Rapid Exploitation of Commercial Remotely Sensed Imagery for Disaster Response & Recovery

Principal Investigator: Jarlath O'Neil-Dunne
Program Manager: Caesar Singh

COOPERATIVE AGREEMENT
No. RITARS-12-H-UVM

Final Progress Report

December 1, 2012 through May 31, 2015

The University of Vermont Transportation Research Center

University of Vermont Spatial Analysis Lab

United States Department of Transportation

Table of Contents

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
PI	Principal Investigator
PM	Program Manager
RiP	Research in Progress database
RITA	Research and Innovative Technology Administration
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

Executive Summary

Natural disasters can severely impact transportation networks. In the hours and days following a major flooding event, knowing the location and extent of the damage is crucial for incident managers for a number of reasons: it allows for emergency vehicle access to affected areas; it facilitates the efficient rerouting of traffic; it raises the quality and reduces the cost of repairs; and it allows repairs to be completed faster, in turn reducing the duration of costly detours. Commercial Remote Sensing (CRS) imagery is increasingly being used in disaster response and recovery, but the ability to acquire CRS data far surpasses the ability to extract actionable information from it. An automated approach to damage assessment is needed, but traditional automated image analysis techniques are inadequate for identifying or characterizing transportation infrastructure damage from high-resolution CRS imagery. Furthermore, new CRS technologies, such as Unmanned Aircraft Systems (UAS) provide a novel approach to gathering imagery during a crisis in which traditional satellite and aerial systems are either cost prohibitive, ineffective, or unresponsive. We propose a project with two objectives: 1) to develop, calibrate and deploy a decision support system capable of identifying road and bridge damage from high-resolution commercial satellite images and; b) to estimate the amount and type of fill material required for repairs using digital surface models derived from lightweight Unmanned Aerial Vehicles (UAS) programmed to fly over damage road segments. This approach would employ state-of-the-art, object-based image analysis techniques, cost-based image matching, and other advanced computing techniques. We also propose to collaborate with state departments of transportation to develop a web-based interface to share information derived from CRS Imagery.

Conclusion

This project succeeded in meeting its two main objectives. The first, to automate the detection of damaged transportation infrastructure from commercial satellite imagery was accomplished through the development of software that provides users with limited remote sensing expertise the ability to rapidly locate areas of damage. The second objective, to develop techniques that enable the volume of fill needed to repair damaged roadways to be estimated from data collected by UAS, was accomplished through the integration of commercial UAS hardware and geospatial software. Perhaps most importantly, the UAS work conducted as part of this project laid the foundation for UAS operations in support of transportation decision support in State of Vermont.

Technical Summary

Task 1 - Creation of a Technical Advisory Committee

We will recruit a committee of relevant professional (e.g. state DOT representatives, academics) near the outset of the project to advise on project activities. A full description of the project tasks can be found in Section 2 of the Cooperative Agreement.

<u>Output/Deliverables:</u> The Advisory Board comprised of 6 to 8 members will provide guidance in specific technical and policy recommendations that the team would take into consideration for implementation. Notes will be taken at each meeting and provided to members as a brief summary report.

<u>Accomplishments:</u>

Provide a clear and complete account of work performed on each task and its relationship to task objectives and milestones.

- The project team created a Technical Advisory Committee (TAC)
  - The Advisory Committee was initially comprised of the following individuals:
    - Guy Rouelle, Aviation Program Administrator, Vermont Agency of Transportation (VTrans)
    - Stephanie Magnan, Asset Management Specialist, VTrans
    - Wayne Gammell, Maintenance Administrator, VTrans
    - Johnathan Croft, GIS Database Administrator, VTrans
    - Zach Borst, Vermont Emergency Management (VEM) Regional Outreach Coordinator (Dec 2012-Nov 2013)
    - Michele Boomhower, Chittenden County Regional Planning Commission (CCRPC) Assistant/Metropolitan Planning Organization (MPO) Director
    - Christopher Jolly, Planning & Programming Engineer, Federal Highway Association (FHWA) - Vermont Division
    - Roger Thompson, ITS/Safety Engineer, FHWA - Vermont Division
    - Charles Hebson, Manager of Surface Water Resources, Maine Department of Transportation (DOT)
    - Amanda Hanaway, Burlington International Airport Engineer (March 2015-May 2015)
  - The TAC met as a group and individually throughout the life of the project and provided input to all tasks and all stages. Key TAC Members became more involved in the project and assisted in the development of further funding opportunities throughout the project as well creating connections with other State Agencies such as VT Agency of Natural

