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The Application of Unmanned Aerial Systems in Surface Transportation - Volume I: Executive Summary

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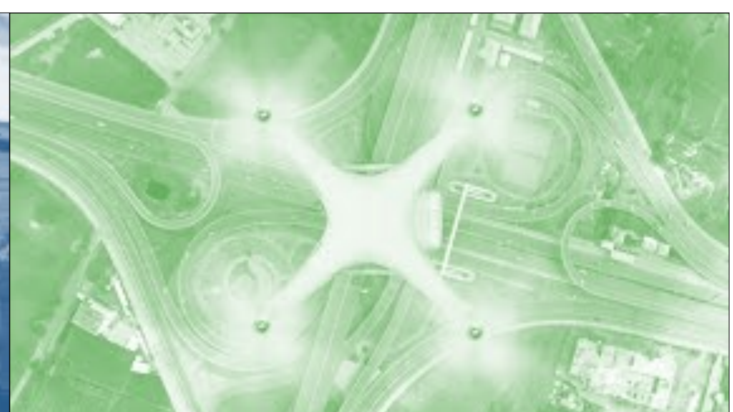

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16. Abstract

Volume I of this two-volume report summarizes a research project designed to assist MassDOT in the development of a pilot program for applying unmanned aerial system (UAS) technology to address surface transportation needs in the Commonwealth. In order to provide MassDOT with a comprehensive understanding of the advantages, challenges, and other aspects of UAS implementation, the project included six research tasks: Task A - Development of a Pilot Program to Integrate UAS Technology into Bridge and Rail Inspections; Task B - Assessment of Roadway Pavement Conditions with UAS Technology; Task C - Evaluation of UAS Highway Speed-Sensing Applications; Task D - Development of a UAS Emergency Service Network for Use in Surface Transportation; Task E - Assessment of UAS Situational Awareness and Counter UAS Technologies in Surface Transportation; and Task F - Evaluation of UAS Cyber Security Threats and Countermeasures in Surface Transportation. The major results of the project indicate that UAS technology integration holds great potential for bridge and rail inspections and monitoring, roadway pavement and speed management, and emergency response, but there are safety and security challenges. The next steps of this research should focus on bringing UAS applications in surface transportation from the state-of-the-art to the state-of-the-practice.

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Disclaimer

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Executive Summary

This project entitled, "The Application of Unmanned Aerial Systems in Surface Transportation", was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program with funding from Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. The purpose of this research project was to assist MassDOT in the development of a pilot program for applying Unmanned Aerial Systems (UAS) to address surface transportation needs in the Commonwealth.

In order to successfully achieve the project objectives, the following six research tasks were carried out:

- Task A: Development a pilot program for integrating UAS technology into bridge and rail inspections
- Task B: Assessment of roadway pavement conditions with UAS
- Task C: Evaluation of UAS application for highway speed sensing
- Task D: Development of UAS emergency service network for use in surface transportation
- Task E: Assessment of UAS situational awareness technology and counter UAS (CUAS) technologies to support applications in surface transportation
- Task F: Evaluation of UAS cybersecurity threats and countermeasures in surface transportation

The research tasks were designed to support MassDOT's interests in applying UAS technology to address statewide surface transportation needs. In order to provide MassDOT with a comprehensive understanding of the advantages, challenges, and other aspects of UAS implementation, the project included six research tasks. Tasks A, B, C, and D assessed the potential benefits of UAS, while Tasks E and F explored mitigation strategies associated with the implementation of new technologies. Expanding the understanding and knowledge of the different aspects associated with the application of UAS is critical for the successful implementation and seamless integration of UAS technology into existing MassDOT surface transportation-related operations.

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Organization of the Final Report

Volume I:

The Application of Unmanned Aerial Systems In Surface Transportation. Executive Summary of the Final Report (This Document).

Volume II:

The Application of Unmanned Aerial Systems In Surface Transportation. Individual Final Reports.

