1.COVER SHEET

RITA-RS-11-01
Full Proposal: University of Vermont

Proposal Submitted by: For Use by DOT	Date Received	Proposal Number
Title of Project Rapid Exploitation of Commercial Remotely Sensed Imagery for Disaster Response & Recovery	Project Duration ____24____ months	
Name/Address of Submitting Organization, Business Contact, DUNS# and Taxpayer ID# Sylvie Butel University of Vermont 85 South Prospect Street, 340 Waterman Building Burlington, VT 05405 DUNS: 066811191 Tax ID: 030179440	Telephone 802-656-3360	Fax 802-656-8406
	Total Project Cost: $754,380________	
Submission Date	DOT Budget $___$371,750_______Cost Sharing $______$382,630___	
Business Type [x] Academic [ ] Profit [ ] Non-Profit	Total Project Cost $______$754,380	
Name/Address of Principal Investigator Austin Troy, PhD Transportation Research Center, 110 Farrell Hall University of Vermont 210 Colchester Ave, Burlington, VT 05405	Size (Number of Employees) [ ] <10 [ ] <100 [ ] <200 [x] >200	
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Summary

This project seeks to harness cutting-edge commercial remote sensing technology to develop decision support tools that will help state transportation departments by automating the process of identifying road damage after a major storm and determining the quantity of construction material needed to make repairs. The proposed tools will help improve the quality of repairs made after major storm events, reduce the cost of those repairs, and increase the speed with which the transportation network returns to its functional state.

2. Public Abstract

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 acquiring imagery is far easier than extracting actionable information from it. An automated approach to damage assessment is needed, but traditional automated image analysis techniques are inadequate for identifying or characterizing road and bridge damage from high resolution imagery. 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 (UAV) 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 the CRS imagery.

Figure 1. Bridge damage in southern Vermont as a result of flooding incurred during Hurricane Irene. Image source: Mansfield Flight LLC.

3. Technical Approach and Understanding

3.1 Project purpose and objectives

This project seeks to develop decision support tools that harness cutting-edge CRS technology and supports incident and asset managers in state transportation departments by automating the process of identifying road damage and determining the amount of construction materials needed to make repairs after a major storm. The intended benefits include saving transportation managers time and money, while increasing the quality and timeliness of repairs. Furthermore, the resulting information on the micro-topography of the roadway void and its surroundings would allow road repair engineers to better re-align roadways during repairs so that these road segments are less vulnerable to future flood damage.

The project is broken up into two objectives.

Objective 1: damage detection

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 via web-based decision support tools and GIS data layers, and disseminates information on road damage via social media.

Objective 2: fill estimation

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

For the first objective, we envision a decision support system that automates the detection of road damage from high-resolution CRS satellite data, then extracts damage point locations and delivers the information through a variety of decision support tools. The first delivery mechanism is a “dots on a map” web-based spatial decision portal that displays the location of the damage, a cropped satellite image of the damage area, and associated information that can be queried from existing transportation GIS data sets (e.g. road name, mile marker, etc.). The second delivery mechanism are point data themselves, in both KML and Shapefile format that can be ingested into either virtual globe software (e.g. Google Earth and ArcGIS Explorer) and standard desktop GIS software (e.g. ArcGIS Desktop and QGIS). The final delivery system will be via social media. As damage is detected, automatic geo-tagged alerts will be sent out via Twitter. The combination of these methods insures that the information will reach the broadest range of end users and provides the requisite decision support capabilities while enabled more advanced spatial queries to be run. It also has the advantage of using lightweight formats that stand the greatest success of reaching the intended end users during situations when communication networks are typically compromised.

For the second objective, we envision a semi-automated system that delivers a fully georeferenced 3D model along with a report containing detailed measurements and site characteristics to support calculation of needed fill quantities by type. This information will be attached to the point data set mentioned above such that users of the web interface could click on a point and immediately see a pop-up box giving the void volume and the estimated fill amounts by type.

The decision support tool described in Objective 1 will be designed and developed using data acquired before and after Hurricane Irene for Vermont, New Hampshire and New York. It will then be deployed to two other areas for final evaluation. These evaluation areas have yet to be chosen as priority will be given to disasters that occur during the course of the project. The desire is to deploy the system in differing geographic areas outside of New England. The decision support tool described in Objective 2 will be calibrated and validated in Vermont, and if requested by neighboring state transportation departments, deployed during either a disaster or to assess damage that occurs during the spring runoff season.

The overarching goal of this project is to develop a method and a set of tools by which raw imagery can be turned into actionable information for decision makers. As such, any automated approach must be both transferable and flexible. The tools for objective 1 will be designed and developed using data acquired in support of Hurricane Irene for the New York-New England region, as this is an event for which we have access to extensive data and personal knowledge. Testing our tools other geographic areas will insure that the system is both transferable and flexible, allowing the system to be modified by others and applied elsewhere, regardless of location. By adhering to industry standards for all inputs, outputs, and visualizations we will insure that the systems work for the broadest range of state transportation departments.