Resources, VT DEMHS, the Vermont National Guard, and local Construction and Engineering firms. Many TAC members continued on as members for OASRTRS-14-H-UVM.

<u>Effort Expended:</u>

Effort expended by task for all staff categories must be reported.

Employee Name/ Labor Category	Budgeted Hours	Revised Budgeted Hours*	Revised Budgeted Hours**	Year 1 (hours)				Year 2 (hours)				Year 3 (hours)		Cummulative
				Quarter 1	Quarter 2	Quarter 3	Quarter 4	Quarter 5	Quarter 6	Quarter 7	Quarter 8	Quarter 9	Quarter 10	(hours)
Austin Troy	200	93.84	93.84	56.5	13.34	24								93.84
Allan Strong	0	0.00	0.00							6	11.88	11.88	6	35.76
Jarlath O'Neil Dunne	50	129.52	129.52	30		15	14.38	15	15		40.14	39.68	36.38	205.58
Ernest Buford	0	0.00	0.00											0
Amanda Hanaway	180	263.96	168.13	16	25	20	23.13	20	20	8	18	18		168.13
Sean MacFadden	0	0.00	0.00											0
James Sullivan	24	24.00	20.00	6	4	2	6	2						20
Zachary Borst	0	TBD	171.77					30	30	30	30	20		140
Technician	0	0.00	0.00											0

Task 2 - Creation of a project website

We will create a project website which will stay in operation throughout the duration of the project and will help to organize, centralize, and disseminate information from the project.

<u>Output/Deliverables:</u> A project web site will be created on the University of Vermont domain (www.uvm.edu) containing a password protected section for internal documents and data products that have access/use restrictions associated with them (e.g. commercial satellite imagery) as well as access to up-to-date documents deemed suitable for the public domain.

<u>Accomplishments:</u>

Provide a clear and complete account of work performed on each task and its relationship to task objectives and milestones.

- The project team has created and maintained a project website for 30 months, the project website will be maintained and kept active as long as is possible though updates will cease 90 days past the end date of this agreement.
- The website has been and will continue to be a repository for agreement documents, deliverables, and products including the following:
    - Project Demographics (Team, TAC Members, TAC Minutes, Quarterly Reports and other project documents)
    - Project Deliverables (News, Updates, Webinars, and White papers)
- A password protected section exists and will remain the repository for our SOP, Flight Checklist, and application to the UVM UAS Working Group for flight operations on this project.

- http://www.uvm.edu/trc/rapid-exploitation-of-commercial-remotely-sensed-imagery-for-disaster-response-recovery/

<u>Effort Expended:</u>
Effort expended by task for all staff categories must be reported.

Employee Name/ Labor Category	Budgeted Hours	Revised Budgeted Hours*	Revised Budgeted Hours**	Year 1 (hours)				Year 2 (hours)				Year 3 (hours)		Cummulative
				Quarter 1	Quarter 2	Quarter 3	Quarter 4	Quarter 5	Quarter 6	Quarter 7	Quarter 8	Quarter 9	Quarter 10	(hours)
Austin Troy	42	38.88	38.88	15	13.75	10.13								38.88
Allan Strong	0	0.00	0.00											0
Jarlath O'Neil Dunne	16	18.34	18.34	9	0						9.34	9.2	9.00	36.54
Ernest Buford	6	6.00	6.00		6									6
Amanda Hanaway	76	78.47	85.50	32.75	12.75	4	5	5	5	7	7	7		85.5
Sean MacFadden	0	0.00	0.00											0
James Sullivan	36	36.00	36.00	18.38	10.38	2	5.24							36
Zachary Borst	0	0.00	0.00											0
Technician	0	0.00	0.00											0

Task 3 - Damage detection system methods development
Design, develop, deploy, and validate a decision support system that automates the detection of post-event damage to roads from CRS satellite imagery and provides actionable information to incident commanders.

