OASRTRS-14-H-UVM Final Report

Unmanned Aircraft Systems for Transportation Decision Support

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Glossary

3D	Three Dimensional
AASHTO	American Association of State Highway Transportation Officials
CAD	Computer-Aided Design
CNL	Cognition Network Language
COA	Certificate of Authorization
CRS	Commercial Remote Sensing
DOT	Department of Transportation
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
GIS	Geographic Information Systems
HDDS	Hazard Data Distribution System
ICS	Incident Command System
LiDAR	Light Detection and Ranging
NAIP	National Agricultural Imagery Program
NIMS	National Incident Management System
NOAA	National Oceanic and Atmospheric Administration
OBIA	Object-Based Image Analysis
OGC	Open Geospatial Consortium
OST-R	Office of the Assistant Secretary for Research and Technology
PI	Principal Investigator
PM	Program Manager
RiP	Research in Progress database
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SAL	Spatial Analysis Laboratory (University of Vermont)
SI	Spatial Information
TAC	Technical Advisory Committee
TRC	Transportation Research Center

UAS	Unmanned Aircraft Systems
USDOT	United States Department of Transportation
USGS	United States Geological Survey
UVM	University of Vermont
VAOT	Vermont Agency of Transportation (also known as VTrans)
VTrans	Vermont Agency of Transportation (also known as VAOT)
XML	eXtensible Markup Language

DISCLAIMER

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EXECUTIVE SUMMARY

Our nation relies on accurate geospatial information to map, measure, and monitor transportation infrastructure and the surrounding landscapes. This project focused on the application of Unmanned Aircraft Systems (UAS) as a novel tool for improving efficiency and efficacy of geospatial data acquisition to provide decision support in five areas: 1) stream geomorphic assessment, 2) construction management, 3) resource allocation, 4) cost decision support, and 5) bridge inspections. UAS provide considerable cost-savings compared to more traditional approaches of geospatial data collection to aid in transportation decision support. In many instances, the data collected by UAS are more detailed and can be turned into meaningful information faster than other alternative approaches. These benefits enable managers to make rapid decisions with greater confidence all while reducing the cost of data acquisition. Nevertheless, UAS should not be seen as a complete replacement for other methods, such as surveying and inspections, but rather a technology that is best employed in concert with these approaches. A more conducive regulatory environment and rapid advances in UAS technology will lead to wide adoption of UAS within the transportation sector in the coming years.

CHAPTER 1: TECHNICAL SUMMARY

1.1. PROJECT COORDINATION

1.1.1. Technical Advisory Committee

The project Team created a Technical Advisory Committee (TAC) that consisted of individuals who have domain expertise in UAS, transportation, and relevant geospatial technology.

The Advisory Committee consisted of the following individuals:

- Jen Davis, Aviation Program, Vermont Agency of Transportation (VTrans)
- Stephen Smith, Railway GIS Lead, VTrans
- Johnathan Croft, Mapping Chief, VTrans
- Zack Borst, University of Vermont Emergency Management Coordinator
- Adam Zylka, Technical Support Engineer, senseFly
- James Clark, Technical Support Engineer, senseFly
- Rita Hunt, Aviation Planner, New Hampshire Department of Transportation
- Bryan McBride, Solutions Engineer, Spatial Networks
- Michael Umansky, Technical Operations Engineer, Applied Imagery
- Charles Hebson, Manager of Surface Water Resources, Maine Department of Transportation (DOT)
- Jason Moghadass, Project Manager, Spatial Informatics Group
- Amanda Hanaway, Principal Engineer, Burlington International Airport

TAC meetings were held throughout the course of the project.

1.1.2. Project Management

Internal project meetings were ongoing throughout the project. The Team used the mind mapping software by MindJet for overall project management and Slack for real-time internal project communications.

1.1.3. Equipment Acquisition

A new high-accuracy fixed-wing system, the senseFly eBee RTK was purchased as part of this project. The eBee RTK is an improvement over prior eBee models in that it incorporates Real Time Kinetic (RTK) GPS corrections. As part of this project a new multi-rotor UAS, the senseFly Albris (Figure 1) was acquired for the specific purpose of carrying out close-range bridge inspections. The UVM Team received extensive training from senseFly on Albris operations and data processing on four separate occasions over the course of the project. Small purchases of other equipment needed to operate the UAS, primarily batteries, were made throughout the project.

Figure 1. senseFly Albris during a demonstration flight.

1.2. REPORTING

Quarterly reports were provided to US DOT. This documents fulfills the requirement of the final report.

1.3. STAKEHOLDER/PARTNERSHIP MEETINGS

The stakeholder/partnership meetings were carried out to drive the scenarios and select sites for the project application areas. Stakeholders and partners were selected from a broad range of government organizations and private sector groups who self-identified as having an interest in UAS or a need for UAS products. Over the course of the project meetings were held with the following groups:

- Aishark
- Spatial Informatics Group
- University of Colorado, Denver
- University of Vermont
- Chittenden County Regional Planning Commission
- Northwest Regional Planning Commission
- Vermont Agency of Transportation
- New Hampshire Department of Transportation
- Missisquoi National Wildlife Refuge
- USDA Forest Service
- Town of Barre, VT
- VHB, Inc.
- Donald H. Hamlin Engineers
- SE Group
- VELCO
- Green Mountain Power
- DuBois & King, Inc.
- Lamoureux & Dickenson, Inc.
- Summit Engineering, Inc.

- Casella Waste Management, Inc.
- Town of Plainfield, VT
- Central Vermont Regional Planning Commission
- Malone & Macbroom, Inc.
- GeoResource Solutions, Inc.
- Fitzgerald Environmental

These stakeholder/partnership meetings were integral to the flight operations, application areas, and decision support tools.

1.4. UNMANNED AIRCRAFT SYSTEMS

UAS Operations consisted of flying both fixed-wing and multi-rotor UAS to acquire data, then processing that data to support the application areas and decision support tools. Fixed-wing and multi-rotor system operations are inherently different. There do, however, exist commonalities when it comes to the planning and preparation UAS missions. We developed a set of procedures, checklists, and workflows to guide our efforts, ensuring safe and effective UAS operations. For the 287 UAS flights that took place, there was only one minor injury in which an operator's hand struck one of the UAS propellers during an incorrect launch.

1.4.1. Procedures

The Team developed a UAS Operations Manual (Appendix A) to guide UAS work done by any entity within the university. This was a request from the Team's risk management office who saw a need for such a manual given the increasing number of UAS flights. Updates were made to our previously published UAS Standard Operating Guidelines (Appendix B)

1.4.2. Checklists

Three sets of checklists were generated: 1) mission planning, 2) flight operations, and 3) post-flight. Collectively, these checklists and the associated apps provide a means by which to ensure accountability throughout the organization. All of the checklists were built using the Fulcrum platform (https://web.fulcrumapp.com). Fulcrum is maintained by Spatial Networks, who was a matching funds contributor to the project. Fulcrum staff came to the University of Vermont to train project Team members on app development. The benefit of the Fulcrum platform is that it provides an easy way to design, develop, and deploy cross-platform spatially-enabled applications. The applications were built using the Fulcrum online interface then used on a variety of smartphones and tablets.

The mission checklist (Figure 2) serves to ensure that flight approval had been granted and that all systems and equipment have been packed and accounted for. It is filled out once before each mission (a single mission may have multiple flights). The flight checklist (Figure 3) is a single application that adjusts depending on the type of system (fixed-wing vs. multi-rotor), model, and sensor the user selects. It is filled out by the flight operator before each flight. The app automatically records the location of the flight. The checklists can be viewed both on a map and in tabular form in an online portal (Figure 4). The post-flight checklist focuses on data storage actions and equipment care.

