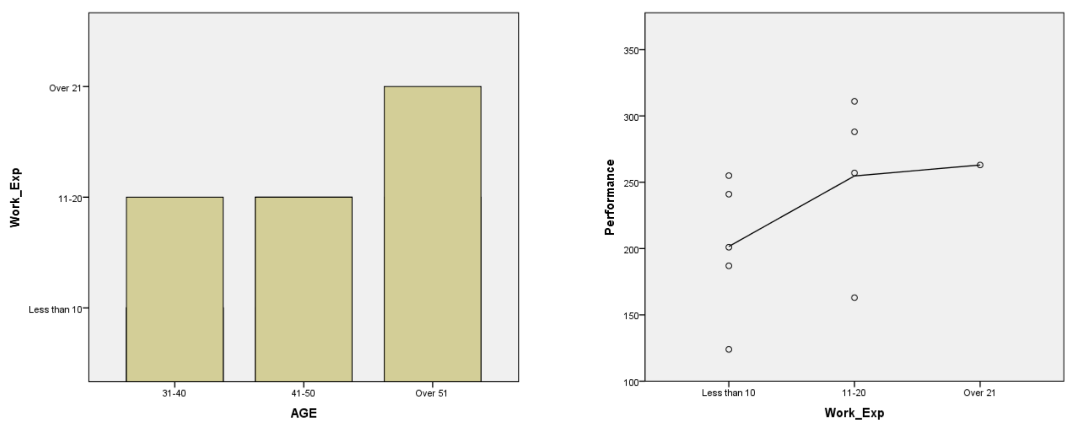


Figure 73 – Work Experience and Age (Left) & Task Performance and Work Experience (Right)

7.2.4.3 Implications for UAS Uses in Construction

The result of the Theme 2 analysis is summarized in Table 39 below. It is obvious that UAS experience affected the performance in the UAS operation. However, the work experience was not clearly related to the performance. The age of the operators had a negative relationship with the time taken to complete the tasks. The PIC should have a high level of familiarity with UAS, or more UAS experience, to perform better in the construction and infrastructure environment. Since the work experience is not closely related to the task performance, it is not necessary for the PIC of the UAS operational team to be construction/infrastructure management-related. Therefore, the related public or private sectors do not need to hire a PIC with simultaneous significant construction work experience or knowledge and UAS experience. They could set up an independent division for UAS, or sign a contract with a third-party (e.g. UAS flight operators) for their tasks. In this case, the field managers (e.g. the PE or CM) should collaborate with the PIC from the outside as an operational team. They could provide the perspective of the construction/infrastructure work sequence, the objectives to be inspected, or the point of interests.

Table 39 – Result of Thematic Analysis (Theme 2)

Theme 2 Element	Result
UAS Experience (Familiarity)	▪ The UAS experience is very clearly related to the performance of the UAS operation. ▪ The age is also clearly related to the performance. ▪ The gender is not related to the performance.
Work Experience	▪ The work experience is naturally related to the age of the workers. ▪ The age is related to the performance of the UAS operation, but does not have strong effects on the performance.

7.2.5 Theme 3. To what extent does user experience have an impact on the human operator's cognitive performance?

The main goal of Theme 3 is to clarify the pattern between the participants' experience and the cognitive abilities of the operators. The narrative analysis describes the relationship between experience and the cognitive capabilities of the participants. This theme can be discussed in two main parts: (1) UAS experience, and (2) work experience. The following section describes the result of the thematic and narrative analyses with the evidence, as well as further implications for using UAS in the construction environment.

7.2.5.1 UAS Experience (Familiarity)

The UAS experience of the participants has a linear relationship with the SA and MWL scores in Figure 74-a. This suggests that the operators with more UAS experience have more SA capabilities. Surprisingly, the person may have higher MWL when operating the UAS. The patterns between UAS experience and cognitive components are very clear. The AD and UAS experience is related (negative linear relationship), and the others (SD and US) are also very related to UAS familiarity (positive linear relationship).

7.2.5.2 Work Experience

As work experience is related to the age of the participants, it can be said that work experience can have a negative linear relationship with SA capabilities. However, it did not show any pattern with the MWL capabilities in Figure 74-b. Between the age-based groups, the SA or MWL scores of the participants between 31 and 40 years of age were relatively higher than in the other two groups. However, it is very difficult to clarify the constant patterns or relationships between the SA or MWL scores and the work experience within age-controlled groups. The AD and work experience of the participants were positively related; however, the US was negatively related to work experience. The AS did not show any meaningful pattern with work experience.

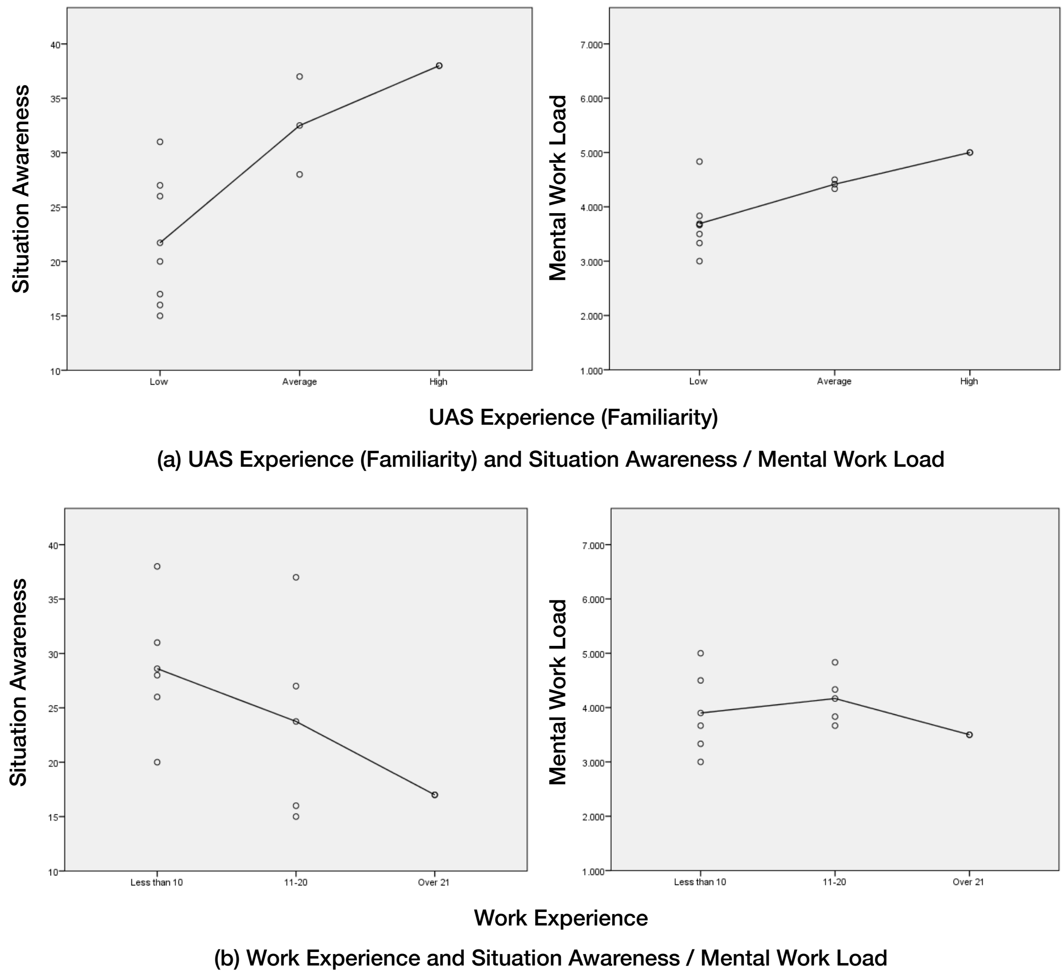


Figure 74 – User Experience and Cognitive Performance

7.2.5.3 <u>Implications for UAS Uses in Construction</u>

The result of the Theme 3 analysis is summarized in Table 40 below. The UAS experience very clearly affected the performance of the UAS operation. However, work experience was not clearly related to performance. The age of the operators had a negative relationship with the time taken to complete the tasks. The most interesting relationship in Theme 3 is between the MWL and the UAS experience. This study revealed that a person who is more familiar with UAS performs better, but performance was not related to the MWL according to Theme 1. However, from the result of the analysis in Theme 3, the MWL and UAS familiarity have a positive relationship. This may suggest that the operator requires a certain level of MWL to perform better. In other words, a certain amount of MWL can help to obtain better performance in the construction environment. Since the construction and infrastructure environment is very complicated and dynamic, the UAS PIC would have, or would require more MWL. Based on this implication, the PIC's work experience in the construction and infrastructure environment cannot be ignored, due to the familiarity with the work sequence, safety issues, and all other considerations on the jobsite. Otherwise collaboration of the UAS PIC and the PM is inevitable for UAS-integrated construction or infrastructure inspections.

Table 40 – Result of Thematic Analysis (Theme 3)

	Situation Awareness	**Mental Work Load**
UAS Experience (Familiarity)	▪ Significant positive relationship ▪ AD is negatively related ▪ AS and US are positively related	▪ Significant positive pattern
Work Experience	▪ AD is positively related ▪ US is negatively related ▪ Related to SA, but not strongly	▪ Not related to MWL

7.3 Summary of Thematic Analysis

During the field experiment, a total of ten participants practiced UAS flights to conduct a series of tasks, including inspecting the construction site environment and taking a picture of it. They were asked about their cognitive capacities and subjective performance in terms of SA and MWL. Three themes were observed from the results of the field experiment and the evaluation of cognitive abilities. Based on the thematic analysis from observing and analyzing the patterns between variables, cognitive and human-centric considerations were presented. Figure 75 summarizes and illustrates the relationships between the cognitive considerations. Moreover, the implications were also disseminated for each theme. The following section will discuss further research and practical implications based on the result of this study.