Below are the six (6) Final Report UAS research tasks:

- Task A: Development a pilot program for integrating UAS technology into bridge and rail inspections.
- Task B: Assessment of roadway pavement conditions with UAS.
- Task C: Evaluation of UAS application for highway speed sensing.
- Task D: Development of UAS emergency service network for use in surface transportation.
- Task E: Assessment of UAS situational awareness technology and counter UAS (CUAS) technologies to support applications in surface transportation.
- Task F: Evaluation of UAS cybersecurity threats and countermeasures in surface transportation.

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List of Acronyms

Acronym	Expansion
COTS	Commercial Off-The-Shelf
CUAS	Counter-Unmanned Aerial System (Technology)
EO	Electro-Optical
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
FRA	Federal Railroad Administration
GPS	Global Positioning System
IR	Infra-Red
LiDAR	Light Detection And Ranging
MBTA	Massachusetts Bay Transportation Authority
MassDOT	Massachusetts Department of Transportation
MEMA	Massachusetts Emergency Management Agency
PCI	Pavement Condition Index
RF	Radio Frequency
UAS[1]	Unmanned Aerial System or Unmanned Aircraft System

[1] The terms "UAS" and "drone" are used interchangeably.
[2] Per current FAA regulations, a sUAS is defined as a small unmanned aircraft (system) with a takeoff weight under 55 pounds.

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1.0 Introduction

1.1 Background

In Phase I of the MassDOT UAS research initiative, recommendations on UAS policy, standard operating procedures, and best practices were formulated along with a proposed set of UAS applications for each MassDOT division (*1*). The project described in this dual volume final report constitutes Phase II of the MassDOT UAS research initiative and is designed to investigate potential UAS applications to support MassDOT's goal of developing a UAS pilot program to address surface transportation needs in the Commonwealth. The expectation is that these UAS applications have the potential to enhance the efficiency of agency operations while also improving safety and security.

1.2 Research Objectives

The objectives of this project were:

1. To develop a pilot program for integrating UAS into current bridge and rail inspection programs (Task A)
2. To explore the use of UAS for assessing roadway pavement conditions (Task B).
3. To evaluate the applicability of UAS for highway speed sensing (Task C).
4. To explore how UAS can assist with emergency response in surface transportation and develop lUAS emergency service drone network options. (Task D).
5. To assess commercial off-the-shelf (COTS) UAS situational awareness and CUAS technology to support surface transportation and protect critical transportation infrastructure (Task E).
6. To evaluate UAS cybersecurity threats and countermeasures in surface transportation (Task F).

The UMass Research Team in collaboration with MassDOT Aeronautics Division staff and other MassDOT personnel carried out all tasks.

1.3 Final Report Outline

The final report consists of two volumes, Volume I and Volume II. Volume I is organized as follows: Section 2 provides a description of each task including the problem statement and the objectives; Section 3 reviews the results of each task; Section 4 presents major project conclusions and recommendations; and Section 5 provides a list of references. A more detailed description of the objectives, methodology, results and conclusions of each Task is presented in Volume II.

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2.0 Project Description

The following sections provide an overview of the individual problem statements and objectives for individual tasks.

2.1 Task A: Development of a Pilot Program to Integrate UAS Technology to Bridge and Rail Inspections

2.1.1 Problem Statement

Previously used for military reconnaissance and for strike programs, UAS technology has increasingly been considered for a variety of civilian tasks, including infrastructure monitoring, precision agriculture, package delivery services, search and rescue operations, photography, and more. With this task, MassDOT sought to learn from current experiences and challenges of bridge and rail inspections and of the use of UAS, and to develop a pilot program to integrate UAS into MassDOT's bridge and rail inspections practices and procedures for the Highway Division, Rail and Transit Division, and MBTA.

2.1.2 Objectives

The objectives of this research were:

1. To conduct a literature review of standard bridge and rail inspection procedures and protocols carried out by state DOTs.
2. To explore the challenges with integrating UAS data outputs into these inspection procedures and protocols.
3. To develop practical procedures and protocols for MassDOT regarding the use of UAS with bridge and rail inspections.
4. To pilot test the developed procedures and protocols.