<u>Output/Deliverables:</u> We will develop, validate, and accurately assess a methodology for automating the identification of large road damage. This methodology will result in the development of a "knowledge base" of expert classification rules that remote sensing technicians can then reuse in other location. This knowledge base will be made available on our website along with documentation and tutorials on using it (see Task 6). We will also create and post an ESRI geoprocessing utility or standalone utility that extracts the geographic coordinates of the center of each damage polygon and then sends that coordinate to a web server (see Task 5).

<u>Accomplishments:</u>
Provide a clear and complete account of work performed on each task and its relationship to task objectives and milestones.

- Commercial satellite imagery was obtained from DigitalGlobe for three areas affected by natural disasters in Colorado, New York, and Vermont.
- A rule-based expert system was developed to automate the detection of damage to roads stemming from a natural disaster, such as flooding and debris.
- The rule-based expert system was tested and validated across numerous satellite images.

- A user interface for the rule-based expert system was developed that enabled a user with limited remote sensing expertise to adjust a limited number parameters enabling the system to work with varied data streams.
- The knowledge base, including documentation and tutorials is posted to the website and kept available as a resource indefinitely for those agencies to call upon as needed during major disasters and other emergency events.
- The development of the geoprocessing utility proved unnecessary as this functionality was incorporated into the damage detection system.
- A manual for the damage detection system was written and is attached as an appendix.
- A tutorial video that provides and overview of the damage detection system can be found here: https://youtu.be/G3cEp-x4c1s

<u>Effort Expended:</u>

Effort expended by task for all staff categories must be reported.

Employee Name/ Labor Category	Budgeted Hours	Revised Budgeted Hours*	Revised Budgeted Hours**	Year 1 (hours)				Year 2 (hours)				Year 3 (hours)		Cummulative
				Quarter 1	Quarter 2	Quarter 3	Quarter 4	Quarter 5	Quarter 6	Quarter 7	Quarter 8	Quarter 9	Quarter 10	(hours)
Austin Troy	42	28.66	28.66		8.66	20								28.66
Allan Strong	0	0.00	0.00								10	10		20
Jarlath O'Neil Dunne	30	49.98	49.98		13	6	6	15	5		4.98	4.88		54.86
Ernest Buford	0	0.00	0.00											0
Amanda Hanaway	170	170.00	133.13		11	37.13	35	10	10	10	10	10		133.13
Sean MacFadden	1191	1191.00	1191.00	325	406.25		172.25	172.25		115.25				1191
James Sullivan	30	30.00	30.00		10	5	15							30
Zachary Borst	0	0.00	0.00											0
Technician	0	0.00	0.00											0

Task 4 - Fill calculation system methods development

Design, develop, deploy, and validate a decision support system that uses CRS Unmanned Aircraft Systems (UAS) to estimating the amount and type of fill material needed to fill damaged areas.

<u>Output/Deliverables:</u> We will develop, validate, accurately assess and document a methodology for automating the calculation of the quantity of fill by type for road damage voids caused by flooding. We will produce a technical document and tutorial that outlines this methodology (see Task 6). We will also produce and make available an ESRI geoprocessing tool capable of performing the fill calculations.

<u>Accomplishments:</u>

Provide a clear and complete account of work performed on each task and its relationship to task objectives and milestones.

- Methods for operating and processing UAS data in support of volume estimation were developed and executed. These activities included the purchase of a UAS, training on its proper use, and the development of flight and equipment checklists.