Furthermore, we will work closely with our state DOT partners to ensure that our research methods and outputs are relevant and useful to them and to DOTs beyond the region. We have already secured support from the seven DOTs for the New York-New England region (see attached letter of support), and we will be in frequent communication with personnel from those agencies as we build our research. We intend to convene a technical advisory committee which will be made up of engineers, technicians, incident/asset/program managers, planners, and decision makers from a selection of these agencies to help guide our research, ensure its relevance, and assist with issues around technical compatibility or systems and methods. This group will convene at the beginning of the project for an official "kick-off" and then again a minimum of twice per calendar year or more, as needed. We will designate a program liaison from the advisory committee with whom we will maintain regular contact in between meetings. Given the UVM Transportation Center staff's regular contact with VTrans and other regional DOTs, we expect this approach not to present any problems.

3.2 Detailed description of technical approach

3.2.1 Damage detection decision support (Objective 1)

Typically vast amounts of high-resolution CRS satellite imagery are acquired for an area following major disasters. Our technical approach seeks to bridge the gap that exists between the satellite imagery and the information on damaged roads and bridges that state transportation departments need to make timely decisions. Our proposed workflow (Figure 2) consists of three phases: (1) data preparation, (2) damage detection/feature extraction, and (3) decision support tools.

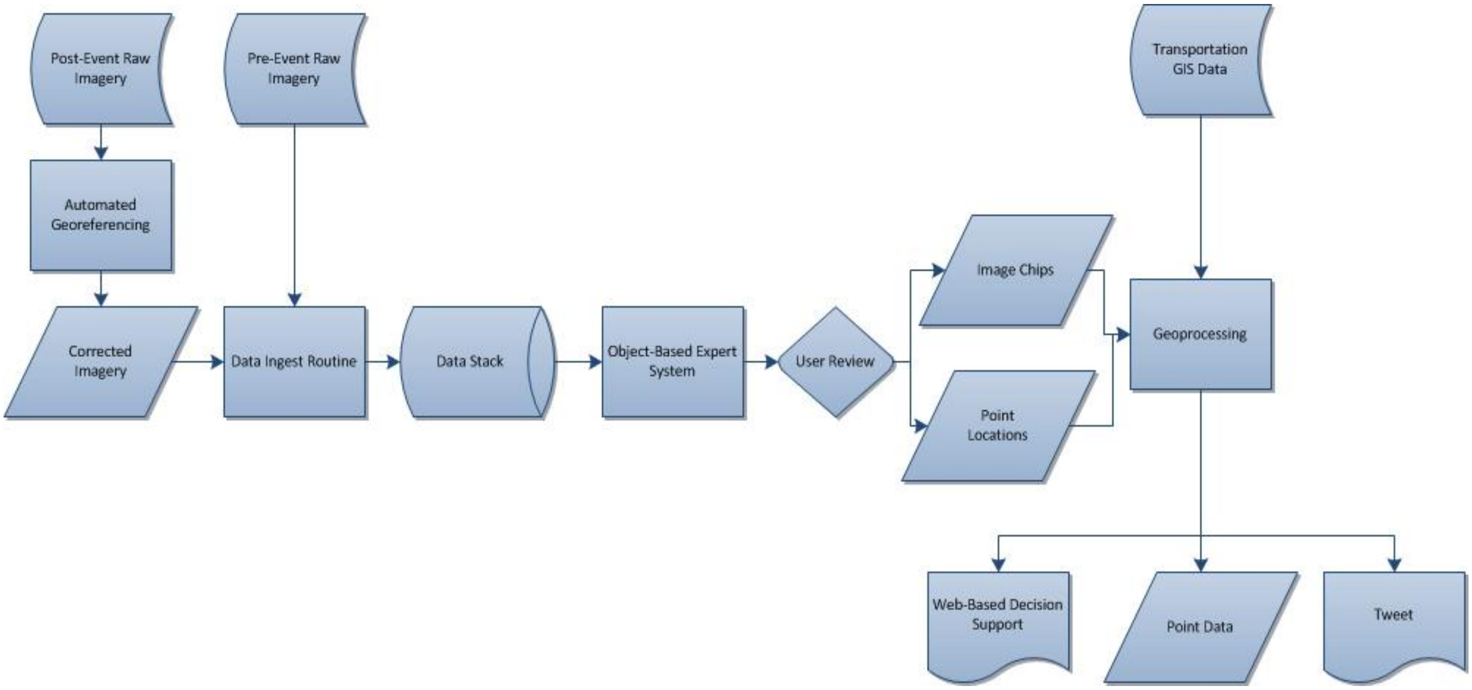

Figure 2. Proposed workflow for the damage detection decision support system (Objective 1).