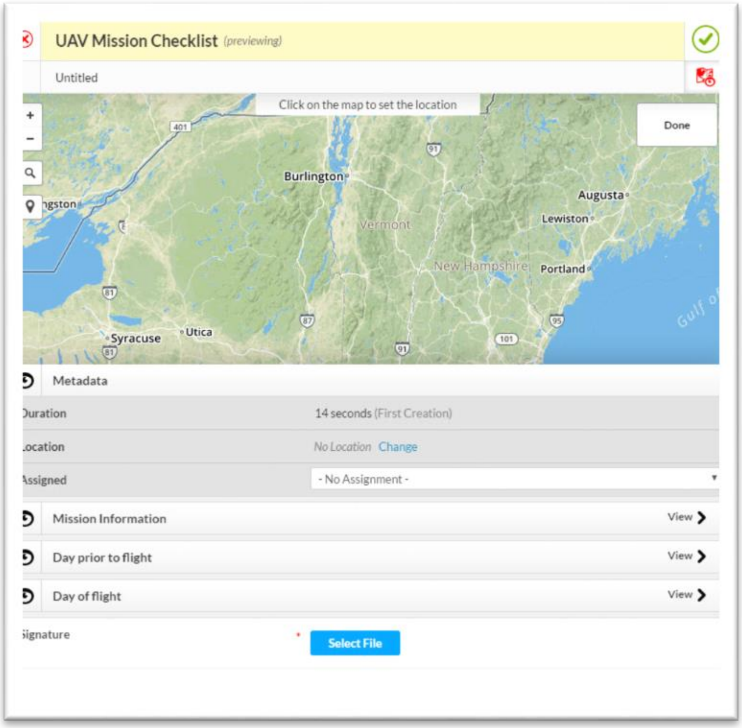

Figure 2. Layout of the mission checklist app.

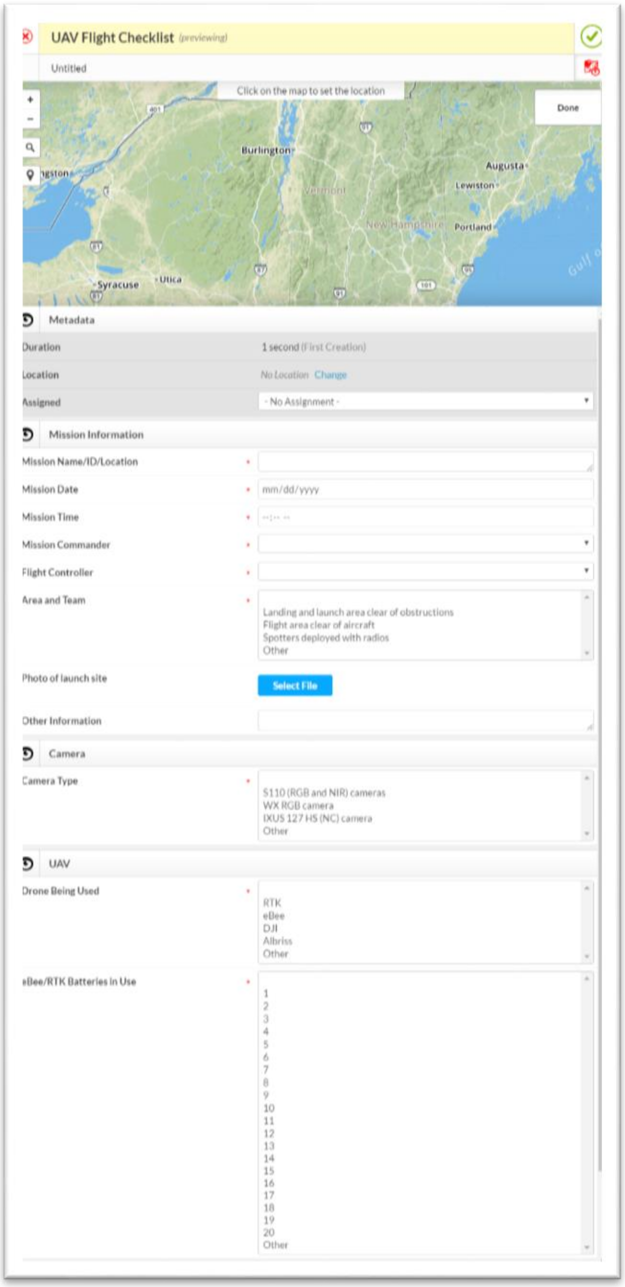

Figure 3. Layout of the flight checklist app.

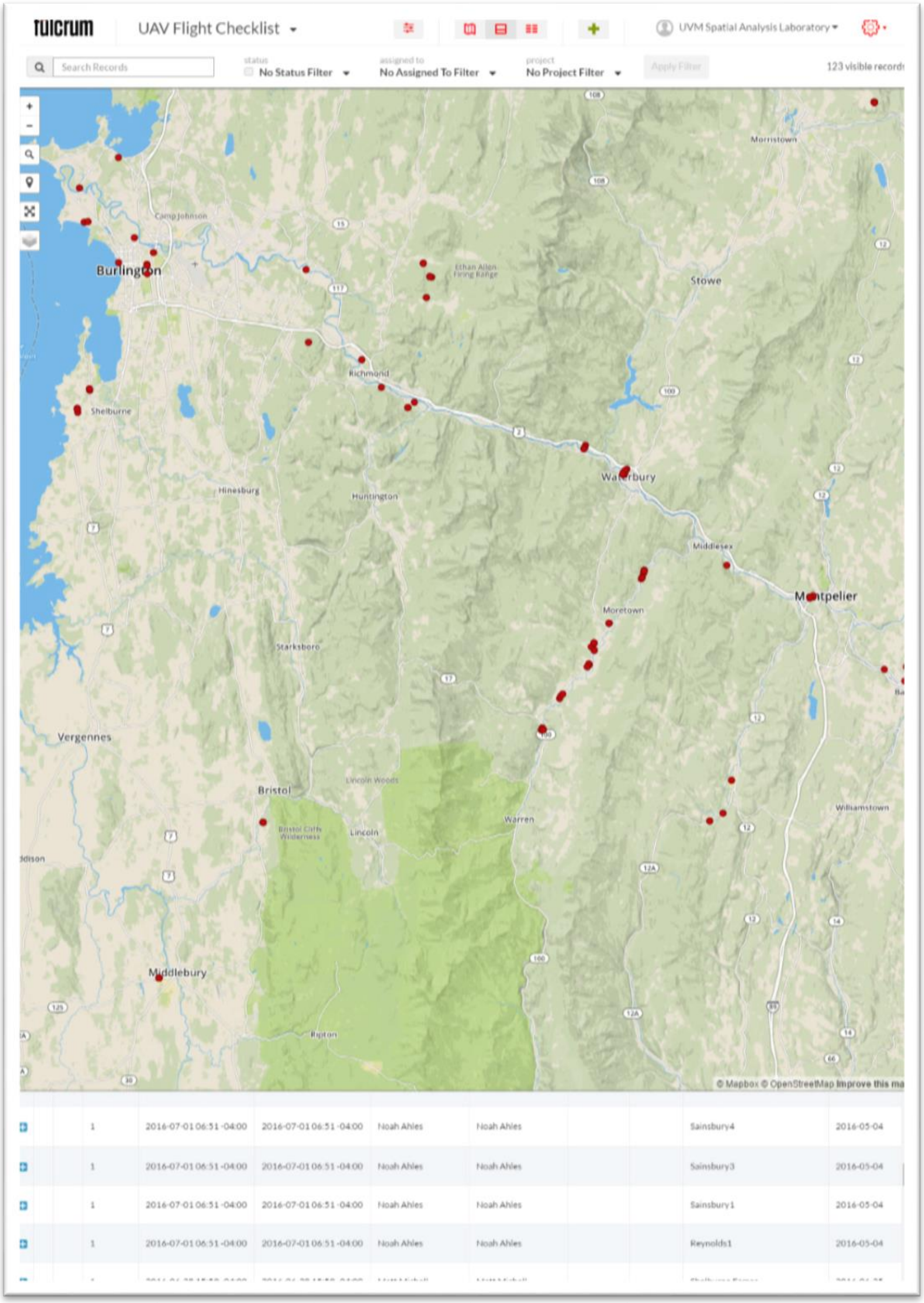

Figure 4. Web-based interface for querying and browsing the flight checklist records. Each red dot represents the location of a flight. Flight records are presented in the table below the map.

1.4.3. Fixed-Wing UAS Operations

The senseFly eBee and eBee RTK models (Figure 5) were used for all fixed-wing UAS operations. Fixed-wing UAS operations consisted of three main phases: 1) flight planning, 2) launch, flight, and recovery, and 3) data processing.

Figure 5. The senseFly eBee undergoing a camera check before launch during a demonstration for international disaster relief agencies.

Flight planning was performed using the eMotion software package (Figure 6). Construction a flight plan is a user-driven process in which the operator establishes a polygon defining the flight area then defining key parameters such as percent overlap between flight lines, target resolution, maximum altitude, maximum operating radius, and launch/landing sectors.

The flight itself is largely autonomous, with the UAS following the pre-programed flight. An operator would only intervene in extenuating circumstances (e.g. abort a landing). A video showcasing our fixed-wing flight operations is available on YouTube (https://youtu.be/_6hA831P4To).