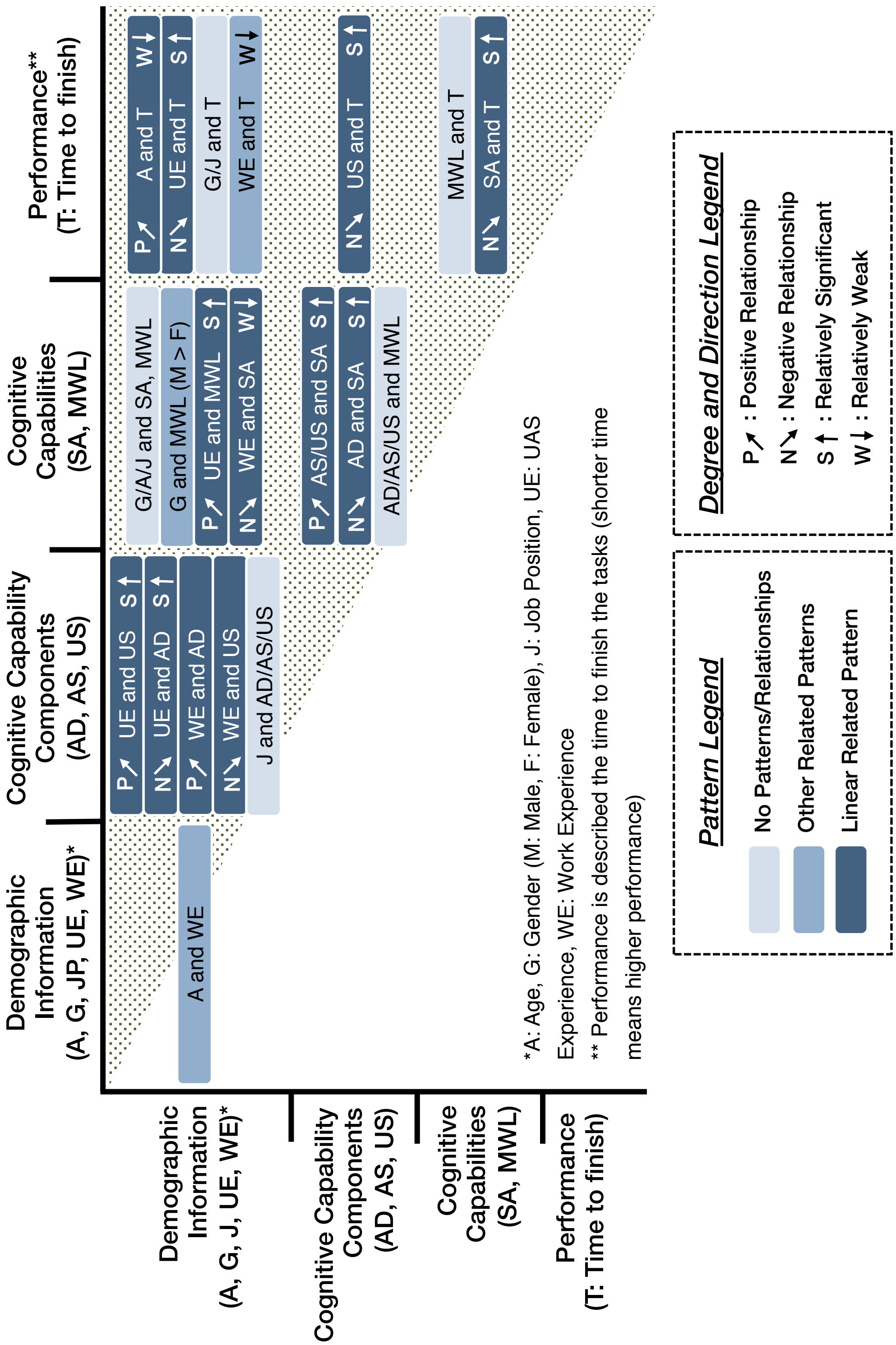


Figure 75 – Summary of Human Performance Analysis and Implication

CHAPTER 8. PROPOSED MULTI-LAYERED PERFORMANCE ANALYSIS (MPA) METHOD

The main goal of this dissertation is to transform the research paradigm from a technology-centric method to a method that addresses both human performance and technology's performance. This conceptual research methodology aims at investigating the information requirements to use a human-integrated technology application (HTA) and evaluate the performance of the HTA as well as the performance of the human operator when the technology is integrated.

This chapter describes how the findings of each step in this method can be linked and interact with each other based on the experimental studies and the findings in the dissertation. In addition, this chapter exploits a multi-layered performance analysis (MPA) method, which demonstrates different layers of performances, including human task performance and technology performance based on performance factors.

The MPA method aims to (1) define the key decision-makers of the technology operation; (2) identify the role and goal of each decision-maker, as well as the common goals of their task environments; (3) identify how they can interact to achieve their common task goals; (4) identify the important factors affecting the technology implementation; and (5) evaluate the value of the technology as well as the performance of the human operator.

8.1 Interaction between the main findings in This Study

This dissertation presented an overall process to investigate how a HTA, particularly an unmanned aircraft system (UAS) can be integrated into the construction task environment. This study identified the information requirements for the integration of UAS in the construction environment, developed a field-testing protocol and experiment design, evaluated the performance of the UAS integration based on the identified factors, and analyzed the human operator of the UAS operation. Figure 76 shows how the findings of each study in this dissertation interact with each other as a conceptual human-technology combined method.

First, an information requirement analysis was conducted by means of a focus group (FG) interview; this provided information on the current method of construction and infrastructure management as well as on potential tasks that could be integrated with the UAS. The current method included the workflow, resources and decision-makers. This result can interact with the goal-driven task analysis (GDTA) to identify the key decision-makers, the nature of their knowledge including goals, and situation awareness (SA) requirements. Based on the identified key decision-makers from the FG interview and the GDTA, the goal-hierarchy model (GHM) and the SA requirements model (SARM) were developed. The model of key decision-makers' interaction developed in Chapter 4.3 can express how they interact to achieve the goals within technology-integrated task environments. The GHM and the SARM can provide the nature of the goals and the SA requirements of the human operators within technology-integrated task environments. Based on the identified potential tasks from the FG interview, the field-testing protocol was developed. Test-bed environments aligned with the potential tasks identified from the FG interview was recommended by the Georgia Department of Transportation (GDOT).

Second, the developed protocol was executed during field-testing. The developed protocol encompasses the ground control station (GCS) setup, equipment setup and inspection, pre-flight meeting, flight mission development, and UAS flight data collection. This protocol aimed to propose the UAS-integrated workflow. In addition, 2D images were collected during the UAS flights at the different test-bed environments. The collected 2D data can be used for generating 3D data, such as point cloud, orthomosaic, and a digital elevation model (DEM). The 3D data were used for de-briefing and a user-demo session for UAS performance analysis in terms of the effectiveness of the UAS. The second group interview during the field-testing session was conducted during the workshop with GDOT professionals. This interview contributed to defining the performance factors and considerations affecting UAS integration into the construction environment. The findings from this interview were used for the third interview and the survey questionnaire to identify the relative importance of the identified factors. The result of the goal-directed task analysis on the information requirement analysis can be linked with the design of participatory user field-experiment. Another field activity in this study was to evaluate the human operators' task and cognitive performance, including SA and the mental work load (MWL), as well as to analyze the patterns between a set of data, such as task performance, cognitive performance, and user experience.

Third, the processed 3D data were used to provide perception and experience to the interview participants from the GDOT. After the de-briefing and demo session, the participants were asked to indicate the importance of various factors, and the effectiveness of the UAS integration into the construction environment. The effectiveness of the UAS integration was evaluated based on the users' perception. The participants, who would be potential users, evaluated the anticipated performance of each critical factor that could be integrated into the UAS workflow. The results of the effectiveness analysis can be referred to for the development of user guidelines for potential practitioners.

Lastly, the result of the participatory user field-experiment evaluated the human operators' performance as well as implied the patterns among the human operators' task performance, cognitive performance, and experiences. Based on the result of the thematic analysis potential implications were identified, for example the requirement for SA training of UAS operators in the construction environment to increase task performance and decrease mistakes. Industry practitioners can also consider the human operators and team composition for UAS operations within their task environments.

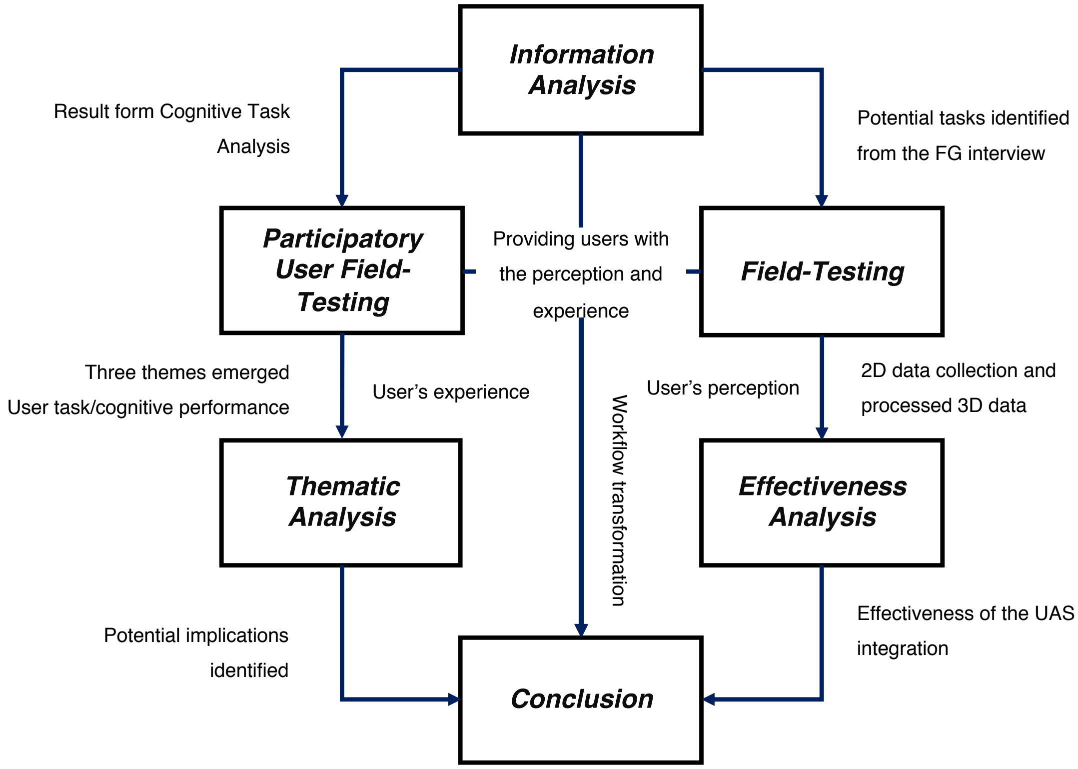


Figure 76 – Interaction of Findings

8.2 Multi-layered Performance Analysis (MPA) Method

Based on the research frameworks to investigate the UAS integration into the construction domain, the MPA method can be standardized to implement any type of HTA integration in any domain, such as manufacturing, infrastructure management, accident responses or even the military, in addition to the construction environments. Figure 77 describes the standardized MTA method.