The first phase of the workflow, data preparation, occurs once the CRS satellite imagery has been obtained, typically via an online portal such as the USGS Hazard Data Distribution System (HDDS). More details on the tasking of CRS systems through the International Charter are presented in section 5.1.2. Due to the rapid tasking and posting of CRS imagery to HDDS, the data are typically not georeferenced with sufficient accuracy to support automated damage detection. To overcome this limitation the first phase will employ automated approaches to image registration. Such techniques are readily available in both open source (e.g. REGEEMY) and commercial (e.g. ERDAS IMAGINE) software packages. For the purposes of this project we will employ the AutoSync module within ERDAS IMAGINE. In this phase pre-event CRS imagery, primarily from the National Agricultural Imagery Program (NAIP), for which there is nationwide 1 meter coverage, will serve as the reference data set. Post-event CRS imagery will be registered to the pre-event imagery and placed on a server. Once on the server an automated import routine will then load the data into an object-based system for feature extraction and damage detection. The automated import routine will be built using the eXtensible Markup Language (XML). It will assemble the pre- and post-event imagery and the existing state transportation GIS vector road data into data stacks within the object-based system. The automated import routine will assign appropriate alias names to imagery bands and GIS vector data sets in addition to clipping the vector data to the extent of the imagery. The benefit of this approach is that it provides a means by which to deploy a consistent set of feature extraction and damage detection algorithms (phase 2) to the data regardless of the sensor.

In the second phase the object-based image analysis system will automatically extract features and detect damage using a combination of pre- and post-event imagery in conjunction with transportation GIS data sets. A knowledge engineering approach will be used in which an expert system applies a series of segmentation, morphology, and classification algorithms to determine areas in which damage has likely occurred. These damaged areas are then presented to the user who has the option of either confirming or denying the presence of damage prior to sending the results on to the decision support tools (phase 3). Detailed information on Object-Based Image Analysis (OBIA) techniques is provided in section 5.1.3.

Figure 3 provides a more detailed look at the specific damage detection workflow for roads within the object-based image analysis system. The first feature extraction process uses expert knowledge to extract road areas from the pre-event imagery and GIS transportation data sets. The expert system will be designed such that precise agreement between the vector GIS data and the pre-event imagery is not required. This will be accomplished by first using segmentation and classification routines to extract linear features resembling roads, then assigning those features to the appropriate road segment based on proximity and orientation measures. The feature extraction for the post-event imagery will be less specific. It will largely center on extracting object primitives. Using the roads identified from the pre-event imagery in combination with the object primitives from the post-event imagery damage areas will be identified. This will be accomplished using object-fate analysis (Schopfer et al., 2008; Schopfer and Lang, 2006). The underlying theory behind object-fate analysis is that features in imagery collected on two time periods will always differ in some way due to a range of factors from sensor collection parameters to actual modifications to the landscape. The advantage of object-fate analysis is that it does not require precise pixel-to-pixel registration in the imagery, something that is difficult to obtain using the automated techniques we will employ in the first phase. By comparing the roads with the object primitives, the expert system will be able to compute the magnitude of change between the two objects using spectral, textual, geometric, and contextual information. Fuzzy logic will then be employed to determine those areas for which damage has likely occurred based on both the magnitude and type of change.

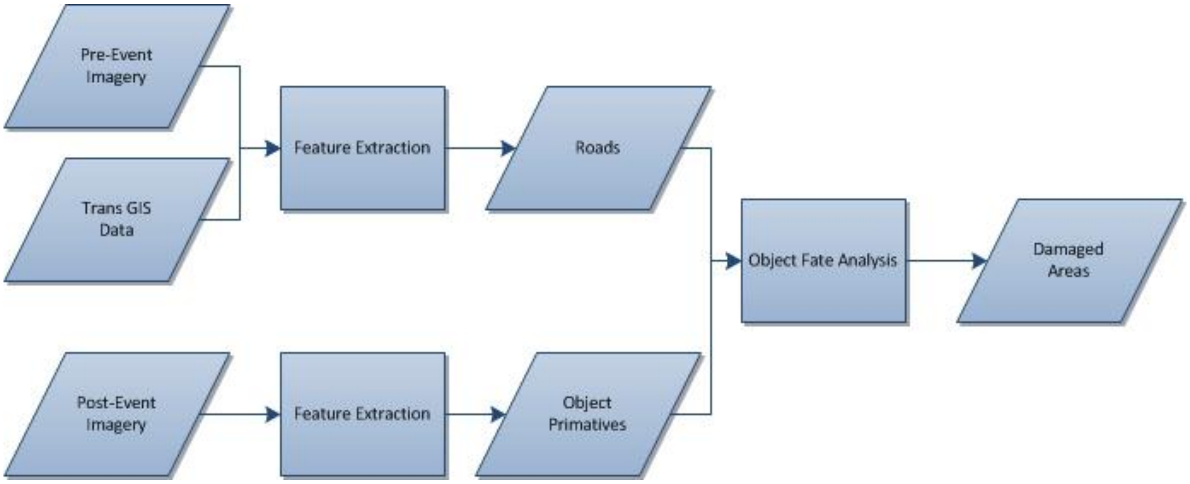

Figure 3. Detailed workflow for the extraction of damage areas within the object-based image analysis system.