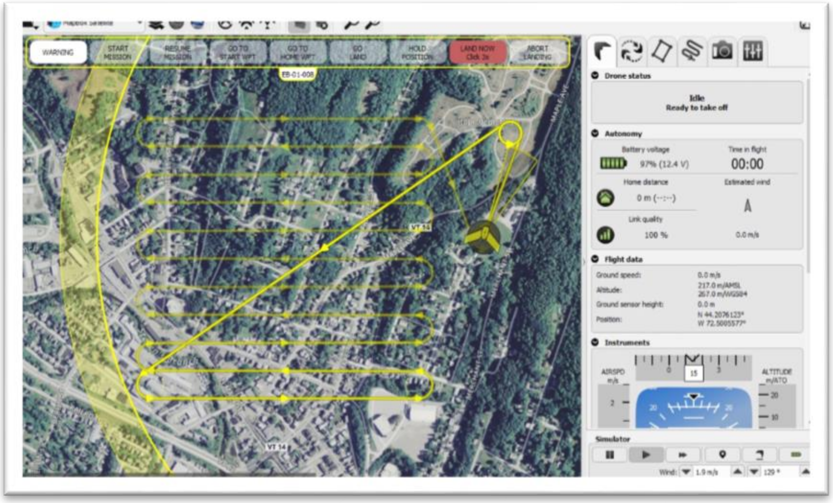

Figure 6. Sample flight plan generated for the eBee using the eMotion software package.

Once the imagery has been collected and downloaded from the system they are feed into Pix4D, a photogrammetric processing software package (Figure 7). Pix4D uses structure from motion combined with GPS and flight log information from the UAS to orthorectify the imagery, thereby removing distortions associated with the sensor and terrain. Pix4D yields a number of products including orthorectified raster imagery (Figure 8), 3D point clouds (Figure 9), and raster surface models. These products use standard, open file formats, enabling them to be viewed and analyzed in virtually any geospatial software package.

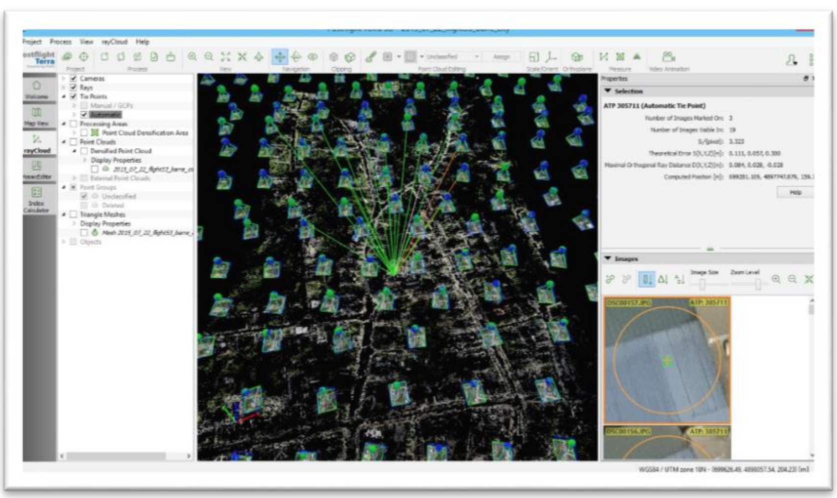

Figure 7. Photogrammetric processing using Pix4D.

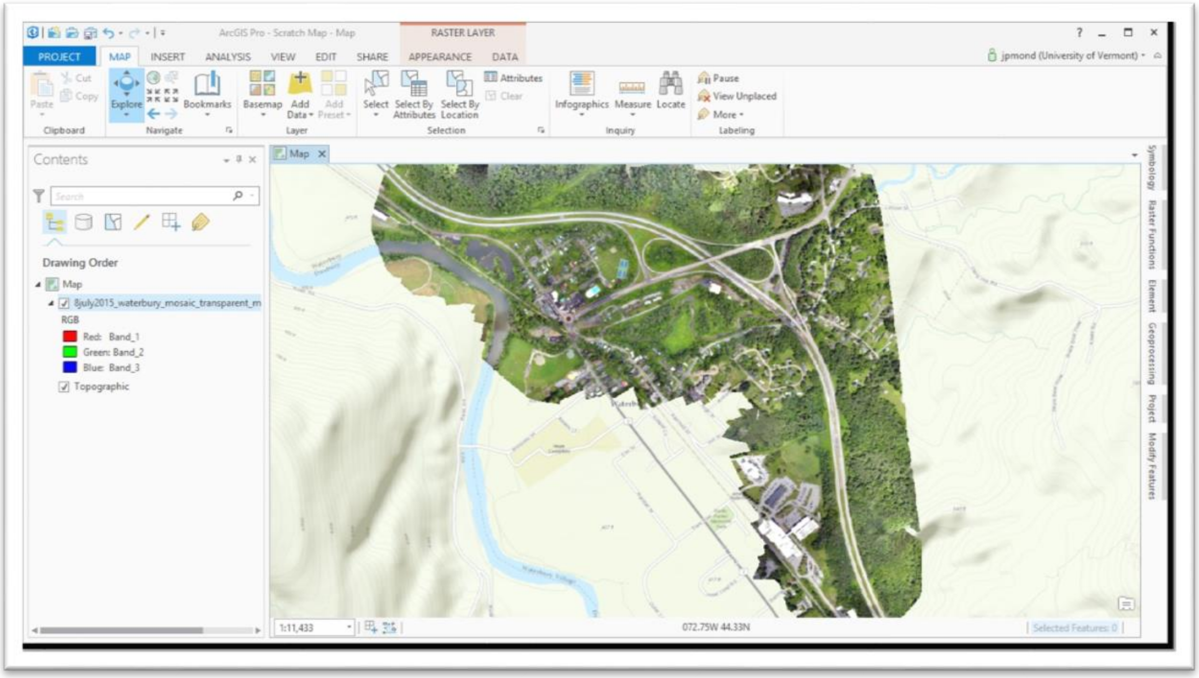

Figure 8. UAS Orthorectified image mosaic generated using Pix4D displayed in ArcGIS.

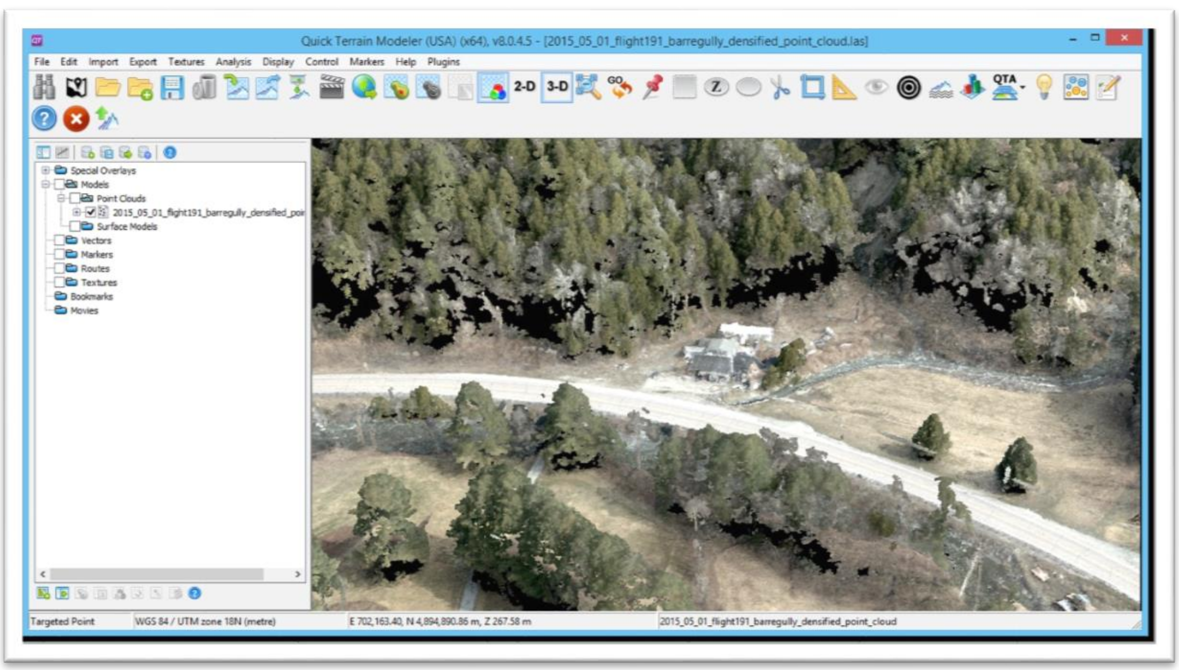

Figure 9. UAS 3D point cloud generated using Pix4D displayed in Quick Terrain Modeler.