The MTA method consists of three research frameworks and two different performance layers that investigate technology implementation and human performance respectively. As the first step of this proposed method, an information requirement analysis should be conducted to identify the information needs for the different performance layers. The finding of the first research framework can interact with the second framework layer in order to develop conceptual technology applications as well as to identify the human cognitive information to design the experiment.

The first level of technology performance can develop the case study or field-testing protocol. Based on the result of the first step, the conceptual technology and workflow integrated with the application can be developed. Based on the task environments, two different methods (subjective vs. objective measurement methods) can be executed to evaluate the performance of the technology applications. The subjective method is a user-perceived performance measurement method based on the survey questionnaire adopted to this dissertation. The objective method is the comparison between controlled environments. On the second level of human performance, a participatory user experiment can be conducted to provide the participants with experience-based insights into how technology can accomplish the tasks in their work environment. In addition, the researcher can evaluate the human operators' task and cognitive performance based on the time to finish the given tasks or the number of human errors during task performance.

Based on the second layer of the research framework, the third layer can be executed to propose the workflow integrating the technology, the value of the technology application, and human task and cognitive performance. Based on the result of this research methodology, academic researchers can provide a better understanding of the information requirements for HTA users, document the value of the HTA, and evaluate the performance of the human operators. Finally, industry practitioners who are the potential users, for example DOT, general or sub-contractors, or the Federal Highway Administration (FHWA) for the construction domain, can develop user guidelines or policies for HTA users.

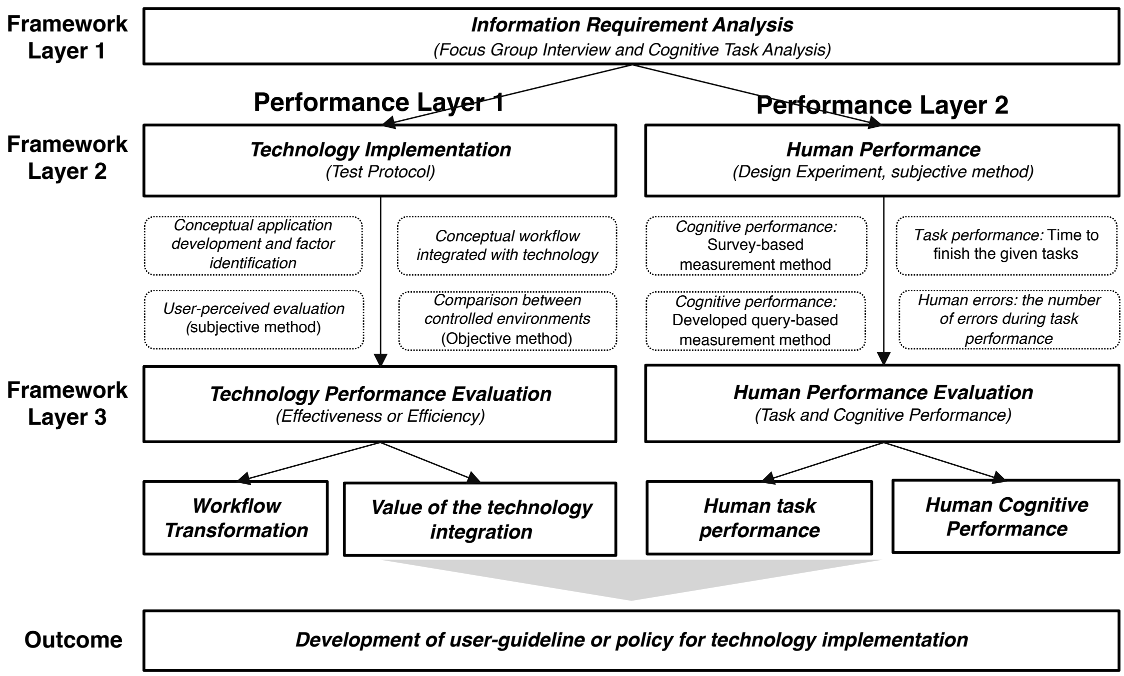


Figure 77 – Multi-layered Performance Analysis Method

8.3 Implementation of MPA Method

The MPA method can address the technology performance as well as the performance of human operator of a HTA in a certain domain. This method can be implemented to study various human-integrated technologies such as UAS, virtual reality (VR), and wearable computing devices. The main targeted task environments can be infrastructure management, construction management, manufacturing processes, disaster responses, or other domains. This method can be also combined with statistical analysis depending on the number of samples. With quantitative evidence, future studies will be able to find more reliable and significant results. The main limitation of the MPA method is that it is very challenging to define any relationship or impact between the performance of the human operators and the technology. In addition, the overall performance or work productivity measurement is outside the scope of this method.

To overcome this problem or improve the method, future studies are needed to investigate as follows:

1) how technology and humans can interact with each other;
2) how human operators can improve their performance based on their experience while using technology;
3) how the level of automation of technologies can help to improve human performance; and
4) how the integration of technology and human operators can improve work productivity.

CHAPTER 9. CONCLUSION AND SUMMARY

The construction and civil infrastructure industry integrates advanced technologies such as unmanned aircraft system (UAS), virtual reality (VR), augmented reality (AR), and other mobile applications into its management tasks. The goal of this dissertation is to provide a better understanding and assessment of the effectiveness of UAS integration or adoption based on user perceptions and experience analysis and to recommend a field-test-based UAS-integrated workflow. In addition, this study provides the implications to human performance when using the UAS in the construction and infrastructure environment.

The specific objectives were as following:

1) To identify the requirements to adopt the UAS technology into the construction management task environment. As for the first contribution of this research, the information analysis based on the focus group (FG) interview and goal-directed task analysis (GDTA) can strengthen and broaden knowledge about the UAS for use in the architecture, engineering, and construction (AEC) domain.
2) To evaluate the significant performance factors and their effectiveness on the transformed workflow. As for the second contribution of this research, this process can document the value of the UAS application in terms of construction progress monitoring and measurement.
3) To investigate human operator's tasks and cognitive performance. As for the third contribution of this study, this investigation can evaluate the associated human performance and recommend further implications and study ideas in the construction and infrastructure environment.

This chapter discusses and summarizes the limitations, research process, implications, and recommendations for future study. Finally, the contribution of this study will be demonstrated.

9.1 Overview and Discussion

9.1.1 Limitations of This Study

This study has several challenges, including the following: 1) a small sample for the interview and user experiment; 2) no comparison between same controlled environment for the effectiveness analysis; and 3) no evaluation of the cost performance.

This research study mainly employed qualitative-based research methods because of the foremost challenge of the small data sample number. To overcome this issue, this study recruited potential and actual UAS end users who have significant work experience. However, it still requires additional samples to quantify the human performance data and to obtain more reliable results about the performance of the UAS integration. The effectiveness analysis has been conducted based on the responses of the interview participants. They indicated the effectiveness and the efficiency of the UAS integration according to their field-testing experience and their perceptions from the debriefing and the demo. It was not impossible to compare the work environments, task performance, or performance factors between the UAS-integrated case and the traditional method in the field test-bed environments. Cost analysis is a very complicated issue in this study, because different divisions in Georgia Department of Transportation (GDOT) have varying cost control systems, payment systems, and wages. In addition, the cost of the UAS platform and the 3D data processing software ranges from hundreds to thousands of dollars.

More specifically, collecting the team performance data, in regard to factors such as team composition and communication, requires a combination of the UAS field-testing protocol and the user experiment. Therefore, the effectiveness of the team-related factors has been assessed by the survey questionnaire based on the user experience. In further research, the organizational performance should be investigated when collecting data by using th e UAS in the construction environment. For the human task performance, human error has not been evaluated in the participatory user field experiment. The total time to finish the task was recorded and considered as the task performance of the human operator. Human error should be considered and investigated in further studies.

9.1.2 Research Process

This research process consists of four main chapters to achieve the main objectives of the study. In the first research framework, an information-requirement analysis was conducted to identify the UAS-integrated potential tasks, the key decision makers for the UAS operation, and the nature of their knowledge by employing the FG interview and a cognitive task analysis. In the second framework, a field-testing data collection described the field-testing protocol and the outcomes of the field testing. A second group interview was also conducted to identify the changes in user perceptions and performance factors in terms of using the UAS in the construction environment. The main findings of the third study are the important factors affecting the UAS integration and the effectiveness of the

UAS integration based on the identified factors. This study also demonstrated that the field-testing-based workflow can be implemented into the current work procedure. Furthermore, it basically employed the qualitative-based user interviews and conducted the third group interviews to evaluate the effectiveness. The assessment results from based on the subjective user perceptions and experience. In addition, the last framework investigated and measured the user task performance and cognitive performance and capabilities, such as situation awareness (SA) and mental work load (MWL). A field experiment was provided for the potential end users. They deployed the UAS to conduct a series of tasks in the construction environments. The direct and subjective measurement, for example, SA rating technique (SART) and NASA task load index (TLX) were utilized after the UAS flight. Based on the four research frameworks, the newly transformed workflow and the effectiveness and efficiency of the UAS integration are documented in this study.