The expert system will purposely be designed in such a manner that it reduces errors of omission to as close to zero as possible, even if this means increasing errors of commission. The rationale for this is that it is much more difficult for an analyst to search through vast amounts of imagery to find errors of omission than it is to flag errors of commission. The system will thus employ an optional tool that provides pre- and post-event image chips to the user that allows him/her to tagged false positives.

An example of a previous object-based image analysis system workflow for damage detection developed by our group is presented in Figure 4. Although this particular system only made use of post-event imagery, the workflow has many similarities, beginning with the identification of the transportation feature (B), to the generation of object primitives (C), to final damage detection (D). Note that only actual damage was detected (craters).

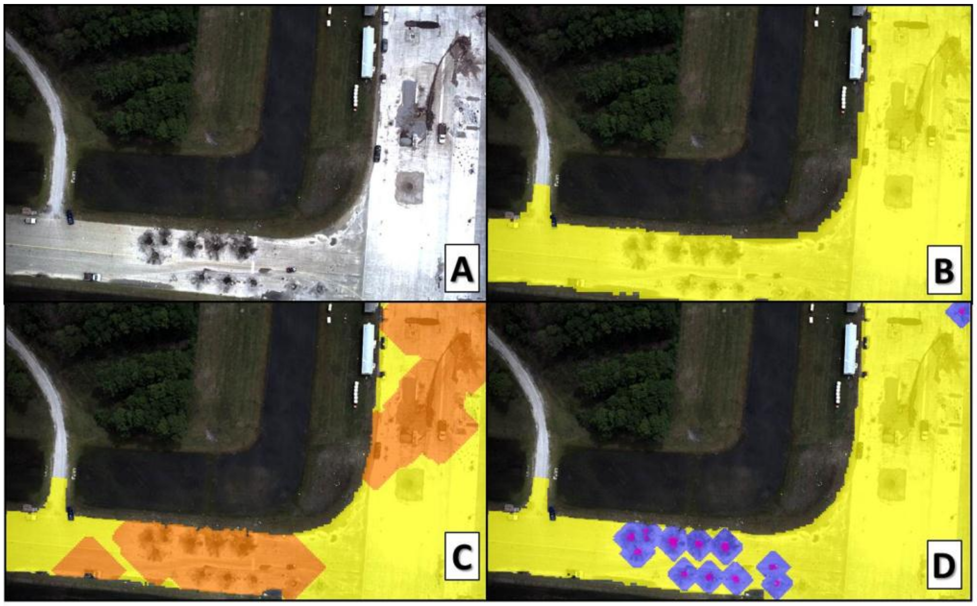

Figure 4. Damage detection workflow developed by our group for a prior project. The goal was to extract craters from imagery (A). The expert system first extracted the transportation features (B), then identified object primitives of interest (C), and finally detected the actual craters (D).

The object-based image analysis system will be built using Trimble’s eCognition software platform. We have selected eCognition based on its wide user base, adoption of industry and Open Geospatial Consortium (OGC) data standards, and enterprise processing capabilities. The expert system will be built using the Cognition Network Language (CNL) within eCognition Developer and deployed using eCognition Server. CNL provides the greatest number of and most robust set of segmentation, classification, and morphology algorithms that we are aware of.

In the third and final phase, the damage data from the object-based image analysis system is fed into the decision support tools. A geoprocessing routine will intersect the damage location with existing transportation GIS data sets to extract relevant attributes. This relatively simple procedure has the advantage in that it will work for standard (e.g. national road databases) and more complex (e.g. state transportation asset data) data sets. The end result of this operation will be a point location representing the center of the damage, an image chip of the damage from the post-event imagery, any information about the damage that can be extracted by the object-based image analysis system, and any information from the transportation GIS database (e.g. road name, mile marker, etc.).

The point information will be uploaded to a web-based decision support portal. For the purposes of the project we propose to use Google Fusion Tables. Although officially in beta, we had great success using Google Fusion Tables during Hurricane Irene. Google Fusion Tables allows one to upload, display, and extract geospatial data, and have any number of authorized users modify that data. One key advantage is that this technology is that it is available to any organization or individual at no cost. Moreover, the multi-user editing functionality of Google Fusion Tables will allow incident commanders or other authorized personnel to update the information, for example, changing the status from “closed” to “delays” for a damaged section of road. The approach has an additional advantage in that the information can be made accessible for direct ingest into other web-based mapping portals without the need for download or perform any conversion. The end result will be a web-based mapping portal that pulls the data directly from Google Fusion Tables. We envision that the product will look similar to the one developed by the Vermont Agency of Transportation following Hurricane Irene (Figure 5).