1.4.4. Multi-Rotor UAS Operations

The multi-rotor system used for bridge inspections in this project, the senseFly Albris, can be operated in both manual mode and a preplanned automated flight mode. Manual mode is most commonly used when conducting close-range inspections (Figure 10). In such cases, the data collection focus is on still images, videos, and thermal imaging. The operator will often work closely with the bridge inspector to capture data of points of interest. One of the unique capabilities of the Albris is that the camera can point up for down, enabling it to capture images of the tops or undersides of bridges (Figure 11).

The purpose of the automated flight mode is to gather images with the appropriate properties to create a detailed 3D model. This process is virtually identical to flying the eBee in that flight planning is carried out in eMotion, followed by autonomous flight operations, and finally photogrammetric processing in Pix4D. While a UAS such as the Albris can acquire imagery from side look angle, thereby improving the quality of a 3D model for an individual structure, its can cover far less of an area in a single flight compared to a system like the eBee. A video showcasing our multi-rotor flight operations is available on YouTube (https://youtu.be/D-HyftUaQKc).

Figure 10. The Albris in manual operation mode while carrying out a close-range inspection of a historic covered bridge.

Figure 11. Inspection photo of the underside of a railroad bridge captured by the Albris.

Figure 12. Pix4D layout showing the images collected of a bridge by the Albris UAS.

Figure 13. Detailed 3D model of a railroad bridge generated by the Albris during an autonomous flight operation.

CHAPTER 2: APPLICATION AREAS & DECISION SUPPORT TOOLS

287 individual flights were carried out to support the following five application areas listed below. For each application area, we developed a suite of decision support tools.

1. Geomorphic assessment
2. Construction management and phasing
3. Resource allocation
4. Cost decision support
5. Bridge inspection.

The decisions support tools developed for this project can be broken into two main categories: 1) general data dissemination and mapping and 2) application specific. The general data dissemination tools benefitted the project as a whole, the specific tools for the five focus application areas were customized to address specific needs and requirements.

2.1.1. Data Dissemination & Mapping Tools

A web portal was developed to house the UAS data products and to provide information on the location and extent of missions. It was developed using the ArcGIS Online platform and is accessible to the public (http://arcg.is/2fFr5cl). The portal displays the point locations of individual missions, and when the user zooms in, the extent of coverage. Clicking on the extent polygons launches a dialog box in which the user can download the imagery and terrain products (Figure 14).

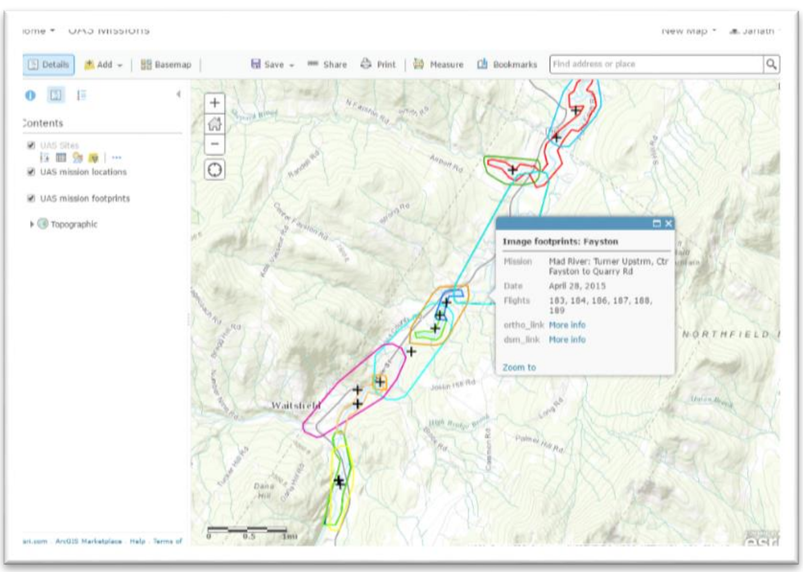

Figure 14. UAS mission data dissemination portal.

The Team also developed an online story map that provides the public with overview of our UAS work, highlighting select projects in an interactive web-based environment (Figure 15). The story map can be accessed online (http://arcg.is/2eKPUAb).

Figure 15. Story map that showcases highlights from this project.

2.1.2. Geomorphic Assessment

In many areas in the United States the transportation network and hydrologic network are tightly linked. Geomorphic assessments, while often considered to fall within the natural resource domain, are increasingly seen as important for evaluating the risk to downstream transportation infrastructure. Our geomorphic assessment applications focused on specific cases in which UAS technology could offer advantages regarding safety, quality of information, and cost effectiveness. There were three principal focus areas within the geomorphic assessment category: 1) cross-section profiles, 2) woody debris quantification, and 3) streambank erosion.

2.1.2.1. Cross-Section Profiles

Cross-section profiles are a key data requirement for hydrologic models, but comprehensive and detailed cross-sections require either lidar data or field surveys. Lidar data are expensive to acquire and may not be current. Field surveys are time-consuming and thus costly. We worked with Fitzgerald Environmental, a Vermont-based consulting group who was contracted by the state to survey the Cold River near Rutland, VT in support of a stream restoration project. The driving factor behind the stream restoration project was the damage the river did to several key bridges caused by floods brought on my Tropical Storm Irene in August of 2011.

The UAS Team spent a morning gathering data in conjunction with the Fitzgerald Environmental survey crew. The UAS Team flew the Cold River study area while the survey crew gathered reference data for comparative purposes. The UAS data were processed into surface models and then cross-section profiles were generated using the cross-section decision support tool (Figure 16).

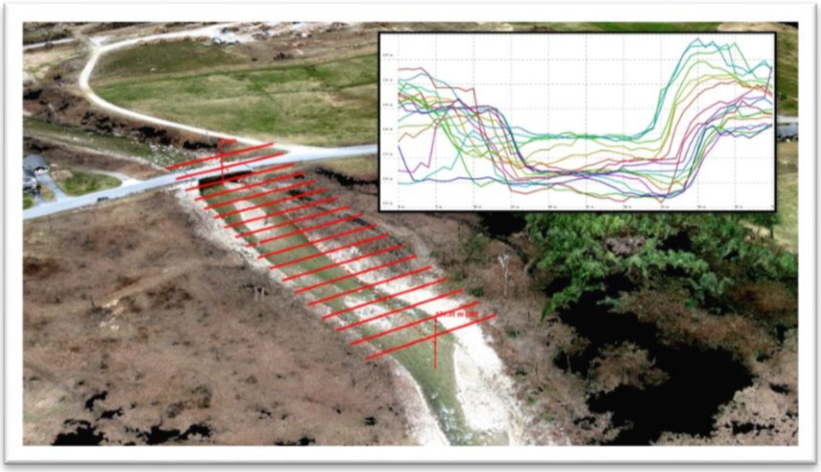

Figure 16. UAS cross-section profile decision support tool.

In the course of a single morning consisting of four UAS flight, the UAS-based workflow was able to produce as many stream cross-sectional profiles as the survey crew could have in four days. Given the comparative cost between survey equipment and UAS equipment, this time savings equates to large savings on person hours. Nevertheless, UAS should not be seen as a complete replacement for field work. The only way to determine the quality of UAS data is to have accurate survey information. Furthermore, in some instances shoreline vegetation, can cause slight errors in the cross-section profiles.

2.1.2.2. Woody Debris Quantification

Woody debris when moved downstream by flood waters, can cause severe damage to bridges and culverts. Our research focused on quantifying woody debris along streams in four separate watersheds in Vermont. Of these streams the Great Brook in Plainfield, Vermont was selected for a long-term monitoring project because of a critical need for detailed woody debris information. One of the Town of Plainfield's bridges regularly sustained significant damage in floods and the town hired the consulting engineering company of Malone and Macbroom to come up with bridge design alternatives. A key piece of information needed for the bridge alternatives was an accounting of the woody debris within the Great Brook, along with an understanding of how it moved during flood events. From December 2015 through July 2015 a total of eight UAS missions were flown. Each mission required four flights to map the area of interest along the Great Brook. Flight operations were challenging due to the varied terrain and the need to coordinate with local landowners for overflight and launch/land locations.

After each flight, the data were processed into orthorectified image mosaics, 3D point clouds, and raster surface models. A geodatabase was developed that contained a point geospatial dataset with attribute domains. A Team of technicians was trained to identify, quantify, mark, and attribute the location and size of woody debris in each image, noting the presence and absence (movement) over time. The original goal was to track the movement of woody debris during spring flood events, but low snowfall during the 2015 winter combined with a dry spring caused an absence of flooding. In July 2015, an abnormal rainfall over one evening resulting in approximately six inches of rain falling over the course of several hours. The Great Brook flooded, with large pieces of woody debris jamming the bridge causing flooding and severe damage. The bridge would end up being closed for months.