2.2 Task B: Assessment of Roadway Pavement Conditions with UAS

2.2.1 Problem Statement

Paved roads deteriorate over time due to load and environment. To capture the extent and severity of the deterioration, and to decide how to best distribute available funds to keep the roads in service, transportation agencies and municipalities conduct pavement condition surveys of their roadway networks, usually on an annual or biennially basis. The data collected during these surveys consist of details on the distresses present on the roadway (cracking, raveling, weathering, etc.) and the roadway profiles. The survey process can be expensive, labor-intensive, and time-consuming. UAS technology offers an alternative way for assessing pavement condition and deterioration. UAS have the potential to evaluate large paved areas significantly faster than existing manual methods. In 2015, UAS technology was utilized by an Airsight to rapidly capture imagery, and conduct what could be classified as semi-automated airfield pavement condition inspections *(2)*. The semi-automated assessments used a combination of CAD software technology that recognized pavement distresses, and human analysis of stitched imagery. Airsight reported a significant reduction in inspection time compared to conventional methods, which resulted in significant cost savings *(2)*. Due to these potential benefits, the application of UAS technology for pavement condition assessment warrants further investigation.

2.2.2 Objectives

The main objective of this research task was to understand the current and future state of practice regarding the use of UAS technology for pavement condition assessment. A synthesis was conducted concurrently with a pavement assessment field test using UAS collected imagery. This task focused on addressing the following major questions:

1. How are agencies using currently available UAS technology for pavement condition analysis?
2. What are the specific current state of practice UAS platform and instrumentation requirements to perform pavement condition analysis?
3. What are the specific prospective UAS platform and instrumentation requirements to perform fully automated pavement condition analysis?
4. What data is collected by UAS and how is the data converted into a useable format?
5. How do traditional pavement assessment methods compare to the semi-automated and fully automated methods with UAS, in terms of quality of data, cost, time, and safety?

2.3 Task C: Evaluation of UAS Highway Speed-Sensing Application

2.3.1 Problem Statement

UAS capability improvements provide an opportunity to revolutionize traffic data collection techniques. Previously, aerial studies of highway vehicle speeds were infeasible due to the high cost of helicopters, and studies conducted at ground level could only capture speed data at specific locations along roadways. MassDOT's *Procedures for Speed Zoning on State and Municipal Roadways* states that "it would be ideal to have speed checks at an infinite number of locations so that the 85th percentile speed could be computed at all points" *(3)* In order to address this need, the use of UAS as a tool to collect traffic speed data on roadways through the space mean speed method is being proposed.

2.3.2 Objectives

The objectives of this research were:

1. To conduct a field study comparing the use of UAS to traditional speed data collection instruments on roadways to evaluate the feasibility and usefulness of UAS as a traffic data collection tool.
2. To develop a methodology defining how aerial data can be utilized in the speed limit-setting process.
3. To explore additional UAS traffic data collection uses for surface transportation needs beginning with an exploration of origin-destination studies.

2.4 Task D: Development of a UAS Emergency Service Network for Use in Surface Transportation

2.4.1 Problem Statement

One promising application of UAS is for emergency services and disaster relief for surface transportation impacts. At MassDOT, the Aeronautics Division is the lead coordinating agency for the Massachusetts Emergency Management Agency (MEMA) on air-based operations. Both MassDOT and MEMA are looking to develop a better understanding of UAS's capabilities to obtain rapid and critical post-disaster information to support lifesaving and damage assessment services.

2.4.2 Objectives

The main objective of this research task is to conduct a literature search and detailed synthesis of the application of UAS in emergency response and disaster damage assessment services on surface transportation networks.
This research task will provide two deliverables:

- Deliverable D1: Technical Memo on Literature Review
- Deliverable D2:
  a) A GIS-based hotspot map of previous incidents and natural disasters in Massachusetts.
  b) An initial UAS deployment network for emergency response.
  c) Python code used to compile data and create the initial UAS deployment network.
  d) A report describing the methods to identify applicable events for UAS missions, development of the UAS network, and the potential ways to use the UAS network for decision-making.