9.1.3 Outcomes and Implications of This Study

The first outcome is the information requirements based on the FG interviews with GDOT industry professionals who have significant work experience. This provided a deeper understanding of the UAS operation, ranging from the required key decision makers, the nature of their goals, and their SA requirements to use the UAS in the construction progress-measurement task environment. In addition, the potential tasks that can be integrated with the UAS in the construction and infrastructure management fields are identified.

The second outcome is developing a workflow based on the UAS integration. This workflow includes the ground control station (GCS) and equipment setup and three-dimensional (3D) data processing step, which requires a longer time to process than the traditional method based on the user's estimation and field-testing result. However, this workflow has much more efficient data collection and analysis steps than the current manual-based method. This outcome implies that the UAS integration can have a significant impact on the visual data collection and analysis among the project stakeholders versus the current method. In addition, it also indicates that the proposed workflow can be developed as the UAS user's guideline, as well as a more detailed policy for the industry sector, such as for the DOT, the Federal Highway Administration (FHWA), or other commercial construction companies.

Third, a total of three group interviews and surveys assisted in collecting the user perspectives and perceptions about the UAS integration, as well as to evaluate the performance of the integration based on the factors in the task environment. This technique was not fully equipped to evaluate the factors' importance and the effectiveness of the UAS technology, because the sample was too small. However, the results of the interviews in this study would be able to function as the initial data to find out further quantitative evidence in this area. In addition, the participants can be regarded as representative of each group in the GDOT, and the results may be significant enough to apply the UAS to their task environment.

The fourth outcome consists of human performance implications based on the user experiment and thematic analysis. Because this study has a limited number of end users, the patterns and relationship between human task performance and cognitive performance, task performance and the experience of the operator, and cognitive performance and the experience of the operator could not be quantitatively analyzed based on the correlation coefficient or any other statistical analysis. However, the thematic analysis can reveal the patterns among the three components. Based on the analysis and its outcome, this study indicates a new research framework to evaluate the technology application's effectiveness.

The last outcome is developing the standardized research method to evaluate the performance of technology application as well as the performance of the human operator. In addition, this method can address the information requirements to integrate the technologies into various work environments. Based on this method, future researchers can investigate the required information to use the technology, the effectiveness of the technology application, and the performance of human operator. This will aim at providing better understanding of the human-integrated technology application (HTA) to use in the real task environment.

Table xx restates the main findings and answers of the research questions established in Chapter 1.3 (shown in Table 1).

Table 41 – Main Findings based on Research Questions and Objectives

	Research Questions	Research Objectives	Main Findings (***Approaches***)
1	What is the required information to integrate the UAS into the construction projects?	To obtain a better understanding of the information requirements and potential tasks to integrate the UAS into the construction environments	1. Common potential tasks (3D-model based inspection and measurement) 2. Key decision makers and their goals *(Focus Groups and Goal-Driven Task Analysis)*
2	What performance factors should be considered for the UAS integration?	To identify the performance factors affecting the effectiveness of the UAS integration into construction worksite	1. Team/human, safety, cost, hardware, usability, and time performance *(Field-testing and group interview and survey)*
3	How can the UAS integration transform the current workflow? Is the proposed UAS-integrated workflow effective/efficient to use?	To propose a UAS-integrated workflow for the construction projects	1.UAS-integrated workflow has about 30% time effectiveness (data collection and analysis have effectiveness) *(Field-testing, and group interview and survey)*
4	Which factors are important? Is the UAS integration in the construction environment effective in terms of the identified factors?	To identify the important factors and to document the value of the UAS integration into the construction domain	1.Safety (priority), data quality, human, and time *(user demo, debriefing, and user-perceived effectiveness analysis – interview and survey)*
5	What is the relationship between the task performance, experience, and cognitive performance? What are the implications?	To evaluate the human performance and to provide and recommend the potential implications of the UAS integration	1. A human operator who has high SA score/more UAS flight experience has better task performance *(Field experiment and thematic analysis)*

9.1.4 Recommendations for Future Studies

Based on the implications, this study disseminates five main recommendations for future studies in the AEC domain:

1) evaluation of the UAS team's or operator's performance, communication, and interaction (HRI concept) for the construction and infrastructure environment;
2) development of a human operator training system (can be leveraged with the technology application—for example, VR or AR);
3) evaluation of the cost and economic benefits of the UAS integration into the construction and infrastructure projects;
4) how can the experience of human operators improve their task performance in technology-integrated task environments, and how do they learn from their experience;
5) Acceptable range of the cognitive performance of human operators to use the UAS in safely and effectively
6) safety performance in terms of the UAS operators and the public during the UAS operation in the construction project worksite; and
7) improvement of the level of automation from the data collection, via 3D processing, analysis, and decision-making.

As a qualitative-based study, it will be able to contribute to generating further ideas and implications in terms of the UAS integration and applications in the construction domain based on both qualitative and quantitative evidence. The academic as well as practical contributions will be discussed in the following section.

9.2 Contributions

9.2.1 Contribution to the Body of Knowledge

First, the main contribution of this study is proposing and transforming the research paradigm from a technology-centric method to a human-and-technology-combined research method in any area, including in the construction and civil engineering domain. When a technological application is introduced and applied to a specific field, the academic researchers can refer to this method for exploring the information requirements, pertinent factors, effectiveness of UAS integration, and human performance.

Second, this study contributes to documenting the effectiveness and efficiency of the current workflow, as well as proposing a new workflow through the UAS integration into the construction and infrastructure industry. There is no evidence pertaining to how the UAS can transform the workflow or which benefits the technology can provide for the new workflow. This study provides a base on which to evaluate the benefits of UAS integration and to conduct further research in the construction domain.

Third, this study provides intensive subject matter on the UAS applications, the potential tasks, the decision makers and their goals, and the cognitive requirements for the specific task environment. Researchers can strengthen the body of knowledge surrounding the UAS applications. They can also broaden their research motivations from the technological applications to psychological concepts such as HRI and human performance.

9.2.2 Contribution to the Body of Practice

This research can be applied to the DOT. The main target of this study is to benefit the potential practitioners in the construction and infrastructure industry. The first contribution to the industry is providing the transformed work procedure to the workers. Thus, they can further develop user guidelines and adjust the new workflow in their task environment. The proposed workflow in this study has been developed based on the field-testing processes and results. The GDOT has been developing its department policy to integrate the UAS based on the results of this study.

The second contribution is providing the industry professionals with better insights and experiences through the user experiment. Because the UAS was deployed into the actual construction jobsite, the workers will receive better perspectives on how the UAS technology can meet their task goals, as well as on which issues they must consider when using the UAS in the work environment.

9.3 Conclusion and Summary

This research study resulted in the development of a research method addressing the performance of technology and human operator. Moreover, this study includes identifying information requirements, exploring technology applications, and evaluating performance considering various human-performance factors. Based on this study's research method, it has identified the nature of the users' knowledge and its potential applications, the important factors, and the workflow that is required for the construction project personnel to integrate the UAS technology into their task environment. Based on the analysis of the collected data from the industry representatives, the following has been concluded:

1) 3D-data has significant potential to be utilized in construction progress monitoring and measurement, bridge structure inspection, and airport runway and obstruction inspection;
2) For the construction progress check and site monitoring, the infrared images do not provide any significant benefits;
3) 3D-data processed from 2D images collected by the UAS contributes to significant effectiveness and efficiency in the stakeholder's communication, analysis, and decision-making, as well as in reporting and documentation;
4) UAS integration supplies much more significant effectiveness and efficiency than the traditional method for collecting data;
5) GCS and equipment setup and removal in the new workflow require more time; however, the total estimated time when the UAS is used is more efficient. In

addition, the industry professional implies that the data quality, analysis, and decision-making are considered much more than the total operational time; and

6) The UAS human operator should have training to improve his or her task performance and cognitive performance (SA); nonetheless, the MWL does not have a significant impact on the operator’s task performance during the UAS operation.

APPENDIX A. IRB AND DATA COLLECTION FORMS

A.1 IRB Approval Form

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

A.2 IRB 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

A.3 Interview Registration Form

School of Building Construction
School of Aerospace Engineering

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

Interview Registration Form

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

A.4 Focus Group Data Collection Forms

School of Building Construction
School of Aerospace Engineering

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

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

1 | Page

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

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:

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

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)

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

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)?

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

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:

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

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?

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

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:

A.5 Group Interview (During Field-Testing) Data Collection Form

School of Building Construction
School of Aerospace Engineering

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

GDOT UAS Research Project Seminar Brainstorming

Date of the Session: Tuesday. July 18th 2017

Dear Seminar Participant:

This document includes several open-ended questions that will be used during the brainstorming session on guidelines, policies and procedures to be developed as part of the ongoing research on UAS integration in GDOT operations. This document consists of two main sections: (1) UAS integration; and (2) UAS policies and procedures. During the seminar, you saw examples of initial products from the field test, all attendees will have the opportunity to participate in the brainstorming sessions to discuss the two topics considering what was presented.

Conversations during the brainstorming session will be recorded to compliment the written comments that you may provide in this document. Participation in the discussion and responding to questions requires approximately 20-30 minutes of your time. There is no compensation offered for participating and your participation does not carry any risks other than what would be found in everyday tasks. In order to ensure that all information will remain confidential, please do not include your name.

Thank you for taking the time to contribute to this research. The data collected will provide useful information regarding implementation of UAS in GDOT operations. Completion of the questionnaire will indicate your willingness to participate in this study.