- Over 60 UAS flights were carried out over the course of the project, under a variety of terrain and in a broad range of weather conditions.
- The geoprocessing workflow for the fill calculations was developed and implemented using Applied Imagery's Quick Terrain Modeler software package.
- The fill estimation methods developed using UAS data were validated against terrestrial LiDAR data. It was found that UAS data provide volume estimates that are within 5% of those obtained from terrestrial LiDAR.
- A video demonstrating the fill estimation methodology can be found here: https://youtu.be/nreeLlgcKy4

Effort Expended:
Effort expended by task for all staff categories must be reported.

Employee Name/ Labor Category	Budgeted Hours	Revised Budgeted Hours*	Revised Budgeted Hours**	Year 1 (hours)				Year 2 (hours)				Year 3 (hours)		Cummulative
				Quarter 1	Quarter 2	Quarter 3	Quarter 4	Quarter 5	Quarter 6	Quarter 7	Quarter 8	Quarter 9	Quarter 10	(hours)
Austin Troy	20	10.00	10.00			10								10
Allan Strong	0	0.00	0.00							6	10	10		
Jarlath O'Neil Dunne	295	309.98	255.02		71.38	68.38	4	61.88	39.38		10.00	10.00		265.02
Ernest Buford	226	226.00	226.00		34.63	167.21				24.16				226
Amanda Hanaway	49	49.00	10.00							10				10
Sean MacFadden	366.9	366.90	366.90				166.9	166.9		33.1				366.9
James Sullivan	40	40.00	26.76			10	12.76	4						26.76
Zachary Borst	0	TBD	0.00											0
Technician	50	50.00	50.00				20	8	8		0			36

Task 5 - Development of web portal decision support tool
Develop web-based decision support tools and GIS data layers, and disseminates information on road damage via social media.

Output/Deliverables: Outputs will include development of a front-end website prototype on our own servers which will pull data from Google Fusion Tables, which is a cloud-based platform. We will then work with our VTrans partners to make these data sets and web resources available to them so that they can freely integrate them into their online information systems. We will document the process of developing the portal and will write up manuals for both users and for website administrators.

Accomplishments:
Provide a clear and complete account of work performed on each task and its relationship to task objectives and milestones.

- A web-based decision support tool was developed to display the results of the automated damage detection system using three online platforms, allowing for a flexible yet robust implementation.
- A manual on how to implement the web-based decision support tool was published to the web site and is attached as an appendix.

<u>Effort Expended:</u>

Effort expended by task for all staff categories must be reported.

Employee Name/ Labor Category	Budgeted Hours	Revised Budgeted Hours*	Revised Budgeted Hours**	Year 1 (hours)				Year 2 (hours)				Year 3 (hours)		Cummulative
				Quarter 1	Quarter 2	Quarter 3	Quarter 4	Quarter 5	Quarter 6	Quarter 7	Quarter 8	Quarter 9	Quarter 10	(hours)
Austin Troy	24.5	0.00	0.00											0
Allan Strong	0	0.00	0.00											
Jarlath O'Neil Dunne	157	193.70	10.00								10	10	15.00	35
Ernest Buford	158.02	158.02	158.65							39.22	126.75			165.97
Amanda Hanaway	40	40.00	0.00											0
Sean MacFadden	197.08	197.08	866.76				148.35	148.35		197.06	325		0.36	819.12
James Sullivan	16	16.00	0.00											0
Zachary Borst	0	TBD	0.00											0
Technician	880	880.00	880.00				79.5	37.5	49.5					166.5

Task 6 - Project outreach and communication

Make the methods and technologies developed in this project to be easily transferable to other state DOTs.