Figure 17. Damage to the bridge over the Great Brook sustained in July 2015.

Figure 18. UAS imagery showing movement of woody debris, stream channel change, and river course adjustments resulting from a major flooding event in the Great Brook

The UAS Team responded to the incident, capturing imagery of the damaged infrastructure in addition to conducting the overhead imagery acquisitions needed for the woody debris inventory. A video of the response effort is available on YouTube ([https://youtu.be/TCydZs8Ax9c)](https://youtu.be/TCydZs8Ax9c). We observed massive movements in woody debris and developed a variety of decision support products to aid the town and consulting engineers.

- A geodatabase containing a complete inventory of woody debris, its size, location, and presence/absence for each time period.
- A summary of woody debris gains and losses by stream segment (Figure 19).
- A web-based application containing the location of all woody debris by date, pre- and post-event UAS imagery, and stream segment woody debris summaries (Figure 20). The map can be accessed online (http://arcg.is/2gIghu0).
- A mobile app that integrates UAS imagery with the woody debris location information for field verification (Figure 21). A video showing how the mobile app was deployed is available on YouTube (https://youtu.be/sZRe9VKRPnY).

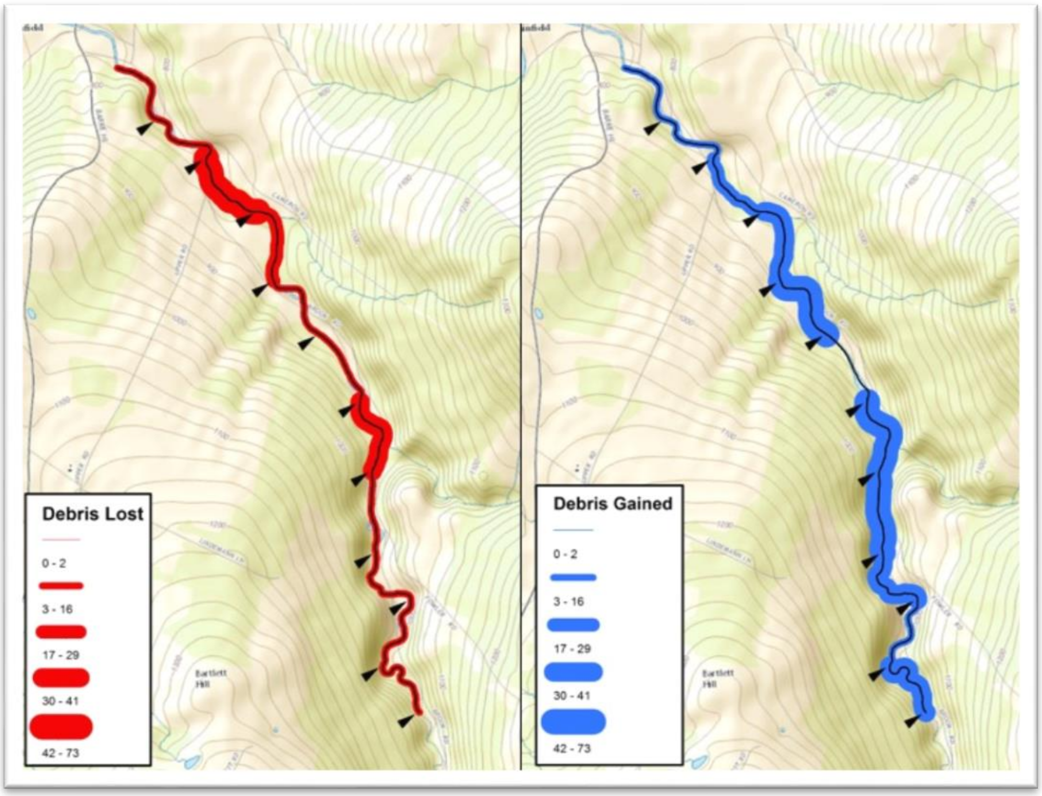

Figure 19. Woody debris gains and losses following the July 2015 flood event summarized by stream segment.

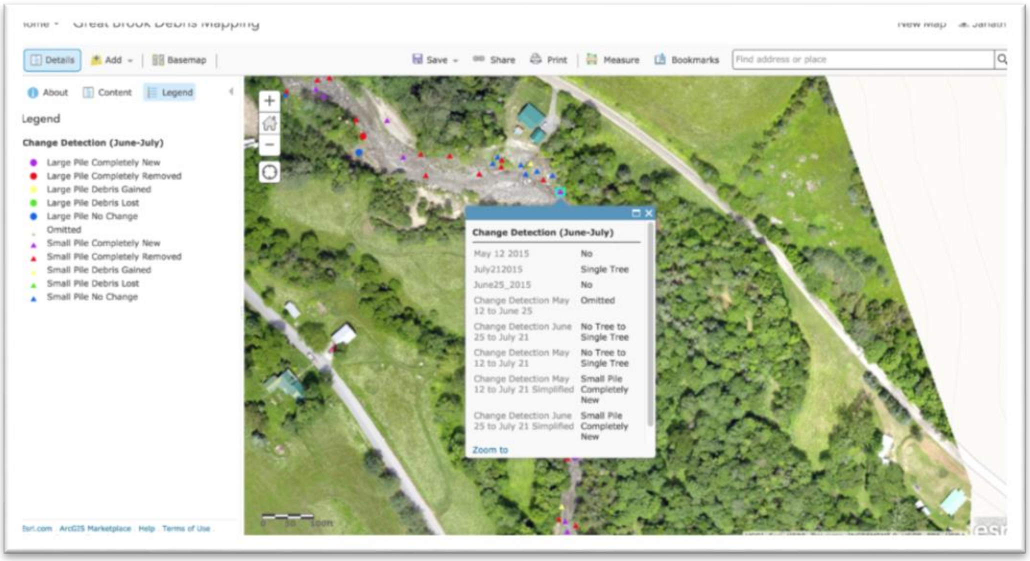

Figure 20. Woody debris web map.

Figure 21. Mobile app that integrates UAS imagery with woody debris data for field verification.

The woody debris mapping was perhaps the most compelling of all the application studies done as part of this project. There simply existed no other means by which to safely, quickly, and accurately gather the type of information on woody debris needed for the bridge redesign, regardless of cost.

2.1.2.3. Streambank Erosion

Streambank erosion is a significant geomorphic process, affecting a wide range of physical, ecological, and socio-economic issues in the fluvial environment such as in-stream habitat, water quality, and on- and near-stream properties and infrastructure. Unmanned Aircraft Systems (UAS) provide opportunities for rapidly and economically quantifying streambank erosion and deposition at variable scales (from site-specific to river network). At the site-specific scale, the capability of UAS to quantify streambank erosion was assessed by comparing it to terrestrial laser scanning (TLS) and RTK (real time kinematic) GPS for validation. At the individual site level, the estimation of bank erosion using UAS was within 4% of the actual erosion at a surveyed cross-section. At the river network-level scale, initial results indicate even bank retreats of less than a meter can be detected, provided banks are not completely obscured by dense vegetation (Figure 22).

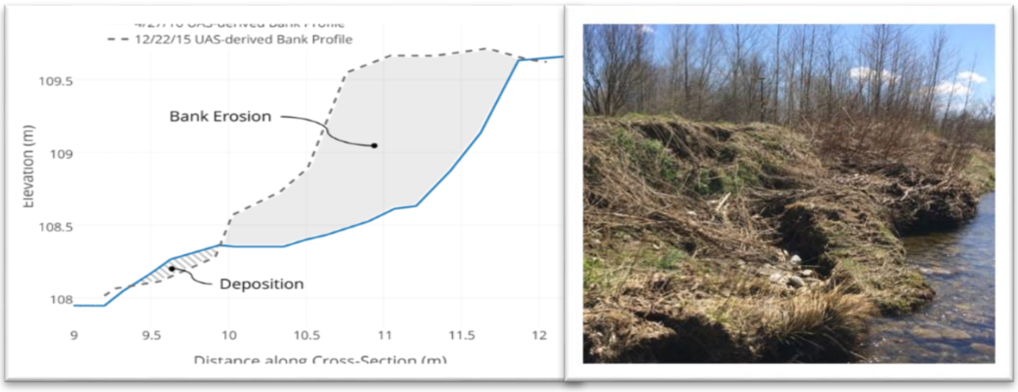

Figure 22. Comparison of UAS-derived bank profiles captured on December 22, 2015, and April 27, 2016, at a site along the New Haven River in Vermont along with a with photo of bank.