Sincerely,

Javier Irizarry, Ph.D. PE., Associate Professor, Georgia Institute of Technology

javier.irizarry@coa.gatech.edu

Sungjin Kim, Ph.D. Student, Georgia Institute of Technology

sungjinkim@gatech.edu

School of Building Construction
School of Aerospace Engineering

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

Demographic Questions

Participant ID: ___________

Gender:
☐ Male ☐ Female

Age:
☐ under 30 ☐ 31 – 40 ☐ 41– 50 ☐ over 51

What is the job title of your current position?
____

Years of experience in current position:
☐ under 10 years ☐ 11 – 20 years ☐ 21 – 25 years ☐ over 26 years

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

Do you have experience with flying 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

Your familiarity with UAS flight (Professionally or as hobby):

☐ Yes

If yes, Level of familiarity:

☐ High level (regular use)

☐ Average level (occasional use)

☐ Low level (rare use)

☐ No

School of Building Construction
School of Aerospace Engineering

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

1. UAS integrations

This section will ask you how you think the UAS integrated into your GDOT group tasks.

1.1. Which platform would be more appropriate to be implemented into your tasks?

☐ Fixed-wing ☐ Multi-rotor ☐ Both

1.2. Discuss why the platform you selected in 1.1. is more suitable to your tasks.

____

____

1.3. Based on your opinion in 1.2., which capabilities of the sensors (e.g., Infrared Camera, Lidar, etc.) equipped on the UAS platform are required to use the UAS for your tasks?

____

____

____

____

1.4. Based on your opinion in 1.2., which capabilities of the sensors (e.g., Infrared Camera, Lidar, etc.) equipped on the UAS platform are recommended to use the UAS for your tasks?

____

____

____

____

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

1.5. Indicate if existing commercial software or new custom software for GDOT (e.g., photogrammetry, documentation, etc.) could be used to process or document the data collected by the UAS for your tasks?

1 (Not required)	2	3	4	5 (Highly required)

If required, please list possible programs:

____

____

____

____

1.7. Discuss how the integration of the UAS can change the planning or process (e.g., insurance, liability, documentation process) of your current tasks. Which important issues must be considered when the changes are made?

1 (Rarely changed)	2	3	4	5 (Significantly changed)

____

____

____

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

2. UAS Policy and Procedures

This section will discuss how policies or legal procedures could apply to GDOT operations involving the UAS.

2.1. Need for permission to use the UAS for your task (department policy, FAA regulation and local law)

____

____

____

2.2. The following roles may be required to operate the UAS: (1) Pilot in Command, (2) Person Manipulating Control, (3) Visual Observer, and (4) Project Engineer or Inspector.

Read all roles of the team members and describe your understanding of training requirements for each. Note that one individual can perform multiple roles.

- Pilot in command (PIC)*: <u>Responsible for the UAS operation and safety during the flight</u>

____

____

- Person Manipulating Control (PMC)*: <u>Responsible for assisting the PIC in terms of hardware (e.g., sensors or platform) as well as flight operation (e.g., battery issues or flight planning)</u>

____

____

***** A PIC and a PMC could be a same person

- Visual Observer (VO): Responsible for Visual Line of Sight (VLOS) of the platform during flight

____

____

- Project Engineer (PE) or Inspector: Responsible for project management or inspection

____

____

2.3. Use of UAS pre-flight checklist (hardware and software)

____

____

____

2.4. Ground Control Station (GCS) setup process

____

____

____

2.5. Team communication procedure (during UAS flight)

____

____

____

2.6. UAS-based data use (e.g., condition report, measurement, quantification, or progress report)

____

____

____

2.7. UAS-based data management (e.g., storage, maintenance, archival, or disposal)

____

____

____

2.8. Privacy issues to be considered

____

____

____

2.9. Response in case of UAS emergency (UAS failure, accident, or external intervention)

____

____

____

2.10. Insurance for UAS operations and liability for damage in case of accident

____

____

____

2.11. If a third party performs the UAS-based data collection, discuss technical, legal, insurance, certification, and license requirements.

____

____

____

____

____

____

A.6 Field Experiment Data Collection Form

School of Building Construction
School of Aerospace Engineering

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

Field-Experiment Post Subjective Survey

(UAS Situation Awareness Measurement)

Date of the Session: Tuesday. July 18th 2017

Dear Seminar Participant:

Situation Awareness (SA) is a concept applied to work tasks and relates to the awareness an individual has of a his/her environment when performing a task. It is an operator's dynamic understanding of "What is going on" when operating the UAS in their GDOT work environments of the areas included in this study: (1) Construction; (2) Bridge Maintenance; and (3) Intermodal, as well as other operations with UAS integrations.

During the short hands-on practice with UAS, you may or may not aware of what is going on during your task performance. This questionnaire is a self-rating technique, which elicits your subjective opinion. This survey has 10 questions with scale-based responses. The scale is a seven-point rating scale (1=low, 7 = high) based on your perceived performance of the task under analysis.

Completing the survey requires less than 10 minutes of your time. There is no compensation offered for participating and your participation does not carry any risks other than what would be found in everyday tasks. In order to ensure that all information will remain confidential, please do not include your name. If you did the hands-on practice and choose to participate, please answer all questions to the best of your abilities.

Thanks you for taking the time to contribute to this research. The data collected will provide useful information regarding implementation of UAS in GDOT operations. Completion of the questionnaire will indicate your willingness to participate in this study.

Sincerely,

Sungjin Kim, Ph.D. Student, Georgia Institute of Technology

sungjinkim@gatech.edu

Javier Irizarry, Ph.D. PE., Associate Professor, Georgia Institute of Technology

javier.irizarry@coa.gatech.edu

School of Building Construction
School of Aerospace Engineering

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

Participant ID: ________________

Situation Awareness Rating Technique (SART)

1. Attentional Demand Test

Attentional Demand has three elements: (1) Instability of Situation, (2) Variability of Situation; and (3) Complexity of Situation. Each of elements has specific definition. The "Instability of situation" means the likeliness of situation to change suddenly. The "Variability of situation" means the number of variables that require attention. The "complexity of situation" means the degree of complication of situation

Domains	Elements	Indicates						
		1 (Low)	2	3	4	5	6	7 (High)
Attentional Demand	Instability of Situation							
	Variability of Situation							
	Complexity of Situation							

2. Attentional Supply

Attentional supply has four elements: (1) Arousal, (2) Spare Mental Capacity; (3) Concentration; and (4) Division of Attention. Each of elements has specific definition. The "Arousal" means the degree that one is ready for activity. The "Spare Mental Capacity" means that amount of mental ability available for new variables. The "Concentration" means that the degree that one's thoughts are brought to bear on the situation. Lastly, "Division of Attention" means that the amount of division of attention in the situation.

Domains	Elements	Indicates						
		1 (Low)	2	3	4	5	6	7 (High)
Attentional Supply	Arousal							
	Spare Mental Capacity							
	Concentration							
	Division of Attention							

3. Understanding

Understanding has three elements: (1) Information Quantity, (2) Information Quality; and (3) Familiarity. Each of elements has specific definition. The "Information Quantity" means the amount of knowledge received and understand. The "Information Quality" means the degree of goodness of value of knowledge communicated. The "Familiarity" means the degree of acquaintance with situation experience.

Domains	Elements	Indicates						
		1 (Low)	2	3	4	5	6	7 (High)
Understanding	Information Quantity							
	Information Quality							
	Familiarity							

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

NASA's Task Load Index

The NASA Task Load Index (TLX) is a multi-dimensional subjective workload rating technique. The workload means that the cost incurred by human operators to achieve a specific level of performance. All dimensions for each element will be rated on 1-7 scale (1 low, 7 high).

Elements	Questions	Indicates						
		1	2	3	4	5	6	7
Mental Demand	How much mental and perceptual activity (thinking, deciding, calculating, remembering, looking, searching, etc) was required? Was the task easy or demanding, simple or complex, exacting or forgiving?							
Physical Demand	How much physical activity was required (Pushing, Pulling, controlling, activating, etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?							
Temporal Demand	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?							
Performance	How successful do you think you were in accomplishing the goals of the task set by yourself? How satisfied wer you with your performance in accomplishing these goals?							
Effort	How hard did you have to work (mentally or physically) to accomplish your level of performance?							
Frustration Level	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?							

A.6 De-briefing Post Interview Data Collection Form

School of Building Construction
School of Aerospace Engineering

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

– Post Interview Session (Debriefing Meeting) –

1. Demographic Questions

Gender:
☐ Male ☐ Female

Age:
☐ under 30 ☐ 31 – 40 ☐ 41– 50 ☐ over 51
What is the job title of your current position?

____

Years of experience in current position:
☐ under 10 years ☐ 11 – 20 years ☐ over 21 years

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

Your familiarity with UAS flight (Professionally or as hobby):
☐ Yes
  If yes, Level of familiarity:
  ☐ High level (regular use)
  ☐ Average level (occasional use)
  ☐ Low level (rare use)
☐ No

Your familiarity with the 3D mapping and photogrammetry
☐ Yes
  If yes, Level of familiarity:
  ☐ High level (regular use)
  ☐ Average level (occasional use)
  ☐ Low level (rare use)
☐ No

1

2. UAS Integration in your task environment

What would be the appropriate UAS platform for your group's tasks?
☐ Fixed-Wing ☐ Multi-Rotor ☐ Both

Which UAS capabilities and sensors would be required for your tasks?

____

____

Which attributes are more significant when you consider UAS application to your task environment? Please indicate the significance of each attribute (1 = not significant, 5 = very significant)

Attributes	Significance				
Effective Operational Cost	1	2	3	4	5
Effective Processing time taken to perform the tasks (To collect, process, analyze 2D/3D data)	1	2	3	4	5
Quality of Visual Assets (2D) (To inspect the checklist items)	1	2	3	4	5
Accuracy of Visual Assets (3D) (For measurement or quantification)	1	2	3	4	5
Usability (Ease of use) (To develop flight plan, control the platform, and process and organize visual assets)	1	2	3	4	5
UAS Platform Capability (i.e. Camera, Sensors, and other capabilities)	1	2	3	4	5
Hiring a 3rd party provider (e.g. UAS Photographer, consultant)	1	2	3	4	5
Safety (public and operational)	1	2	3	4	5
Risk Management (Liability)	1	2	3	4	5
UAS Team Composition and Training (e.g. Pilot, Visual Observer, and Project Engineer/Inspector)	1	2	3	4	5
Capability of the UAS Pilot (e.g. Flight Experience, Situation Awareness, or Mental Work Load)	1	2	3	4	5
Communication between project stakeholders	1	2	3	4	5
Others:	1	2	3	4	5
a.	1	2	3	4	5
b.	1	2	3	4	5
c.	1	2	3	4	5

3. Effectiveness of UAS Integration and Visual Assets

Based on what you have seen, you will be asked to indicate the effectiveness of UAS integration based on the above attributes in section 2.