<u>Output/Deliverables:</u> We will complete, make available and disseminate all outreach materials. For the damage-detection methodology, this will include our knowledge base of classification/detection rules, which can then be ported and reused in object-based image-classification software using different imagery, as well as a detailed methodological document and video tutorial that will assist technicians in replicating this system. For the fill calculation task, it will include the ArcGIS geoprocessing tool files and user manual, a methodological document, and a set of video tutorials. For the decision support portal development, we will include a methodological document about setting up the interface and serving the data from Google Fusion Tables, as well as guides for users and administrators. We will hold a focus group meeting with select partners to get feedback on our outputs and determine what additional information or clarification may be needed for subsequent adopters to make use of the project's methods. We will also follow up with VTrans and, if applicable, other New England DOTs, to determine if and how the methods we developed were actually employed and what improvements could potentially be made. Finally, we will write a final report (draft and revised versions), give presentations on the project at professional meetings and prepare manuscripts on the project for publication.

<u>Accomplishments:</u>

Provide a clear and complete account of work performed on each task and its relationship to task objectives and milestones.

- The aforementioned tools, methods, and corresponding videos and documentation were made available through the project web site.
- The project team was able to reach out to many external entities through social media, the website, presentations at local and national conferences, and flight

operations. Key accomplishments include four blog posts, three videos, four technical documents, nine presentations, and two publications.

- Numerous informal briefings were given to the Vermont Agency of Transportation, the Vermont Agency of Natural Resources, the Vermont National Guard, the Vermont Department of Homeland Security and Emergency Management, Regional Planning Commission, Local Emergency Planning Commissions, and elected officials, and local transportation planners.

<u>Effort Expended:</u>

Effort expended by task for all staff categories must be reported.

Employee Name/ Labor Category	Budgeted Hours	Revised Budgeted Hours*	Revised Budgeted Hours**	Year 1 (hours)				Year 2 (hours)				Year 3 (hours)		Cummulative
				Quarter 1	Quarter 2	Quarter 3	Quarter 4	Quarter 5	Quarter 6	Quarter 7	Quarter 8	Quarter 9	Quarter 10	(hours)
Austin Troy	100.5	10.62	10.62			10.62								10.62
Allan Strong	0	0.00	0.00							6	12	12	6	
Jarlath O'Neil Dunne	78.18	123.12	71.79		5			30	30		6.79	6.67	16.00	94.46
Ernest Buford	0	0.00	0.00											0
Amanda Hanaway	69.99	114.93	85.87			12	10	13.75	13.75	13.75	13.75	8.87		85.87
Sean MacFadden	0	0.00	0.00											0
James Sullivan	165.98	165.98	23.76			5.38		18.38						23.76
Zachary Borst	0	TBD	270.02					43.13	43.13	43.13	43.13	28.73	24.37	225.62
Technician	70	70.00	22.50								0			0

Business Status

Labor-Hours Expended for the Program

Provide a tabulation of the planned, actual and cumulative labor-hours expended for the program.

Employee Name/ Labor Category	Total Budgeted Hours	Revised Total Budgeted Hours*	Revised Total Budgeted Hours**	Year 1 (hours)				Year 2 (hours)				Year 3 (hours)		Cummulative
				Quarter 1	Quarter 2	Quarter 3	Quarter 4	Quarter 5	Quarter 6	Quarter 7	Quarter 8	Quarter 9	Quarter 10	(hours)
Austin Troy	429.00	182.00	182.00	71.5	35.75	74.75	0	0	0	0	0	0	0	182
Allan Strong	0.00	0.00	0.00	0	0	0	0	0	0	18	43.88	43.88	12	117.76
Jarlath O'Neil Dunne	626.18	824.64	534.65	39	89.38	89.38	24.38	121.88	89.38	0	81.25	80.43	76.38	691.46
Ernest Buford	390.02	390.02	390.65	0	40.63	167.21	0	0	0	63.38	126.75	0	0	397.97
Amanda Hanaway	584.99	716.36	482.63	48.75	48.75	73.13	73.13	48.75	48.75	48.75	48.75	43.87	0	482.63
Sean MacFadden	1,754.98	1,754.98	2,424.66	325	406.25	0	487.5	487.5	0	345.41	325	0	0.36	2377.02
James Sullivan	311.98	311.98	136.52	24.38	24.38	24.38	39	24.38	0	0	0	0	0	136.52
Zachary Borst	0.00	0.00	441.79	0	0	0	0	73.13	73.13	73.13	73.13	48.73	24.37	365.62
Technician	1,000.00	1,000.00	952.50	0	0	0	99.5	45.5	57.5	0	0	0	0	202.5