2.1.3. Construction Management and Phasing

UAS data can play a role in providing current, verifiable, and accurate data of construction projects underway in addition to updating base maps once the project is complete. We performed UAS-based monitoring of some construction sites (Figure 23). In most cases, we found that UAS products provided no appreciable safety or cost savings. Managers did find the imagery products valuable for situational awareness, particularly when carrying out status briefings. In one case the imagery was used in lawsuit over environmental compliance. The dollar benefits of these instances are difficult to quantify. Updating basemaps using a UAS approach were 1/10th the cost of manned aircraft flights. Mobile app integration of UAS data, similar to what was done for the woody debris mapping was not considered valuable as construction crews are not using such technology at this time.

Figure 23. Multi-temporal imagery of construction occurring at an interstate interchange.

One area of construction management in which UAS mapping did provide clear cost savings and improved decision making was in a runway construction project at the Newport State Airport in Coventry, VT. The expanded runway meant that the surrounding landscape had to be surveyed to determine if any obstructions (principally trees) fell within the minimum distance to the landing approach surface set by the FAA. By capturing data of the airport and surrounding area we were able to reduce the field survey effort from four days to less than one. Unlike a field survey, the 3D products generated as part of the UAS workflow enabled us to measure the height of every single tree within the area of interest, giving airport managers greater confidence that they were in compliance with FAA regulations. Collecting data in tandem with field survey crews was important as the UAS 3D models were not suitable for estimating the ground elevations under dense forest canopy.

Some decision support tools were developed for the Newport State Airport. The first was a geodatabase containing the tree heights. The second was a 2D map viewer that allows the user to swipe between imagery collected before construction as part of the Vermont statewide imagery program and the post-construction UAS imagery (Figure 24). This web map can be accessed online (http://arcg.is/296E3gw). The third consisted of a 3D web app that displayed the heights of trees along with the approach surface (Figure 25). This web app can also be accessed online (http://arcg.is/296E3gw).

Figure 24. Web application that enables users to swipe between pre-construction basemap imagery and post-construction UAS imagery for the Newport State Airport.

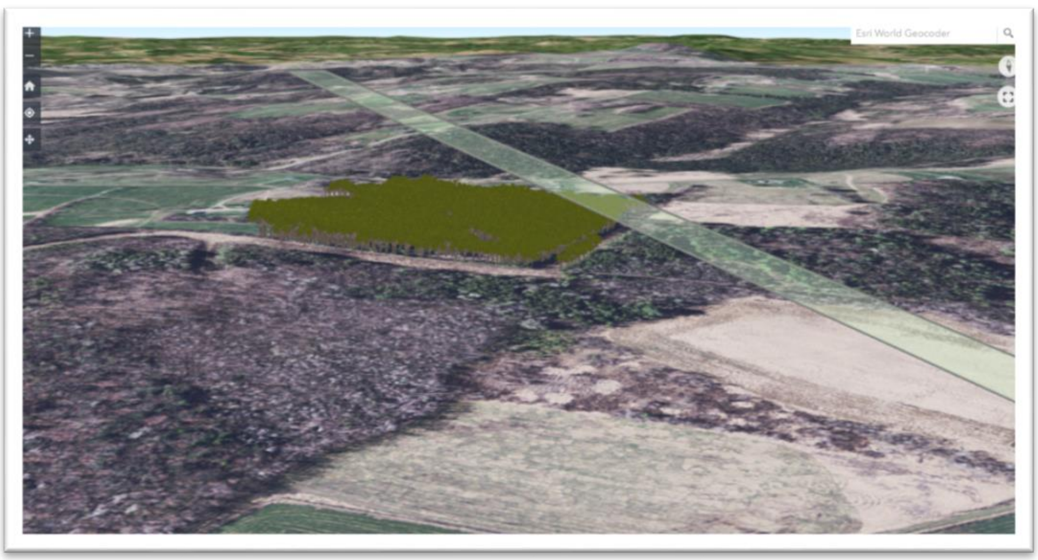

Figure 25. 3D web application for runway 36 of the Newport State Airport showing the heights of trees in relation to the approach surface.

2.1.4. Resource Allocation

In a disaster response, scenario managers face competing demands for limited resources. To deploy resources in an efficient and effective manner they need to know what portions of the transportation network are at risk, and if damage has occurred, the extent and type. Over the course of this project, our UAS Team developed extensive experience in disaster response operations, participating in both disaster response exercises and being called out by Vermont Emergency Management to capture data during actual disasters.

During the disaster response exercise, Hard Knox held in October of 2015, the UAS Team was the only asset capable of capturing overhead imagery of the scenario sites. Low cloud cover prevented any manned aircraft from flying low enough. This fact alone proved the value of UAS for such operations. Also, the co-location of the UAS assets with the incident commanders facilitated real-time information flow. As part of the scenario, the UAS Team collected imagery of the transportation network leading to a fictitious town and identified the type and location of obstructions (Figure 26). This information enabled managers participating in the exercise to dispatch crews with the appropriate equipment to remove the obstructions.

Figure 26. UAS imagery collected during the disaster response exercise Hard Knox

In the fall of 2015, the UAS Team was activated to acquired imagery of an Amtrak train that had derailed in Northfield, VT. Although response crews were already on the scene, the UAS Team collected the only geospatial products of the accident site. These products were used in the subsequent accident investigation by Amtrak and by VTrans to analyze the eroded slope that put the debris onto the tracks that caused the crash. The imagery collected is shown in Figure 27 and can be viewed in an online map (http://arcg.is/2gIBrYK).

In February of 2015, the UAS Team was activated to acquire data along the Winooski River in Vermont. Unseasonably warm temperatures and rain resulted in rising water levels, ice jams, and flooding. Emergency managers wanted to know two key pieces of information to assist with resource allocation: 1) how much would flood waters have to rise to put the adjacent rail network at risk and 2) the extent of flooding along Route 100 in Middlesex. 3D models derived from UAS data indicated that the water levels would have to rise by more than five meters before the railroad tracks were at risk, an implausible amount given the precipitation (Figure 28). Orthorectified imagery was used to document the high-water marks on Route 100 in Middlesex (Figure 29). This information was used to estimate the linear distance of roads that were flooded. A video summary of the Winooski River flooding effort is available online (https://youtu.be/8pI6QtS8Lro).

Figure 27. UAS imagery of the Amtrak train derailment that occurred on October 5, 2015, in Northfield, VT.

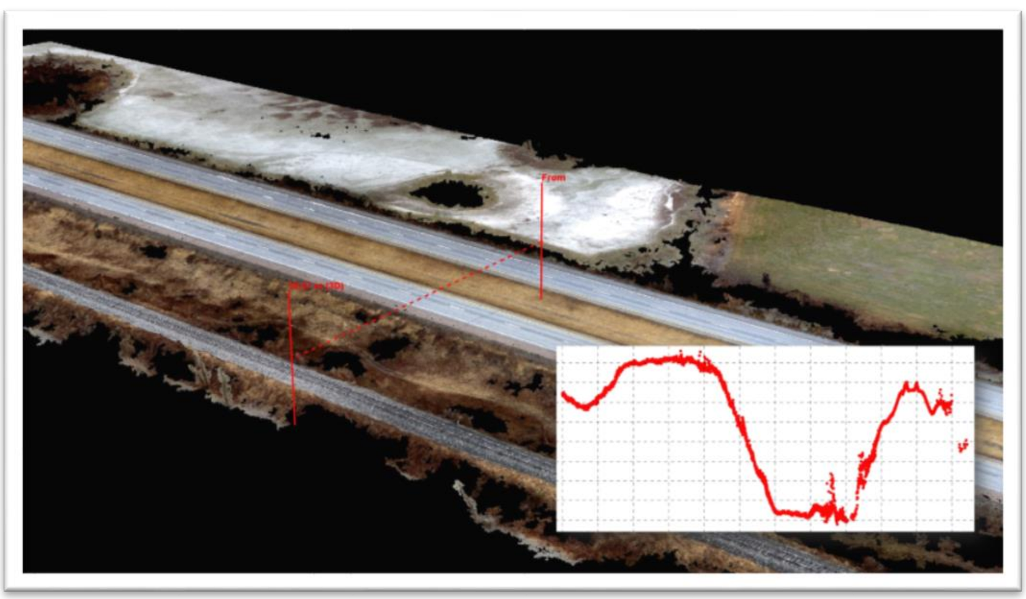

Figure 28. UAS-derived 3D profile model used to estimate the rise in river water that would have to occur before the transportation network was at risk.