3.1. Quality and Accuracy of Visual Assets (2D and 3D)

The data collected by UAS is mainly 2D images or videos. For this debriefing meeting and post interview session, the 2D data set includes (1) still images, (2) infrared images and (3) video. The 3D data processed through the photogrammetry (using Pix4D) includes (1) point cloud, (2) digital elevation model and (3) orthomosaic. This section asks the participants if they can extract the information based on the checklist from the 2D images and if they can measure and survey the points of interests on the 3D models.

Which type of 2D images would you prefer to use for your task environment? (Select all applicable)
☐ Still Images ☐ Infrared Images ☐ videography

Based on what you have seen, can you see the listed checklist items on the visual assets? How effective is the visual asset for extracting the information?
Please indicate how effective each 2D data is. (1 = not effective, 5 = significantly effective)

Checklist Items	Effectiveness		
	Still images	Infrared images	Video
For construction inspection:			
Construction progress monitoring			
Overall construction site condition			
Progress measurement/quantification			
Others:			

Was there an unexpected application for 2D images in your task environment? If so, please describe how the UAS could be used.

____

____

Based on what you have seen, what do you think about the quality of 2D images?
Please indicate how effective each 2D image is (1= very low, 5 = very high).

Checklist Items	Quality				
For construction inspection:	1	2	3	4	5
Construction progress monitoring	1	2	3	4	5
Overall construction site condition	1	2	3	4	5
Progress measurement/quantification	1	2	3	4	5
Others:	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5

Based on what you have seen, which 2D image view would be more effective for extracting the information? (1 = not effective, 5 = significantly effective)

Checklist Items	Image view type		
	Close Up[1)]	**Medium Altitude View[2)]**	**Overall View[3)]**
For construction inspection:			
Construction progress monitoring			
Overall construction site condition			
Progress measurement/quantification			
Others:			

1) Approach the points of interest on site for a close up view
2) Climb or descend to medium altitude and film points of interest. The flight altitude depends on the points of interest (always below 400ft per FAA)
3) Takeoff and climb to high altitude (below 400ft per FAA)

Which type of 3D models would you prefer to use for your tasks? (Check all applicable)
☐ Point Cloud ☐ digital elevation model (DEM) ☐ orthomosaic

Based on what you have seen, can you measure/inspect/quantify the listed checklist items on each 3D data? How effective is the each 3D data for extracting the information?
Please indicate how effective the 3D data is (1 = not effective 5 = significantly effective)

Checklist Items	Effectiveness				
For construction inspection:	1	2	3	4	5
Construction progress monitoring	1	2	3	4	5
Overall construction site condition	1	2	3	4	5
Progress measurement/quantification	1	2	3	4	5
Others:	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5

Was there an unexpected application for 3D data in your task environment? If so, please describe how the UAS could be used.

____

____

____

3.2. Effectiveness of the time to perform tasks

Please indicate which steps are required to do your tasks (manual observation vs. using UAS) and estimate how long it takes to complete each required step.

Steps (when applicable)	**Manual Observation (Not use UAS)**		**UAS Operation (Use UAS)**	
	Applicable (Yes/No)	Time (Hours)	Applicable (Yes/No)	Time (Hours)
Go to site				
Onsite meeting (pre data collection)				
Ground control station setup				
Ground Control Point (GCP) setup				
Data collection plan				
Flight mission plans development				
Prepare equipment (manual equipment as well as UAS)				
Equipment check (manual equipment as well as UAS)				
Data collection (inspection/monitoring) or UAS flight				
Data processing				
De-briefing meeting (on-site or off-site)				
GCP removal				
Ground control station removal				
Data analysis and decision-making				
Additional data collection (if needed)				
Data documentation (reporting)				
Others:				
Total Estimate	-		-	

Please indicate how effective is the performance time with the UAS (1 = not effective, 5 = very effective, compared with your manual observation method)

By Stage	**Effectiveness**				
Pre-flight stage (developing flight plan and set up the UAS)	1	2	3	4	5
UAS flight (collecting data)	1	2	3	4	5
Data process (transferring 2D from UAS and developing 3D)	1	2	3	4	5
Data analysis (debriefing, analyzing, and decision making)	1	2	3	4	5
Data documentation (reporting)	1	2	3	4	5
Overall Time	1	2	3	4	5

3.3. Usability of UAS and Visual Assets

Please rate the usability of the UAS in your task environment? (1 = very hard, 5 = very easy)

Step	Usability					Justify your rating
Pre-flight (developing flight plan and set up the UAS)	1	2	3	4	5	
UAS flight (collecting data)	1	2	3	4	5	
Data process (transferring 2D from UAS)	1	2	3	4	5	
Data process (processing 3D data)	1	2	3	4	5	
Data analysis (debriefing, analyzing, and making decision)	1	2	3	4	5	
Data documentation (reporting)	1	2	3	4	5	
Overall usability	1	2	3	4	5	

3.4. UAS Team Composition and Communication with Project Stakeholders

FAA Part 107 requires a certified Pilot-in-Command (PIC) to operate the UAS. For GDOT, how the requirement would be met?

❒ PART 107 pilots assigned to groups (e.g., Intermodal Group, Bridge Maintenance Group, or Construction Group)
❒ PART 107 pilots assigned to departments or districts (e.g., Aviation Department, Railway Department, or District)
❒ PART 107 pilots assigned to GDOT-wide UAS FLIGHT TEAM
❒ PART 107 pilots hired through 3rd party consultants

Do you think that the UAS and the visual assets (2D and 3D) contribute to improving communication between all project stakeholders (e.g., UAS PICs, coordinators, project engineers, managers, or inspectors) for decision-making? How effective is the UAS for improving communication during task performance? (1 = not effective, 5 = very effective)

Step	Effectiveness					Justify your rating
Pre-flight (developing flight plan and set up the UAS)	1	2	3	4	5	
UAS flight (collecting data)	1	2	3	4	5	
Data process (transferring 2D from UAS)	1	2	3	4	5	
Data process (processing 3D data)	1	2	3	4	5	
Data analysis (debriefing, analyzing, and making decision)	1	2	3	4	5	
Data documentation (reporting)	1	2	3	4	5	
Overall	1	2	3	4	5	

3.5. Safety and Risk (Liability)

Please indicate how effective is the UAS in improving the safety of your team during task performance? (1 = not effective, 5 = very effective)

Step	Effectiveness					Justify your rating
Pre-flight (developing flight plan and set up the UAS)	1	2	3	4	5	
UAS flight (collecting data)	1	2	3	4	5	
Data process (transferring 2D from UAS)	1	2	3	4	5	
Data process (processing 3D data)	1	2	3	4	5	
Data analysis (debriefing, analyzing, and making decision)	1	2	3	4	5	
Data documentation (reporting)	1	2	3	4	5	
Overall	1	2	3	4	5	

Please indicate how effective the UAS in improving the safety of the public (e.g., neighbors, traffic, or pedestrians) during task performance? (1 = not effective, 5 = very effective)

Step	Effectiveness					Justify your rating
Pre-flight (developing flight plan and set up the UAS)	1	2	3	4	5	
UAS flight (collecting data)	1	2	3	4	5	
Data process (transferring 2D from UAS)	1	2	3	4	5	
Data process (processing 3D data)	1	2	3	4	5	
Data analysis (debriefing, analyzing, and making decision)	1	2	3	4	5	
Data documentation (reporting)	1	2	3	4	5	
Overall	1	2	3	4	5	

REFERENCES

AASHTO. (2010). *AASHTO Bridge Element Inspection Guide Manual*

Armstrong, G., & Filge, C. (2016). *Building a Technology Advantage: Global Construction Survey 2016*. Retrieved from KPMG International:

Austin, R. (2011). *Unmanned aircraft systems: UAVS design, development and deployment* (Vol. 54): John Wiley & Sons.

Barfuss, S. L., Jensen, A., & Clemens, S. (2012). *Evaluation and development of unmanned aircraft (UAV) for UDOT needs*. Retrieved from Utah State Department of Transportation:

BCG. (2015). *2015 ECS Value Creators Report: Opportunities Aimd Uncertainty*. Retrieved from Boston Consulting Group:

BCG. (2016). *Shaping the Future of Construction a Breakthorugh in Mindset and Technology*. Retrieved from World Economic Forum:

BEA. (2017). *Gross Domestic Product by Industry: Third Quarter 2016*. Retrieved from Bureau of Economic Analysis:

Berlin, M., Gray, J., Thomaz, A. L., & Breazeal, C. (2006). *Perspective taking: An organizing principle for learning in human-robot interaction.* Paper presented at the AAAI.

Blinn, N., & Issa, R. R. A. (2016). *Feasibility Assessment of Unmanned Aircraft Systems for Construction Management Applications.* Paper presented at the Construction Research Congress 2016.

BLS. (2016). May 2015 National Occupational Employment and Wage Estimates

United States.   Retrieved from https://www.bls.gov/oes/current/oes_nat.htm

Bolstad, C. A., Cuevas, H., Gonzalez, C., & Schneider, M. (2005). *Modeling shared situation awareness.* Paper presented at the Proceedings of the 14th Conference on Behavior Representation in Modeling and Simulation (BRIMS), Los Angles, CA.