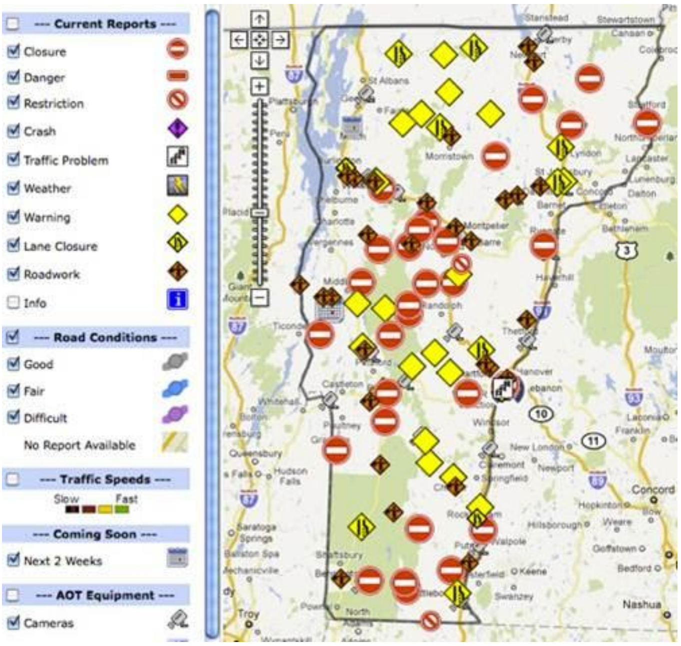

Figure 5. Incident map developed by the Vermont Agency of Transportation to display road closures following Hurricane Irene. The map was deployed using infrastructure hosted by Google.

Realizing that there is a need to have the actual GIS data we will also distribute the point information in both KML and Shapefile format. Both are accepted standards for geospatial data and can be easily ingested into a wide variety of web-based and desktop GIS and mapping software packages.

We will also employ a novel method to report the location of the damage using social media platforms. Social media is increasingly being used as a mechanism for disseminating information during a disaster. As part of the damage detection geoprocessing operation we will incorporate a routine that tweets the location of the damage via the Twitter social media platform. This capability is available within the FME software package, a commercial software package used for data translation and conversion that runs on both the desktop and server.

Testing of this approach will occur for the areas of Vermont, New York, and New Hampshire using data collected in support of Hurricane Irene. As we had extensive involvement in the response to Tropical Storm Irene, and have access to numerous reference data sets, it provides an ideal case study. The expert system will be developed on a set of CRS scenes reserved specifically for development, then validated on an entirely separate set of CRS images. We will employ standard remote sensing accuracy assessment protocols (Congalton and Green, 2009) to assess producer's, user's, and overall accuracy of the damage detection. Once we have a validated system we will select at least one other geographical area outside of the Northeast to test its effectiveness. Preference will be given to a recent disaster and will be coordinated with the AmericaView network, a national remote sensing consortium with expertise in disaster response for which Co-PI O'Neil-Dunne serves on the board of directors. Thanks to the generosity of GeoEye we will have access to massive amounts of pre- and post-event imagery for which to test this within the United States.

3.2.2. Fill calculations with Unmanned Aerial Vehicles

We intend to approach the second objective through the use of commercial, lightweight, deployable unmanned aerial vehicles (UAVs). UAVs can cost-effectively yield 3D point clouds through stereo-imagery, and the resulting data sets can yield information that is on par with Light Detection and Ranging (LiDAR) data both in terms of point density and accuracy (Heuchel et al., 2011). The proposed workflow is presented in Figure 6.

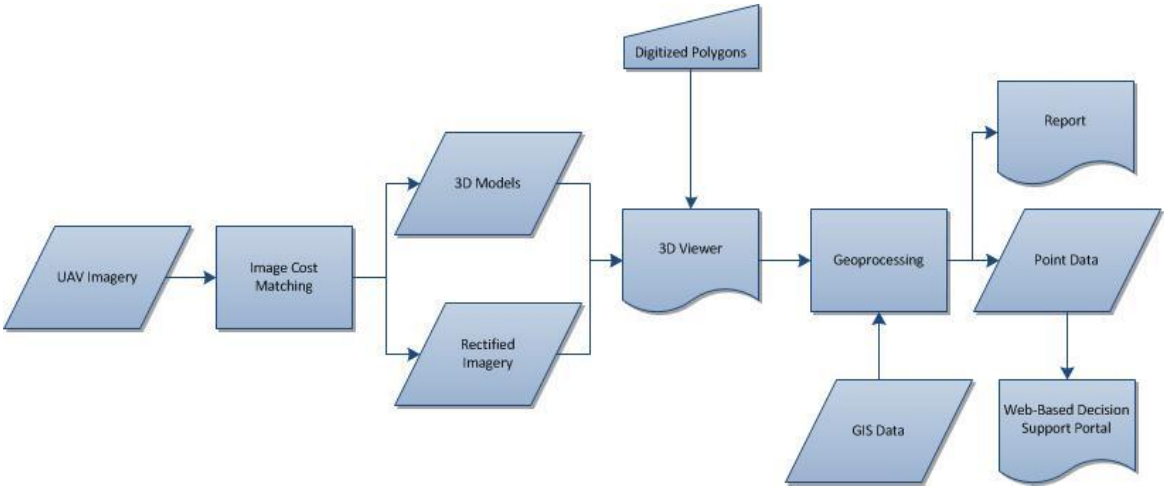

Figure 6. Proposed workflow for fill estimation decision support (Objective 2).