Funds Expended for the Program

Provide a chart showing current and cumulative expenditures versus planned expenditures

Employee Name/ Labor Category	Total Invoiced for Salary	Revised Total Invoiced for Salary*	Revised Total Invoiced for Salary**	Year 1 (Invoiced Salary)				Year 2 (Invoiced Salary)				Year 3 (hours)		Cummulative (Invoiced Salary)
				Quarter 1	Quarter 2	Quarter 3	Quarter 4	Quarter 5	Quarter 6	Quarter 7	Quarter 8	Quarter 9	Quarter 10	
Austin Troy - Regular	$0.00	$0.00	$8,723.04	$0.00	$0.00	$8,723.04	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$8,723.04
Austin Troy - Cost Share				$8,343.78	$4,171.89	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	
Allan Strong - Regular	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Allan Strong - Cost Share				$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$3,351.75	$8,170.83	$8,170.83	$2,234.50	
Jarlath O'Neil Dunne - Reg	$45,570.75	$64,239.71	$55,210.75	$3,038.10	$6,962.71	$6,962.71	$1,899.20	$9,494.45	$6,962.70	$0.00	$6,788.76	$6,720.25	$6,381.85	$55,210.75
Jarlath O'Neil Dunne - CS				$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	
Ernest Buford	$107,418.82	$107,418.82	$148,408.59	$0.00	$2,306.16	$9,490.84	$0.00	$0.00	$0.00	$3,597.45	$7,194.33	$0.00	$0.00	$22,588.78
Amanda Hanaway	$23,559.89	$23,559.89	$10,309.62	$3,596.78	$3,596.78	$5,395.53	$5,395.53	$3,596.78	$3,596.78	$3,771.20	$3,771.20	$3,393.70	$0.00	$36,114.26
Sean MacFadden	0	0	$23,929.56	$19,891.95	$24,864.94	$0.00	$29,839.88	$29,839.88	$0.00	$21,142.55	$19,893.25	$0.00	$22.04	$145,494.47
James Sullivan	$19,891.05	$19,891.05	$18,946.23	$1,813.91	$1,813.91	$1,813.91	$2,988.70	$1,868.32	$0.00	$0.00	$0.00	$0.00	$0.00	$10,298.73
Zachary Borst	$0.00	$0.00	$0.00	-	-	-	-	$3,446.62	$3,446.62	$3,607.14	$3,607.14	$2,403.61	$1,202.05	$17,713.17
Technician	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$1,979.26	$905.09	$1,143.80	$0.00	$0.00	$0.00	$0.00	$4,028.15
Non-Salary Expenditures	$71,578.65	$59,062.99	$71,578.65	$0.00	$25,987.91	$3,603.04	$939.72	$1,333.84	$322.00	$4,063.82	$798.20	$1,294.28	$33,235.84	$71,578.65
Non-Salary Cost Share				$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$300,000.00	$0.00	$0.00	$41,442.50	$341,442.50
Total	**$268,019.16**	**$274,172.45**	**$371,750.00**	**$28,340.74**	**$65,532.40**	**$35,989.07**	**$43,042.29**	**$50,484.97**	**$15,471.89**	**$36,182.15**	**$42,052.88**	**$13,811.83**	**$40,841.78**	$371,750.00
Cost Share:	$382,630.00	$373,118.00	$375,886.09	$8,343.78	$4,171.89	$0.00	$0.00	$0.00	$0.00	$303,351.75	$8,170.83	$8,170.83	$43,677.00	$375,886.09
Invoiced:	$371,750.00	$371,750.00	$371,750.00	$28,340.74	$65,532.40	$35,989.07	$43,042.29	$50,484.97	$15,471.89	$36,182.15	$42,052.88	$13,811.83	$40,841.79	$371,750.00
Total:	**$754,380.00**	$744,868.00	$747,636.09	**$36,684.51**	**$69,704.29**	**$35,989.07**	**$43,042.29**	**$50,484.97**	**$15,471.89**	**$339,533.91**	**$50,223.71**	**$21,982.66**	**$84,518.79**	**$747,636.09**