2.5 Task E: Assessment of UAS Situational Awareness and CUAS Technology in Surface Transportation

2.5.1 Problem Statement

The reduction in cost and innovations for Global Positioning Systems (GPS), cameras, and other advanced sensor-based technologies have led to an increase in the use of UAS. The FAA has estimated that there could be more than 2.5 million UAS in the United States by 2020 that require registration *(3)*. While promising new opportunities, this rapid proliferation of UAS also has the potential to harm people and property. In order to ensure public safety and security, there is a need to identify and test available technologies capable of detecting, tracking, and identifying cooperating and non-cooperating UAS operating in the open air, above ground level, and near important transportation infrastructure.

2.5.2 Objectives

The objectives of this research were twofold:

1. To expand the MassDOT Phase I UAS 2016 literature synthesis (*1*) to include technologies that are specific to other critical surface transportation infrastructure; and
2. To prepare a prototype to field test selected technologies, to assess their reliability and operational effectiveness related to surface transportation.

2.6 Task F: Evaluation of UAS Cyber Security Threats and Countermeasures in Surface Transportation

2.6.1 Problem Statement

As public and private entities expand their use of UAS for surface transportation functions, UAS systems and data must be kept safe from security breaches and cyberattacks. In worse case scenarios, seized UAS could be used to attack critical infrastructure, particularly in surface transportation, and sensitive UAS-collected data could be compromised. There is an urgent need to ensure that UAS are engineered with sufficient security to withstand and recover from inevitable cyberattacks. GPS spoofing, radio controller signal interference, and malicious software are serious threats to UAS integrity. A comprehensive system-engineering plan must be specified to address the spectrum of attacks and damage to which UAS are susceptible. In order to enable this secure system engineering strategy, a greater understanding is needed of the technologies capable of cyberattacks against UAS and corresponding defensive strategies, and of the security standards under development for UAS and the compliance of COTS technologies used in building UAS.

2.6.2 Objectives

The objectives of this research were to identify:

1. Technologies to attack and defend UAS from cyber threats.
2. Security standards under development relevant to UAS.
3. Degree of compliance of a representative sample of COTS used in the construction of UAS to these standards such that critical infrastructure and surface transportation can be defended.

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3.0 Results

This chapter briefly presents the results of the research tasks, including the key findings from literature syntheses and field tests, and key points in the proposed UAS procedures and protocols. Further details on the research tasks and their findings are described in the detailed reports for each task.

3.1 Task A: Development of a Pilot Program to Integrate UAS Technology into Bridge and Rail Inspections

For the literature synthesis, the research team identified and reviewed 51 inspection-related documents, including 43 state DOT bridge inspection manuals; two other state DOT bridge-related inspection documents; four state rail inspection manuals; and 2 federal bridge and rail inspection documents. It was found that twelve state DOTs either have implemented or studied the integration of UASs into their highway bridge inspection processes. It was also found that UAS integration into highway and rail bridge inspections could provide significant savings of time for both DOT inspection crew and road users, as well as reduce costs and improve the safety of operations. On the basis of the conducted literature synthesis, the research team successfully demonstrated some practical procedures and protocols for UAS integration into bridge and rail inspections. Those newly designed practical procedures and protocols have been field tested and demonstrated their effectiveness. Looking ahead, one preferred methodology for structures inspections (bridge and rail) is to utilize UAS software that would allow for autonomous flights. Similar to the reasoning behind the use of autopilot on manned aircraft, the use of pre-programmed UAS operations would improve safety.

3.2 Task B: Assessment of Roadway Pavement Condition with UAS

The literature review results for Task B suggested that the use of UAS for pavement condition assessment is still in its infancy, with little experience and information available. For integration with UAS, photogrammetry appears to be the most popular technique, while the use of multi- or hyperspectral imaging is getting increasing attention. The integration of LiDAR (Light Detection and Ranging) remote sensing with UAS for pavement condition assessment has not been thoroughly explored yet, although it does show potential.