We will make use of the Gatewing UAV. The Gatewing is a commercial UAV that flies low enough to be exempt from FAA regulations. Using preprogrammed flight paths that take it over the same feature from two slightly different angles, the Gatewing is capable of acquiring stereo imagery. Another commercial UAV, the Sensefly, has virtually identical capabilities.

The first step in developing the UAV approach will be calibrating our measurements over void areas for which precise volumes are already known. We plan to conduct these calibrations over empty swimming pools and/or quarries. 3D surface models will be extracted from the stereo imagery using cost-based image-matching techniques. These techniques are widely available in both open-source and commercial software packages. For this project, we will employ the Inpho software package. 3D surface models will be distributed in the GeoTIFF format, an open format that is supported by all open-source and commercial GIS, mapping, and computer-aided design (CAD) software packages.

In conceptual terms, the automated fill calculation algorithm will work by generating a digital surface model that includes the eroded or damaged void and its immediate surroundings. Interpolation will be used to create an artificial plane representing where the bottom of the pavement meets underlying fill. Using standard 3D GIS functionality, the volume of the area between that plane and the bottom of the void (as estimated by the digital surface model) will be calculated. This calculation will yield a total compacted fill quantity. However, as described in section 5.2 below, a roadbed is made up of different layers, including the surface course, the base course, and the subbase course, each using different materials. Embankment materials may also be required on the side slopes of the roadway. Therefore, additional calculations will estimate the volume of each design layer in the void based on a specific thickness of each material, which will then help yield an estimated amount of material needed by type.

There are, however, many types of fill (4 types of stone fill are commonly used in Vermont, for instance) and embankment material, and the appropriate type and thickness varies by many factors relating to the site, like the surrounding hydrology and the use of the road. Knowing the correct type and thickness is important not only because of road-quality concerns but also because there is considerable price variability between the types. When engineers choose to rebuild a roadway after a flooding event to its pre-existing condition and the roadbed design parameters are known, the design of the roadway section is relatively straightforward. However, in other cases, so much of the roadway is washed away that it is difficult to identify the pre-existing roadway design. Or, alternately, engineers lack information on design parameters for that segment and are unable to make a site visit. In this situation, new design calculations will need to be performed. As described in section 5.2 of this proposal, many states currently use a program called DARWin, which takes basic information input by the user, cross references the information with state standards and the 1993 AASHTO Guide for Design of Pavement Structures, and outputs the roadway design parameters needed to conduct repair. In this case, our model would allow users to take the outputs of DARWin and use them as inputs to our fill calculation module, thereby eliminating the need for a site visit. We would work with our DOT counterparts to ensure that the appropriate information passes between these two programs. So cost savings will be realized from a more cost-effective design and from the elimination of the need for a site visit.

Whether the user is a field engineer trying to match pre-existing conditions or a design engineer using a program such as DARWin to calculate the roadway design, the interface will be the same. The model will consist of a series of geoprocessing tools within the commonly used ESRI ArcGIS platform and will utilize objects from ArcGIS 3D Analyst toolbox. When users click on the model, it will bring up an interface that will ask the user to draw a polygon around the segment of road for which they would like a fill estimate. Next, the user will be prompted to input the roadway design criteria by identifying the pavement surface, base, and subbase thicknesses and material types, as well as embankment armoring depth and material type. The module will take the typical cross section for the roadway, align it with the selected roadway segment centerline, apply it to the void identified in the 3D surface model, and provide an estimation of the type and quantity of fill required. If possible, it will also output a typical cross section for the roadway design. We will work with transportation engineers with access to ArcGIS desktop who will beta-test this module and provide feedback to help improve it.

Given that a major disaster on the order of magnitude of Hurricane Irene is fortunately unlikely to happen over the course of this project our plan is to deploy the UAV system during the spring flood season for validation purposes. In any given year spring floods generally cause at least minor erosive damage to the transportation network. Working in collaboration with incident commanders at our partner state transportation departments we will receive notification when damage occurs and program our UAVs to fly these areas before they are repaired. Field crews will measure the volumes using ground-based measurement and photographic methods so that we can validate our estimates.