Notes on Cost Share

1) The $300,000 match from Trimble was recorded in quarter 3 of 2014.
2) GeoEye, who agreed to the original match, was acquired by DigitialGlobe after the project began. In addition, the program manager who made the agreement with us left the company after the acquisition. Despite this, DigitalGlobe agreed

to honor the imagery donation. The match from DigitalGlobe was recorded in quarter 10 of the project, quarter 3 of 2015.

3) The $27,797 in match from former Principal Investigator Austin Troy, was partially met with his effort in the first year, for year two the match was met with effort from Principal Investigator Jarlath O'Neil-Dunne and Faculty Advisor Allan Strong.

Budget for Non-Salary Expenditures

Airfare Domestic	$1,831.20
Computing Supplies	$163.48
Conference Regstr Fee Domestic	$375.00
Consult/Prof Svcs Org Fees	$1,820.00
Express Mail & Delivery Svcs	$90.22
IC - Micro Comp Srvcs/Accsr	$72.00
IC – Research Services	$14,480.66
Laboratory & Research Supplies	$1,186.22
Lodging Domestic	$854.40
Mileage Domestic	$220.92
Meals Domestic	$217.56
Other Domestic Travel	$91.00
Shipping	$282.44
Non-Cap Cmptr Hardware <$5000	$3,047.72
Non-Cap Equip < $5000	$3,705.00
Non-Cap Moveable Equip >$5000	$24,167.91
Grand Total	$52,605.13

Meetings

List of Advisory Committee Meetings:

- 3/19/2013 Meeting. Meeting minutes and webinar recording are provided on the project website.
- 12/6/13 Meeting. Meeting minutes and webinar recording are provided on the project website.
- 6/12/15 Meeting. Meeting minutes are provided on the project website.

List of Meetings with the USDOT Project Management Team:

- 1/15/14 Meeting. A technical and financial update was provided to Caesar Singh and Vasanth Ganesan. The meeting minutes will not be posted to the website due to the detailed level of information exchanged in the meeting.
- 8/8/14 Meeting. The USDOT Project Manager, Caesar Singh, visited the University of Vermont. The visit included a demonstration of the UAS flight and post-processing procedures. It also included a discussion of a Modification to the original proposal. The modification would act as a Phase II and would focus on more flights that demonstrate the versatility of the UAS, as well as establishing a process whereby it can be incorporated into State Agency operations.
- 1/12/15 Meeting. The project team met with Program Manage Ceaser Singh for the Annual Project Progress Meeting. Principal Investigator Jarlath O'Neil-Dunne presented on project updates and the roadmap to completion. The meeting minutes will not be posted to the website due to the detailed level of information exchanged in the meeting.
- 4/29-30/2015. US DOT CRS & SI Workshop in Oklahoma City, OK.