Bolstad, C. A., Riley, J. M., Jones, D. G., & Endsley, M. R. (2002). *Using goal directed task analysis with Army brigade officer teams.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Breazeal, C., Kidd, C. D., Thomaz, A. L., Hoffman, G., & Berlin, M. (2005). *Effects of nonverbal communication on efficiency and robustness in human-robot teamwork.*

Paper presented at the Intelligent Robots and Systems, 2005.(IROS 2005). 2005 IEEE/RSJ International Conference on.

Brooks, C., Dobson, R. J., Banach, D. M., Dean, D., Oommen, T., Wolf, R. E., . . . Hart, B. (2015). *Evaluating the Use of Unmanned Aerial Vehicles for Transportation Purposes*. Retrieved from Michigan Tech Research Institute, Ann Arbor, Michigan:

Candamo, J., Kasturi, R., & Goldgof, D. (2009). *Using color profiles for street detection in low-altitude UAV video.* Paper presented at the Proc. of SPIE Vol.

Casper, J., & Murphy, R. R. (2003). Human-robot interactions during the robot-assisted urban search and rescue response at the world trade center. *IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics), 33*(3), 367-385.

Chan, B., Guan, H., Jo, J., & Blumenstein, M. (2015). Towards UAV-based bridge inspection systems: a review and an application perspective. *Structural Monitoring and Maintenance, 2*(3), 283-300.

Cheng, P., Zhou, G., & Zheng, Z. (2009). *Detecting and counting vehicles from small low-cost UAV images.* Paper presented at the ASPRS 2009 Annual Conference, Baltimore.

CIOB. (2016). *Productivity in Construction: Creating a Framework for the Industry to Thrive*. Retrieved from Chartered Insitute of Building:

Connelly, S., Lindsay, P., & Gallagher, M. (2007). *An agent based approach to examining shared situation awareness.* Paper presented at the Engineering Complex Computer Systems, 2007. 12th IEEE International Conference on.

Cooke, N. J., Pedersen, H. K., Connor, O., Gorman, J. C., & Andrews, D. (2006). Acquiring team-level command and control skill for UAV operation *Human factors of remotely operated vehicles* (pp. 285-297): Emerald Group Publishing Limited.

Christ G. (2016) Drone used in turnpike bridge inspection crashes into water, Retrieved from *http://www.cleveland.com/metro/index.ssf/2016/09/drone_used_in_turnpike_bridge.html*

d'Oleire-Oltmanns, S., Marzolff, I., Peter, K. D., & Ries, J. B. (2012). Unmanned Aerial Vehicle (UAV) for monitoring soil erosion in Morocco. *Remote Sensing, 4*(11), 3390-3416.

Demoz Gebre-Egziabher, & Xing, Z. (2011). *Analysis of Unmanned Aerial Vehicles Concpet of Operations in ITS Applications*. Retrieved from Intelligent Transportation Systems Institute:

Denning, J. D., & Verschelden, C. (1993). Using the focus group in assessing training needs: Empowering child welfare workers. *Child Welfare: Journal of Policy, Practice, and Program*.

DJI, (2018a) Mavic Pro, Retrieved from https://store.dji.com/product/mavic-pro

DJI, (2018b) DJI Phantom 4 Pro, Retrived from https://store.dji.com/product/phantom-4-pro

DJI, (2018c) Matrice 100, Retrived from https://store.dji.com/product/matrice-100

Drury, J. L., Riek, L., & Rackliffe, N. (2006). *A decomposition of UAV-related situation awareness.* Paper presented at the Proceedings of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction.

Ellenberg, A., Branco, L., Krick, A., Bartoli, I., & Kontsos, A. (2014). Use of Unmanned Aerial Vehicle for Quantitative Infrastructure Evaluation. *Journal of Infrastructure Systems, 21*(3), 04014054.

Endsley, M., & Jones, W. M. (1997). *Situation Awareness Information Dominance & Information Warfare*. Retrieved from

Endsley, M., R, Bolte, B., & Jones, D. (2003). Designing for situation awareness: an approach to human-centred design Taylor & Francis, London.

Endsley, M. R. (1988). *Design and evaluation for situation awareness enhancement.* Paper presented at the Proceedings of the Human Factors Society annual meeting.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human factors, 37*(1), 32-64.

Endsley, M. R., & Garland, D. J. (2000). *Situation awareness analysis and measurement*: CRC Press.

EquipmentWorld (2015), Drone, Retrieved from https://www.equipmentworld.com /drones/

FAA. (2013). *Unmanned Aircraft Systems (UAS) Operational Approval (N 8900.207)*. U.S. Department of Transportation.

FAA. (2015). *Unmanned Aircraft Systems in the National Airspace System (NAS) (N JO 7210.891)*. U.S. Department of Transportation.

FAA. (2016a). *Small Unmanned Aircraft Systems (sUAS)*. U.S Department of Transportation.

FAA. (2016b). *TITLE 14 CFR PART 107 - SMALL UNMANNED AIRCRAFT SYSTEMS.* U.S. Department of Transportation.

FAA. (2017). Unmanned Aircraft Systems (UAS). Retrieved from https://www.faa.gov/uas/

Fong, T., Thorpe, C., & Baur, C. (2001). *Collaboration, dialogue and human-robot interaction, 10th international sumposium of robotics research (lorne, victoria, australia).* Paper presented at the Proceedings of the 10th International Symposium of Robotics Research.

Frierson, T. (2013). *Use of Unmanned Aerial Vehicles for AHTD Applications "Studying Visual Aids to Assist in Corridor Analysis"*. Retrieved from Arkansas State Highway and Transportation Department:

Furnham, A. (1994). *Personality at work: The role of individual differences in the workplace*: Psychology Press.

GDOT. (2012). *Bridge Structure Maintenance and Rehabilitation Repair Manual*. Georgia Department of Transportation.

Gheisari, M., & Esmaeili, B. (2016). *Unmanned Aerial Systems (UAS) for Construction Safety Applications.* Paper presented at the Construction Research Congress 2016.

Gheisari, M., Irizarry, J., & Walker, B. (2014). *UAS4SAFETY: the potential of unmanned aerial systems for construction safety applications.* Paper presented at the Proc., Construction Research Congress.

Gheisari, M., Karan, E. P., Christmann, H. C., Irizarry, J., & Johnson, E. N. (2015). *Investigating Unmanned Aerial System (UAS) Application Requirements within a Department of Transportation.* Paper presented at the Transportation Research Board 94th Annual Meeting.

Gillins, M. N., Gillins, D. T., & Parrish, C. (2016). *Cost-Effective Bridge Safety Inspections Using Unmanned Aircraft Systems (UAS).* Paper presented at the Geotechnical and Structural Engineering Congress 2016.

Golparvar-Fard, M., Peña-Mora, F., & Savarese, S. (2009). D4AR–a 4-dimensional augmented reality model for automating construction progress monitoring data collection, processing and communication. *Journal of Information Technology in Construction, 14*(13), 129-153.

Goodrich, M. A., & Schultz, A. C. (2007). Human-robot interaction: a survey. *Foundations and trends in human-computer interaction, 1*(3), 203-275.

Gu, Y. (2009). *Evaluation of Remote Sensing Aerial Systems in Existing Transportation Practices*. Retrieved from Virginia State Department of Transportation:

Gucunski, N., Kee, S.-H., La, H. M., Basily, B., & Maher, A. (2015). Delamination and concrete quality assessment of concrete bridge decks using a fully autonomous RABIT platform. *Structural Monitoring and Maintenance, 2*(1), 19-34.

Guerrero, J. A., & Bestaoui, Y. (2013). UAV path planning for structure inspection in windy environments. *Journal of Intelligent & Robotic Systems, 69*(1-4), 297-311.

Hallermann, N., & Morgenthal, G. (2014). *Visual inspection strategies for large bridges using Unmanned Aerial Vehicles (UAV).* Paper presented at the 7th International Conference on Bridge Maintenance, Safety and Management, IABMAS.

Ham, Y., Han, K. K., Lin, J. J., & Golparvar-Fard, M. (2016). Visual monitoring of civil infrastructure systems via camera-equipped Unmanned Aerial Vehicles (UAVs): a review of related works. *Visualization in Engineering, 4*(1), 1.

Han, C.-s. (2011). *Human-robot cooperation technology-An ideal midway solution heading toward the future of robotics and automation in construction.* Paper presented at the International Symposium on Automation and Robotics in Construction, Keynote TIT.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Advances in psychology, 52*, 139-183.

Hart, W. S., & Gharaibeh, N. G. (2010). *Use of Micro Unmanned Aerial Vehicles for Roadside Condition Assessment*. Retrieved from

Heikkilä, R. H. J., & Mikkonen, M. (2013). *Applicability of an unmanned aerial vehicle surveying to the measurement of digital terrain model.* Paper presented at the 30th International Symposium of Automation and Robotics in Construction (ISARC), Montreal, Canada.

Hinsz, V. B. (2006). *Enhancing Coordination and Collaboration in Unmanned Air Vehicle (UAV) Crews*. Retrieved from

Hinsz, V. B., Wallace, D. M., & Ladbury, J. L. (2009). Team performance in dynamic task environments. *International review of industrial and organizational psychology, 24*, 183-216.

Hunt, R. C. (2016). *The Use of Unmanned Aircraft Systems to Increase Safety and Decrease Costs of Transportation Projects and/or Related Tasks*. New Hampshire Department of Transportation.

Irizarry, J., & Costa, D. B. (2016). Exploratory Study of Potential Applications of Unmanned Aerial Systems for Construction Management Tasks. *Journal of Management in Engineering, 32*(3), 05016001.

Irizarry, J., Gheisari, M., & Walker, B. N. (2012). Usability assessment of drone technology as safety inspection tools. *Journal of Information Technology in Construction, 17*, 194-212.