Besides the mentioned sensing technologies, new algorithms for analyzing pavement condition data were also reviewed with a specific focus on deep learning. The results suggested that many neural network models have been developed to detect cracks from images, and that these models have achieved considerable success. However, most of the methods are designed to identify and highlight cracked regions in pavement images with a rectangular shape, instead of identifying cracks at the pixel level, which is an important step towards calculating pavement's Pavement Condition Index (PCI) value. To develop deep neural network based crack detection algorithms, it is important to have a large database of pavement images with cracks clearly labeled; transfer learning appears to be one effective way to get around this issue.

The research team collected a number of runway pavement images using UAS from the Fitchburg Municipal Airport to evaluate the pavement crack detection performance of a MATLAB® toolbox called CrackIT and two deep learning methods. Overall, the deep learning methods outperformed the CrackIT toolbox. Between the two deep learning methods, the U-Net model has the advantage of generating crack detection results at the pixel level. It also performed very well on the Fitchburg Airport data given a limited training dataset.

3.3 Task C: Evaluation of UAS Highway Speed-Sensing Application

Using the data collected in the field, a literature review, a methodology was developed to understand the accuracy of the data, and how it may be useful in the speed-limit setting process. Two studies were completed to understand the accuracy and cost of using UAS as compared to traditional methods: one for volume data collection and another for speed data collection. For the speed-limit setting process, more detailed speed data may be required. The research found that the accuracy of the speed data collected with UAS is comparable with the traditional methods.

Compared to traditional methods, UAS data collection method was found to have a similar capital cost, while UAS has the potential to significantly reduce time, and therefore the operational cost, associated with data collection and processing. It was found that on medium to high volume roadways, UAS have the potential to be more time-cost effective than traditional methods.

3.4 Task D: Development of UAS Emergency Service Drone Network for Use in Surface Transportation

A literature review was conducted to understand the public policy and administration aspects of UAS applications in the United States. With the help of the literature review, an algorithm to design a specific UAS network for emergency response was developed on a basis of multiple empirical geospatial datasets, including traffic incident data, natural disaster data, and maintenance depot locations. The features of the traffic incidents in a five-year period were investigated, and then a two-step method was developed to select the applicable incidents for UAS applications and optimally determine the UAS network parameters. The first step identified the applicable incidents by the severity as well as duration filters. In the second step, a greedy algorithm was used to determine the number of UAS response stations needed and the locations of the stations, based on the given radius of the stations and the expected coverage. The results from the developed algorithm indicated that the UAS network parameters vary with the UAS station radius and the expected coverage. It was also found that the UAS network developed for the traffic incidents might be capable of providing sufficient coverage on the influence area for many natural disasters.

3.5 Task E: Assessment of UAS Situational Awareness and CUAS Technology in Surface Transportation

During the literature synthesis, the research team identified 49 different products from 30 manufacturers, based in the U.S. or overseas. Consistent with the findings from Phase I, as well as similar reviews and field tests conducted by others, this study have found that there is no CUAS product that utilizes any single type of sensing technology while at the same time being capable to address all challenges associated with sUAS detection, tracking, and identification. The most promising technologies include RF signal intelligence, EO systems, acoustic signature techniques, and surveillance radar. Each technology has distinctive advantages and drawbacks related to its capabilities, reliability, and capital and operating costs. Hence, the research team recommends to select products that combine multiple UAS detection, identification and tracking technologies that would provide the most robust protection for critical transportation facilities.

Based on a preliminary evaluation carried out by the research team, seven commercially available CUAS products have been identified for field testing. A prototype was developed for pilot testing of these products and assessing their performance, capabilities, and reliability for protecting critical surface transportation infrastructure. In order to further improve understanding of challenges associated with field testing of CUAS technologies, MassDOT personnel and the research team attended field demonstrations of UAS and CUAS technology organized by one of the vendors. Field-testing of the prototype was not conducted during this phase of the project but is proposed for future work.