Figure 29. UAS imagery showing the extent of flooding in Middlesex.

2.1.5. Cost Decision Support

In the previously funded RITA project, a UAS-based decision support tool was developed to estimate the volume of fill needed to repair a damaged road. A video demonstrating the tool is available online (https://youtu.be/nreeLlgcKy4). As part of this project, some minor adjustments were made to the workflow and were able to use the approach in a novel use case. Contractors working for the City of Burlington, VT removed soil as part of a recreational path expansion project. Only after the soil was removed did the city find it was contaminated with heavy metals. To estimate the cost of removal and disposal, an accurate volume estimate was required. A 10-minute UAS flight collected all the necessary imagery, and within 2 hours the volume of soil was computed from the UAS-derived 3D models (Figure 30). The UAS workflow was cheaper and faster than the alternative, terrestrial laser scanning.

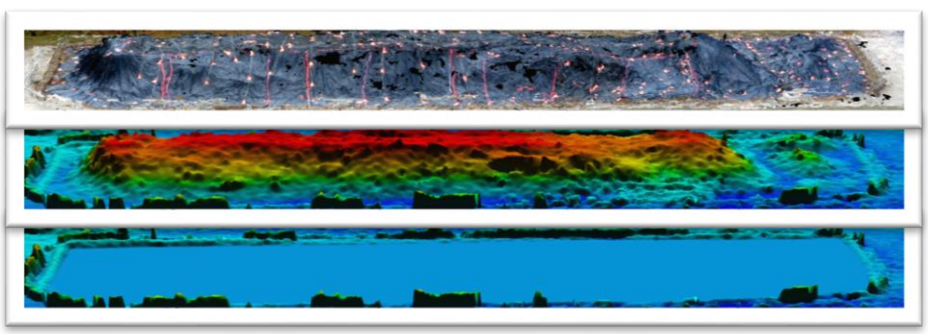

Figure 30. 3D models of the contaminated soil pile.

2.1.6. Bridge Inspection

VTrans has a single A-30 Hi-Rail Under Bridge Unit. This truck, specifically designed for railroad bridge inspections, is costly to purchase and challenging to deploy throughout the state. The result is that bridges are not inspected as often as desired. Furthermore, despite be designed for the sole purpose of railroad bridge inspections, it cannot give an inspector to all of the underside and over-story portions of select bridges. Multi-rotor UAS, which are far less costly, are easier to deploy and provide access to virtually any part of a bridge, are thus a compelling alternative. While the primary focus was on railroad bridge inspection, data was also collected on auto bridges and a historic covered bridge that was slated for renovation. Decision support tools consisted of image catalogs containing still imagery and thermal scans (Figure 31), videos, and 3D models.

The data that can be collected by multi-rotor UAS are unmatched in that the images provide verifiable evidence of condition. The problem lies with the volume of data. For one railroad bridge, two hours of UAS inspection yielded over 6GB of images, videos, and 3D models. The total amount of inspection data for the bridge, which was built in 1904, before the UAS data collect was less than 15MB. This project was not able to address the challenges of fully utilizing these data through an enterprise distribution system that would enable the data to be accessible to bridge inspectors in the office and the field. Another shortcoming is that the still images cannot be associated with individual bridge components (e.g. a bolt) unless they are tagged as such during the flight. The integration of 3D models with other 3D data (e.g. terrestrial and airborne lidar scans) is also an area ripe for future research.

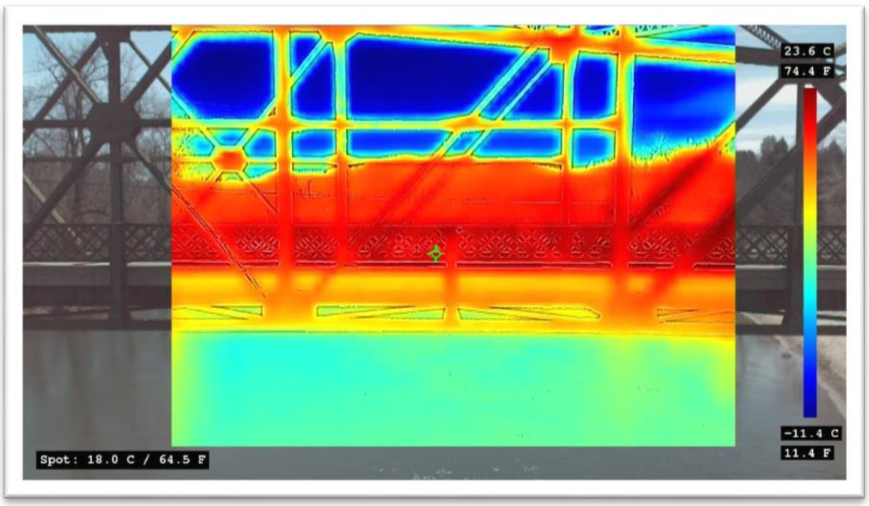

Figure 31. Thermal image of a bridge collected using a multi-rotor UAS.

A detailed 3D model with over 150 points per square meter was developed for a historic covered bridge in Waitsfield, VT slated for renovation (Figure 32). The model was considered valuable by state historic preservationists and cost less than 1/5th of what a lidar scan would have cost.

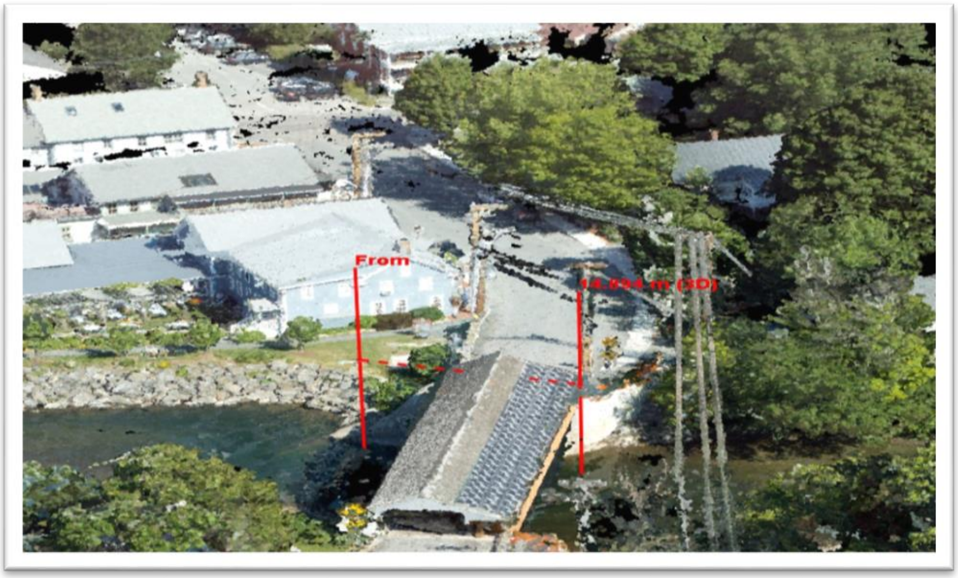

Figure 32. UAS-derived 3D model of a historic covered bridge under construction.

CHAPTER 3: OUTREACH

3.1. TRAINING & OUTREACH

Three workshops were conducted as part of this project. The first occurred on Wednesday, November 11, 2015, at the NEARC conference in Burlington, VT. NEARC is a regional, annual geospatial conference. 34 people attended the workshop, which consisted of a presentation along with a live demonstration of multi-rotor and fixed-wing UAS operations. The second workshop took place on June 22, 2016, at Harvard University. The workshop, which devoted an entire day to training personnel from international disaster relief agencies on UAS, was carried out in collaboration with the Harvard Humanitarian Initiative. Attendees participated in a live fixed-wing UAS flight demonstration, learned how to process UAS data, and were informed on a variety of technical, ethical, and legal issues surrounding UAS. 28 people attended the workshop. The final workshop was a two-day event held for transportation professionals at the University of Vermont on August 9-10, 2016. Twelve people attended the workshop. The first day was devoted to UAS flight operations. All attendees learned how to plan and execute fixed-wing UAS operations to support 2D and 3D geospatial product generation. In the second day, attendees devoted the morning to process UAS data and then spent the afternoon integrating the UAS products with other geospatial datasets. A YouTube playlist of 21 training videos we produced or participated in is accessible online (https://www.youtube.com/playlist?list=PLG0a9U3eef7oQquIJC9I3p8reS_mk9_-k). The training workbook is presented in Appendix C.