Irizarry, J., & Johnson, E. N. (2014). *Feasibility study to determine the economic and operational benefits of utilizing unmanned aerial vehicles (UAVs)*. Retrieved from Georgia State Department of Transportation:

Irizarry, J., Kim, S., Johnson, N. E., & Lee, K. (2017). *Potential Unmanned Aerial Systems Based Operations within a Department of Transportation: Findings from a Focus Group Study.* Paper presented at the 53rd Annual Associate School of Construction (ASC) International Conference, Seattle.

IUASOTF. (2016). *UAS Recommendation Reports*. Retrieved from Illinois Department of Transportation:

Judson, F. (2013). The Ohio Department of Transportation and Unmanned Aircraft Systems. *Lidar News*.

Karan, E. P., Christmann, C., Gheisari, M., Irizarry, J., & Johnson, E. N. (2014). *A comprehensive matrix of unmanned aerial systems requirements for potential applications within a department of transportation.* Paper presented at the Construction Research Congress.

Karpowicz, R. (2014). *The Use of Unmanned Aerial Systems for Steep Terrain Investigations*. Retrieved from Caltrans:

Khan, F., Ellenberg, A., Mazzotti, M., Kontsos, A., Moon, F., Pradhan, A., & Bartoli, I. (2015). *Investigation on Bridge Assessment Using Unmanned Aerial Systems.* Paper presented at the Structures Congress 2015.

Kidd, P. (1992). *Design of human-centered robotic systems.* Paper presented at the Human Robot Interaction.

Kim, S., Irizarry, J., & Costa, D. B. (2016). *Potential Factors Influencing the Performance of Unmanned Aerial System (UAS) Integrated Safety Control for Construction Worksites.* Paper presented at the Construction Research Congress 2016.

Kim, S., Irizarry, J., Costa, D. B., & Mendes, A. T. (2016). *Lessons Learned from Unmanned Aerial System-Based 3D Mapping Experiments*. Paper presented at the Associated Schools of Construction (ASC) Proceedings of the 52nd Annual International Conference., Provo, Utah.

Kitzinger, J. (1995). Qualitative research. Introducing focus groups. *BMJ: British medical journal, 311*(7000), 299.

Kuutti, K. (1996). Activity theory as a potential framework for human-computer interaction research. *Context and consciousness: Activity theory and human-computer interaction*, 17-44.

Laa, H. M., Gucunski, N., Kee, S.-H., & Nguyen, L. (2014). *Visual and Acoustic Data Analysis for the Bridge Deck Inspection Robotic System.* Paper presented at the ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction.

Lazar, J., Feng, J. H., & Hochheiser, H. (2010). *Resaech Methods in Human-Computer Interaction*: John Wiles & Sons Ltd.

Lee, H. (2007). Essentials of Behavioral Science Research: A First Course in Reserach Methodology. Retrieved from

Liu, J., Jennesse Jr, M., & Holley, P. (2016). *Utilizing Light Unmanned Aerial Vehicles for the Inspection of Curtain Walls: A Case Study.* Paper presented at the Construction Research Congress 2016.

Mastronardi, M. (2014). *GDOT Constructoin Manual* Retrieved from Georgia Department of Transportation:

McCormack, E. D., & Trepanier, T. (2008). *The use of small unmanned aircraft by the Washington State Department of Transportation*. Retrieved from Washington State Department of Transportation:

McGuire, M., Rys, M., & Rys, A. (2016). *A Study of How Unmanned Aircraft Systems Can Support the Kansas Department of Transportation's Efforts to Improve Efficiency, Safety, and Cost Reduction*. Retrieved from Kansas State Department of Transportation:

Metni, N., & Hamel, T. (2007). A UAV for bridge inspection: Visual servoing control law with orientation limits. *Automation in Construction, 17*(1), 3-10.

Moller, P. S. (2008). *CALTRANS Bridge Inspection Aerial Robot Final Report*. Retrieved from California Department of Transportation:

Murphy, R. R., Pratt, K. S., & Burke, J. L. (2008). *Crew roles and operational protocols for rotary-wing micro-UAVs in close urban environments.* Paper presented at the Proceedings of the 3rd ACM/IEEE international conference on Human robot interaction.

NCDOT. (2017a). *Final Report - North Carolina UAS Airspace Integration Exercise*. Retrieved from North Carolina Department of Transportation:

NCDOT. (2017b). *UAS Operational Procedure Guide*. Retrieved from North Carolina Department of Transportation:

Norman, D. A., & Draper, S. W. (1986). User centered system design. *New Perspectives on Human-Computer Interaction, L. Erlbaum Associates Inc., Hillsdale, NJ, 3*.

Ochoa, S. F., Bravo, G., Pino, J. A., & Rodríguez-Covili, J. (2011). Coordinating loosely-coupled work in construction inspection activities. *Group Decision and Negotiation, 20*(1), 39-56.

Oskouie, P., Becerik-Gerber, B., & Soibelman, L. (2015). A data quality-driven framework for asset condition assessment using LiDAR and image data. *Computing in Civil Engineering, 2015*, 240-248.

Otero, L. D., Gagliardo, N., Dalli, D., Huang, W., & Cosentino, P. (2015). *Proof of Concept for Using Unmanned Aerial Vehicles for High Mast Pole and Bridge Inspections*. Retrieved from

Pekcan, o., La, H. J., Kelley, R., & Rapp, W. (2015). *Development and Implementation of Autonomous Drone Technology for Efficient Inspection of Highway Bridge Structures*. NEVADA DEPARTMENT OF TRANSPORTATION.

Pekuri, A., Haapasalo, H., & Herrala, M. (2011). Productivity and performance management–managerial practices in the Construction Industry. *International Journal of Performance Measurement, 1*(1), 39-58.

Perez, M. A., Zech, W. C., & Donald, W. N. (2015). Using Unmanned Aerial Vehicles to Conduct Site Inspections of Erosion and Sediment Control Practices and Track Project Progression. *Transportation Research Record: Journal of the Transportation Research Board*(2528), 38-48.

Pix4D, (2017). Pix4D Mapper 4.1 User Manual, Pix4D Support.

Prewett, M. S., Johnson, R. C., Saboe, K. N., Elliott, L. R., & Coovert, M. D. (2010). Managing workload in human–robot interaction: A review of empirical studies. *Computers in Human Behavior, 26*(5), 840-856.

Reinhardt, J., Garrett, J. H., & Scherer, R. J. (2005). *The Preliminary Design of a Wearable Computer for Supporting Construction Progress Monitoring*.

Reising, J. M. (2003). *Uninhabited Military Vehicles: What Is the Role of the Operators?* Retrieved from

Rodriguez-Gonzalvez, P., Gonzalez-Aguilera, D., Lopez-Jimenez, G., & Picon-Cabrera, I. (2014). Image-based modeling of built environment from an unmanned aerial system. *Automation in Construction, 48*, 44-52.

Rubio, S., Díaz, E., Martín, J., & Puente, J. M. (2004). Evaluation of subjective mental workload: A comparison of SWAT, NASA-TLX, and workload profile methods. *Applied Psychology, 53*(1), 61-86.

Scholtz, J. (2003). *Theory and evaluation of human robot interactions.* Paper presented at the System Sciences, 2003. Proceedings of the 36th Annual Hawaii International Conference on.

Schwab, K. (2016). *The Fourth Industrial Revolution*. World Economic Forum.

Sheridan, T. B. (1992). *Telerobotics, automation, and human supervisory control*: MIT press.

Siebert, S., & Teizer, J. (2014). Mobile 3D mapping for surveying earthwork projects using an Unmanned Aerial Vehicle (UAV) system. *Automation in Construction, 41*, 1-14.

Sim, J. (1998). Collecting and analysing qualitative data: issues raised by the focus group. *Journal of advanced nursing, 28*(2), 345-352.

Taylor, R. (1990). Situational Awareness Rating Technique(SART): The development of a tool for aircrew systems design. *AGARD, Situational Awareness in Aerospace Operations 17 p(SEE N 90-28972 23-53)*.

TradingEconomics. (2017). United States GDP From Construction. Retrieved from http://www.tradingeconomics.com/united-states/gdp-from-construction

Vacanas, Y., Themistocleous, K., Agapiou, A., & Hadjimitsis, D. (2015). *Building Information Modelling (BIM) and Unmanned Aerial Vehicle (UAV) technologies in infrastructure construction project management and delay and disruption analysis.* Paper presented at the Third International Conference on Remote Sensing and Geoinformation of the Environment.

Wen, M.-C., & Kang, S.-C. (2014). Augmented reality and unmanned aerial vehicle assist in construction management *Computing in Civil and Building Engineering (2014)* (pp. 1570-1577).

Wierwille, W. W., & Eggemeier, F. T. (1993). Recommendations for mental workload measurement in a test and evaluation environment. *Human factors, 35*(2), 263-281.

Wierwille, W. W., Rahimi, M., & Casali, J. G. (1985). Evaluation of 16 measures of mental workload using a simulated flight task emphasizing mediational activity. *Human factors, 27*(5), 489-502.

Wortel, T. P. (2009). *Automating quantity surveying in road construction using UAV Videogrammetry.* TU Delft, Delft University of Technology.

Yaghoubi, S., Kazemi, M. R., & Sakhaii, M. (2012). ICT Technologies, Robotic and Automation in Construction. *International Journal of Basic and Applied Science, 12*(4), 112-116.

Yagoda, R. E. (2010). *Development of the human robot interaction workload measurement tool (HRI-WM).* Paper presented at the Proceedings of the human factors and Ergonomics society annual meeting.

Yanco, H. A., & Drury, J. (2004). *Classifying human-robot interaction: an updated taxonomy.* Paper presented at the Systems, Man and Cybernetics, 2004 IEEE International Conference on.

Zhai, D., Goodrum, P. M., Haas, C. T., & Caldas, C. H. (2009). Relationship between automation and integration of construction information systems and labor productivity. *Journal of Construction Engineering and Management, 135*(8), 746-753.

Zink, J., & Lovelace, B. (2015). *Unmanned Aerial Vehicle Bridge Inspection Demonstration Project*: Minnesota Department of Transportation, Research Services & Library.