3.6 Task F. Evaluation of UAS Cyber Security Threats and Countermeasures in Surface Transportation

The research team found that risks can be introduced at every stage of the mission and business process. Inflight risks are commonly the focus of attention, due to safety concerns, but preflight and post-flight risks are equally if not more important. Preflight risks include the acquisition, assembly and configuration of the UAS hardware and software as well as multiple web-based applications that pose both security and privacy threats. Post flight risks include data processing and related storage infrastructure that threaten privacy. The business process helps define the mission process. Therefore, business processes can serve as a gatekeeper to mitigate technical risk before it is introduced. Standards are necessary but not sufficient. Specifically, domain specific standards often fail to recognize the shift toward software-enabled capabilities or prominently emphasize corresponding cybersecurity risks introduced by implementing such functionality in software. As a result, these standards regularly fall short of offering references to quantitative procedures that can enable desired decision support capabilities such as design for security and cyber risk mitigation. The research team identified the need for simple quantitative procedures to assess cyber risk, compare the effectiveness of alternative countermeasures, and communicate related findings graphically to MassDOT who must also consider the broader business context.

4.0 Conclusion and Recommendations

For each project task, the UMass Research Team conducted a literature synthesis to identify current practices of using UAS technology in surface transportation applications, and to evaluate current experiences and challenges associated with the integration of UAS technology into current practices.

Based on the literature synthesis, the research team concluded that UAS technology could serve as a useful tool in the majority of the explored applications, including bridge and rail inspections; roadway pavement condition evaluation; traffic speed evaluation and monitoring; and emergency response and assessment. The major factors that affect the success of the UAS integration relate to selection of the proper types of UAS platforms and sensors, as well as availability and ease of use of data processing software.

It was also found that there are a number of effective methods and techniques to mitigate potential threats associated with implementation of UAS technology. For example, there are commercially available counter-UAS technologies that can provide a comprehensive situational awareness in the proximity of important infrastructure and sensitive transportation facilities. In addition, there are effective cybersecurity methods that can reduce the risks of malicious cyberattacks on UAS technologies used for surface transportation functions and other purposes.

Based on the results of the literature syntheses and field tests, the research team developed practical procedures and protocols for UAS integration into MassDOT operations.

The UMass Research Team has developed a set of recommendations to further evaluate UAS applications in MassDOT divisions. The recommendations include the following:

- Develop a pilot program for further evaluation of UAS applications in highway and railroad bridge inspections and in railroad right-of-way maintenance inspections in MassDOT divisions. Conduct field tests to evaluate UAS accuracy and efficiency in detection of structural deficiency of bridge structures. (Task A)
- Conduct additional research to understand how to determine PCI values from the pixel-level crack detection results, and then compare the PCI values with the assessment results of qualified engineers. Also, a programmable procedure needs to be established to generate reliable and consistent PCI outcomes from UAS images. (Task B)
- Explore the best vehicle tracking methods using UAS to gain the most accurate results. This could include volume and speed studies along with the development of a software platform to aid with the implementation of UAS for traffic data collection. Other potential uses of UAS for traffic monitoring could also be investigated including turning movement counts, conflict-event studies, intersection delay measurements, parking utilization tracking, and queue studies. (Task C)
- Conduct a pilot study to improve the network design and to optimize the location of UAS stations for emergency response, assessment, and management. Specifically,

there is a need to calibrate the operational parameters of drones and identify potential issues that may arise in practice. Additionally, the network design should refine the criteria filters to incorporate more operational characteristics of drones. (Task D)

- Conduct a field study to evaluate selected CUAS technologies to test their detection, tracking, and identification capabilities in a real-world environment under a variety of environmental conditions and with different UAS products A special effort should be made to test CUAS against intruder drones flying in fully autonomous, radio-silent mode. (Task E)
- In terms of cybersecurity and security risks, the two main recommendations are to survey the MassDOT UAS mission portfolio to identify where cyber risk assessment can be applied for the greatest benefit and to assess and certify humans and UAS to prevent and close gaps in the mission and business processes of the organization/agency. (Task F)

It is recommended that future MassDOT research focus on bringing UAS technology applications from the state-of-the-art to the state-of-the-practice.

A more detailed presentation of the objectives, methodology, results and conclusions of each Task is presented in Volume II.

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