3.2. PUBLICATIONS, PRESENTATION, & MEDIA COVERAGE

3.2.1. PRESENTATIONS

- TRB 2015: January 11, 2015
- VTrans Aviation Section: April 5, 2015
- Montpelier High School: April 13, 2015
- Spatial Informatics Group: April 13, 2015
- Vermont Local Emergency Planning Committee: April 14, 2015
- Northeastern Vermont Development Association: April 17, 2015
- Rutland Airport: April 23, 2015
- Oklahoma CRSSI DOT meeting: April 29, 2015
- Central Vermont Regional Planning Commission: May 1, 2015
- Spatial Networks: May 11-12, 2015
- US Department of Interior: May 13, 2016
- VT National Guard Intel Symposium: May 17, 2015
- Airshark: May 18, 2015
- VTrans Mapping Division: May 18, 2015
- Vermont Geospatial Forum: June 2, 2015
- Dubois & King UAS presentation: June 4, 2015
- Town of Plainfield: June 25, 2015
- Stantec: July 16, 2015.
- Champlain College: August 2, 2015

- Vermont Enterprise Geospatial Consortium Emergency Management Workgroup: August 5, 2015
- Malone & MacBroom: September 8, 2015
- NEURISA presentation: September 14, 2015
- Town of Plainfield Flood Committee: September 17, 2015
- Tahoe Science Consortium: September 23, 2015
- FEMA: September 30, 2015
- VT State Senate Judiciary Committee: October 12, 2016
- NEARC 2015: November 9, 2015
- CRS&SI Workshop #2: December 2, 2015
- Earth Science Information Partnership: December 5, 2016
- TRB 2016: January 11, 2016
- Governor's Emergency Preparedness Advisory Committee: January 26, 2016
- VCGI Webinar: January 26, 2016 https://youtu.be/jSpm5BC2x6c
- UAS for Transportation, GIS for Strategic Asset Management: February 18, 2016.

3.2.2. Publications

- "GIS-Ready sUAS." XYHT magazine. http://bt.e-ditionsbyfry.com/publication/?i=258885
- "UAS Photogrammetric Point Clouds: A Substitute for LiDAR?" LiDAR Magazine -- http://www.lidarmag.com/PDF/LiDARMagazine_ONeilDunne-UASPointClouds_Vol5No5.pdf
- "Do We Have Enough Parking? A Remote-Sensing Approach to Parking Inventory." Erath Imaging Journal - http://eijournal.com/print/articles/do-we-have-enough-parking-a-remote-sensing-approach-to-parking-inventory

3.2.3. Media Coverage

- Inside Unmanned Systems. An overview of the how this project was influenced by the damage Tropical Storm Irene caused to Vermont's transportation network. http://insideunmannedsystems.com/tropical-storm-irene-prompts-uas-research-at-the-university-of-vermonts-spatial-analysis-lab/
- WCAX. How UAS technology is being employed at the University of Vermont to assist in recovering from natural diasters. http://www.wcax.com/story/29697525/drones-put-to-work-to-avoid-natural-disasters
- Times Argus. The NADO Excellence in Regional Transportation Award was given to the Team in recognition of the project work with one of the regional planning agencies to assist the Town of Plainfield, VT with their bridge redesign efforts. http://www.timesargus.com/articles/bridge-project-study-nets-award-for-plainfield/
- Slate. Describes how the Team employed UAS technology to respond to the Amtrak train derailment in Vermont. http://www.slate.com/blogs/future_tense/2015/10/09/how_vermont_used_drones_after_an_amtrak_derailment.html?wpsrc=sh_all_mob_tw_top

- WCAX. The "odd jobs" segment reports on interesting jobs. Project PI Jarlath O'Neil-Dunne was interviewed and his work on this project was discussed. http://www.wcax.com/story/30251032/odd-jobs-geospatial-analyst
- Vermont Public Radio. Segment on the issues surrounding UAS technology in Vermont. Project PI Jarlath O'Neil-Dunne is one of two guests. http://digital.vpr.net/post/eye-sky-drones-vermont#stream/0
- Vermont Public Radio 2015 best of. The above interview was cited as one of the "best of" for 2015. http://digital.vpr.net/post/pattis-best-2015-drones-school-lunches-and-armenian-genocide
- Senator Tim Ashe highlights Northfield train crash on VPR (starting at 6:30). In an interview on Vermont Public Radio (VPR), State Senator Tim Ashe highlights the work of this project in responding to the Amtrak drain derailment. http://digital.vpr.net/post/bill-seeks-balance-privacy-rights-law-enforcement-needs
- Inside Unmanned Systems. Coverage of how the UAS data from this project assisted a consulting engineering firm in coming up with a bridge design for the town of Plainfield, VT. http://insideunmannedsystems.com/data-and-images-from-uas-used-to-help-improve-bridge-design-prevent-flooding/
- WCAX. TV news segment on how this project is using UAS technology to make the transportation infrastructure in the state more resilient to natural disasters. http://www.wcax.com/story/31329449/tracking-vermont-storm-damage-by-drone
- Commercial UAV Expo. Interview conducted with project PI Jarlath O'Neil-Dunne on how UAS technology is assisting with assessing flood damage and emergency response. http://www.expouav.com/assessing-flood-damage-emergency-situations-and-more-with-drones/
- ABC News. A summary article on how states are making use of UAS. This project is mentioned in the article. http://abcnews.go.com/Technology/wireStory/traffic-backed-bridge-states-deploying-drones-37962071
- AASTHO Transportation TV. A video summary of how UAS are being used in the transportation sector. This project receives coverage. https://youtu.be/ppvL5CZqumM
- Seven Days. This article on "International Drone Day" mentions our project Team. http://www.sevendaysvt.com/vermont/international-drone-day-siv442/Content?oid=3349618
- Burlington Free Press. Sunday cover story on how our project Team is using UAS technology to help local government's with the transportation challenges. http://www.burlingtonfreepress.com/story/news/local/vermont/2016/07/24/uvm-lab-cutting-edge-drone-tech/87434586/

CHAPTER 4: BUSINESS MODEL

4.1. OPERATING COSTS

Over the duration of the project, a detailed accounting was conducted of all costs associated with parts, supplies, travel, operations, training, computer software, computer hardware, and repairs. With assistance from a senior class project in the Grossman School of Business, we determined that the annual cost of sustaining a functioning UAS program is $38,400, excluding salaries. After multiple iterations, we adopted a straightforward cost recovery structure for UAS operations.

Fixed-wing mobilization cost: $500

Multi-rotor mobilization cost: $660

Fixed-wing and multi-rotor mobilization cost: $730

Mapping cost per 200 acres: $310

Multispectral mapping surcharge per 200 acres: $120

Bridge inspection, small: $420

Bridge inspection, medium: $690

Bridge, inspection, large: $1,710

Mileage: $0.45

4.2. COMPARISONS TO EXISTING APPROACHES

Satellite imagery. Costs per unit area are 25%-200% cheaper for areas up to 1500 acres. It should also be noted that UAS imagery offer a ~10x improvement in the spatial resolution, are not affected by cloud cover, and have a faster turnaround.

Aerial imagery from traditional aircraft. Costs per unit area are 150%-800% cheaper for areas up to 1500 acres. The turnaround for UAS products can be weeks or days faster.

Field-based surveying. In most cases, UAS should not be considered a replacement for field-based surveying, but rather a complementary technology that can reduce the work of a field survey crew. Over the course of this project we partnered with a number of survey firms on topographic mapping work in support of transportation projects. When traditional survey techniques are coupled with UAS-based surveying, project times decreased in the range of 125%-250%, saving $2500-$8000.

Field-based surveying. The most compelling cost reduction associated with UAS is that it reduces the need for inspection equipment that can cost upwards of $500,000. Furthermore, UAS can access areas of the bridge that traditional techniques cannot. UAS are not a direct replacement for traditional techniques as “hands-on” inspections are an important component of examining bridge infrastructure, but they offer time savings of anywhere from 50%-500% for a given bridge.

APPENDICES

Appendix A – UAS Operations Manual

Appendix B – UAS Standard Operating Guidelines

Appendix C – Workshop Training Materials

Appendix D - Geomorphic Assessment UAS

Appendix E - Airport Approach UAS

Appendix F - Airport Construction UAS

Appendix G - Bridge Inspection with UAS

Appendix H - Cost Decision Support UAS

Appendix I - Resource Allocation using UAS

Appendix J - UAS Inspection Fact Sheet

Appendix K - UAS Mapping FactSheet