Presentations

- Emerging Remote-Sensing Technologies for Studying the Vermont Landscape. December 12, 2013, University of Vermont, Burlington, VT
- Rapid exploitation of commercial remotely sensed data for transportation damage assessment. January 12, 2014, Transportation Research Board, Washington D.C.
- Rapid Assessment of Storm-related Damage Using Commercial Remote-sensing Imagery. May 8, 2014, Geospatial Information Systems for Transportation Symposium in Burlington, VT.
- Rapid Exploitation of Commercial Remotely Sensed Imagery for Disaster Response & Recovery. June 6, 2014. University of Vermont Transportation Research Center, Brown Bag Lecture Series, Burlington, VT

- Unmanned Aerial Systems for Disaster Response and Recovery. May 6, 2014, Geospatial Information Systems for Transportation Symposium, Burlington, VT
- Unmanned Aerial Systems for Disaster Response and Recovery. July 16, 2014, Office of the Assistant Secretary for Research and Technology (OST-R) Transportation Innovation Series, Washington DC.
- Commercial Unmanned Aerial Systems for Transportation Decision Support. January 11, 2015, Transportation Research Board, Washington D.C.
- UAS for Transportation Decision Support. DOT CRS & SI Workshop, Oklahoma City, OK
- A Tool for the Automated Detection of Damaged Transportation Infrastructure. May 7, 2015, Imaging & Geospatial Technology Forum, Tampa, FL.

Publications

- MacFaden, S.W. and J.P.M O'Neil-Dunne. 2015. A Tool for the Automated Detection of Damaged Transportation Infrastructure. *Proceedings from the Imaging and Geospatial Technology Forum*, Tampa, FL, May 4-8, 2015.
- O'Neil-Dunne, J.P.M. A. Zylka, and S.W. MacFaden. Submitted. A Methodology for Fill Estimation of Damaged Roadways Using UAS. *Urban, Planning, and Transport Research*.

Partnerships

The Project Team collaborated not only with the project's Technical Committee, but the following organizations as well:

- Vermont Agency of Natural Resources. The project team worked with ANR on their stream monitoring program. The discussions focused around using Unmanned Arial Vehicles to monitor sections of rivers and streams that are difficult to access on the ground. After Tropical Storm Irene, it was determined that debris which had accumulated upstream was forced downstream and caused severe blockages.
- Vermont Agency of Transportation. The project team worked with the Maintenance and Operations Department at VAOT on their culvert maintenance program. The discussions focused on what is happening upstream which may be causing culverts downstream to become blocked. This working is being continued under the Vermont Research Advisory Council (RAC) Program project: "Using Remote Data Collection to Identify Bridges and Culverts Susceptible to Blockage During Flooding Events.
- Department of Emergency Management and Homeland Security. The project team is working with DEMHS on their critical infrastructure program. The discussions have been focused on how UASs and GIS data can be used to determine what should be considered critical infrastructure, and how to maintain and protect it better in the future. The project team also conducted a

demonstration of the UAS flight operations to DEMHS. The project team will be participating in the VT DEMHS and VT National Guard exercise, Vigilant Guard 2016, putting their Disaster Response capabilities into practice and further solidifying their ties with the emergency management community.

- Green Mountain Power. The project team met with Green Mountain Power to determine ways that a UAS could be incorporated into their processes and procedures.
- Vermont Department of Environmental Conservation. The project team worked with Todd Menees, P.E., P.H., a River Management Engineer in the Watershed Management Division of the Rivers Program at VT DEC, flying sites eligible for Hazard Mitigation Grant Program (HMGP) Buyout money through FEMA. The homes demolished by Irene are removed and the flood zone needed survey data to determine how to re-stabilize the banks.
- Town of Readsboro. The project team assisted the town by acquiring UAS data of an area damaged by flooding. The data is being used by the town for transportation and disaster response planning.
- Town of Wardsboro. The project team assisted the town by acquiring UAS data of an area damaged by flooding. The data is being used by the town for transportation and disaster response planning.
- Windham Regional Planning Commission. The project team assisted the commission by acquiring UAS data of an area damaged by flooding. The data is being used for transportation and disaster response planning.
- UVM, Dr. Jeff Frolik, The project team was able to borrow a Terrestrial LIDAR scanner from Dr. Frolik for use in the fill estimation validation task. The Terrestrial LiDAR scanner was obtained through a previous National Science Foundation Grant.