3.2.3 Development of web portal decision support tool

As has been discussed, both the objectives (damage detection and fill estimation) will feed the information into a common web portal for decision support. We will work with our primary state DOT partner, VTrans, to develop a web portal that intelligibly and simply delivers storm damage information to incident managers and the public. This web portal will consist of a basic zoomable map interface (e.g. Google Maps) with damage points overlayed on it. A protocol will be developed to feed data from our damage identification analysis into the website upon completion of the analysis. As described above, the output of the damage identification is simply a list of points, giving the geographic centroid of each damage polygon. This list will be automatically geocoded to form a set of points on the web map. Using automated GIS overlay analysis each damage point can be populated with a series of relevant attributes (e.g. proximity to stream, stream order, grade, soil type, road type, etc.) that will “pop up” as a callout when users click on a damage point. As for the fill calculations, we will attempt, if feasible, to migrate that module from the desktop ArcGIS environment to a web-based environment, in which case the functionality can be accessed through an ordinary web browser and the resulting information can immediately populate the damage location web interface discussed above, to be linked with individual damage points. If this is not feasible, we will include functionality in the desktop version of the fill module that allows users to automatically upload the outputs to the online database which in turn will populate the damage-point web map. Users of the damage-point web map will be able to click on a “more information” button in order get background information on how the fill calculation was done and what assumptions were used. The interface will also allow users to query for damage locations based on certain criteria, such as location within a town or county, network/Euclidean distance to a certain facility or location, or type of road.

3.2.4 Transferring technologies

We intend to make the methods and technologies developed in this project to be easily transferable to other state DOTs. For the damage-detection methodology, we will make our knowledge base of classification/detection rules freely available. This rule set can then be ported into object-based image-classification software and, with some minor adjustment, reused in other contexts. We will also produce a detailed methodological document that will assist technicians in replicating this system. If we successfully deploy the web version of the Arc model, others will be able to access it to run the model online, or reuse its code. In partnership with our state DOT colleagues, will we explore whether the damage-point web map could potentially be expanded to include all states in the region. This expansion would require extensive coordination of information flows. The code for this web map interface will also be made available to others who wish to replicate it.

3.5 Technical barriers: identifying and overcoming

Automated feature detection has long been considered the “Holy Grail” of remote sensing. It has a checkered past due to the complexity of task. Given our extensive experience in developing object-based systems for general feature extraction and damage detection we believe that our group brings the requisite expertise to overcome this challenge.

Calculating volume estimations from UAV imagery to our knowledge has never been attempted before. Although this is challenging, the Trimble Corporation has kindly agreed to not only provide access to their cutting-edge software packages, but also staff time, which consists of some of the world’s leading photogrammetric experts. Therefore, the project team is confident that this implementation is feasible.

3.6 Discussion of equipment or facility needs

This project will leverage existing resources at the University of Vermont Transportation Research Center (TRC) and Spatial Analysis Laboratory (SAL). The SAL maintains cutting-edge hardware and software. Additional hardware and software resources for this project consist of UAVs, laptops to support UAV operations, and additional licenses for eCognition software and Inpho software. The UAVs and the laptops are included in the budget. The licenses for eCognition and Inpho are being provided as part of the matching funds from Trimble.

3.7 Tasks and division of labor

This project will have six major concurrent tasks:

- **Project coordination**. Activities related to the supervision, scheduling, and phasing of personnel and resources associated with the project.
- **Reporting**. Activities related to reporting progress and results to the funding agency.
- **Stakeholder/partnership meetings**. Meetings with external groups and collaborators, including state transportation departments, industry partners, and the advisory committee.
- **Damage detection decision support (objective 1)**. Developing, designing, validating and deploying a system that extracts post-event transportation damage from CRS satellite imagery.
- **Fill estimation decision support (objective 2)**. Developing, designing, validating and deploying a system that provides fill volume and fill type estimations using UAVs and GIS-based models.
- **Publications/presentations**. Publishing the information about the project and results in the form of videos, blog posts, technical reports, white papers, and peer-reviewed journal articles. Presenting information about the project at conferences.

The level-of-effort budget for the major project tasks along with the division of labor by general category are presented in Table 1.

Table 1. Lists of tasks by category.

Task		**Hours by Category**			
	Description	Management	Engineering	Technical	Clerical
	Project coordination	120			65
	Reporting	20			75
	Stakeholder/partnership meetings	1			20
Table continues next page					

	Damage detection decision support (objective 1)	15	40	1520	5
	Fill estimation decision support (objective 2)	15	115	1260	5
	Publications/presentations	20	5	20	85
Totals		191	160	2800	255

3.8 Proposed deliverables

The deliverables from this project will include the following:

- A web page for the project that provides a centralized location for information on the project, project updates, and links to products.
- A white paper outlining the role in which CRS satellite imagery plays in disaster response and recovery targeted at state transportation departments.
- A minimum of four blog posts about various aspects of the project posted to the Spatial Analysis Lab's blog "Letter from the SAL" (http://letters-sal.blogspot.com/). Letters from the SAL is replicated through the popular Planet Geospatial blog aggregator.
- A video showing users how to download CRS satellite imagery from the USGS Hazard Data Distribution System.
- An object-based image analysis system that allows an end-user with basic GIS skills to load imagery, detect damage, and review candidate damage locations.
- A knowledge base of feature extraction and classification rules for identifying road damage from high resolution imagery, for re-use in commercially available object-based image analysis software.
- A video demonstrating the damage detection workflow within the object-based image analysis system.
- A customized geoprocessing model that automates the calculation of fill amounts by type for road damage.
- A mapping portal that identifies road damage on a web map and, when points are clicked, gives information on fill. This web map will be deployed for Vermont, including data from the 2011 Tropical Storm Irene and any subsequent major spring floods that occur during the project period. If we have the opportunity, we will also deploy a similar web-mapping portal for one other flood disaster in another state.

- A technical report that describes how these products were developed, in accessible terms.
- A minimum of one scholarly publication on the methodological approach.
- A “best practices” white paper on the use of low-cost commercial UAVs for transportation-related mapping.
- A minimum of two presentations on the project or aspects of the project at regional or national transportation/geospatial conferences.

4. Proposed Work Plan and Budget

4.1 Activities

1. Internal meeting following project award. Modifications to the plan as necessary.

2. Stakeholder/partnership kick-off meetings.
    a. Meetings with state departments of transportation
    b. Meetings with industry partners
    c. Finalize advisory committee

3. Damage detection decision support
    a. Design
    b. Technical specifications
    c. Obtain CRS imagery
    d. Set aside imagery for validation
    e. Web-based portal specs
    f. Develop
    g. Image registration workflow
    h. Automated import routine
    i. Knowledge-based CNL rule set for damage detection
    j. Post-damage geoprocessing routines
    k. Web-based portal back end
    l. Web-based portal front end
    m. Validate
    n. Apply to reserved data
    o. Conduct accuracy assessment
    p. Deploy
    q. Identify candidates states/areas
    r. Obtain imagery
    s. Run decision support system

4. Fill estimation decision support

    a. Design
        i. UAV system setup
        ii. Geoprocessing tool diagramming
    b. Develop
        i. UAV test flight operations
        ii. Standard operating procedures
    c. Validate
        i. Fill estimations for known areas
        ii. Geoprocessing tool evaluation

5. Deploy
    a. Image damaged sites
    b. Run geoprocessing tool
    c. Feed results to report and web-based portal

6. Reporting
    a. Quarterly reports
    b. Annual reports
    c. Final reports

7. Presentations/publications
    a. White papers
    b. Technical reports
    c. Videos
    d. Blog posts
    e. Presentations
    f. Peer-reviewed publications
    g. Technical outreach to state DOTs

4.2 Major activities, deliverables and milestones

A listing of the major activities, deliverables, milestones, and associated costs are presented in the "Deliverables and Milestones" spreadsheet (separate document).

4.3 Research results presentations

Results will be presented to DOT, partners, and interested parties at least four times:

1. Beta version of the damage detection decision support system
2. Beta version of the fill estimation decision support system
3. Final version of the damage detection decision support system
4. Final version of the fill estimation decision support system

5. Presentations will occur via webinar using Go To Meeting or similar software.

4.4 Travel

Travel for this project includes 12 short distance (average 100 miles roundtrip) trips in year 1 and 4 short distance trips in year 2, primarily for field crews to visit research sites, for the purposes of calibration, validation and ground truthing. Some of these short trips will also include travel to nearby state DOTs, such as in Vermont and New Hampshire. We propose 3 medium distance trips in year 1 and year 2 for two people to meet with state DOTs that are far enough away that they require overnight stays (average distance 400 miles roundtrip). We propose one trip to Washington DC in both year 1 and year 2, for the two Principal Investigators to meet and debrief with US DOT. Ideally, the second trip would correspond with the Transportation Research Board annual meeting so that it could be combined with a presentation on the project at that meeting.

5. Merit of the Technology

5.1 Background on object-based image analysis of commercial remote sensing

5.1.1 Advances in CRS

As high resolution has become more prevalent, it has opened up great possibilities for automated detection of fine-resolution features.Commercial remotely sensed (CRS) data has grown in importance as a resource for planners and decision makers, particularly since the IKONOS-2 satellite became operational in 1999. The latest generation of commercial satellite systems, such as WorldView-2 and GeoEye-1, offer sub-meter resolution imagery with revisit times of 1-3 days. Lightweight Unmanned Aerial Vehicles (UAV), such as the Gatewing, can be deployed in a matter of minutes, fly low enough so as to avoid needing Federal Aviation

Administration Approval (FAA), and capture highly accurate centimeter-resolution stereo imagery.

5.1.2 CRS in disaster response

CRS plays a growing and important role in disaster response. During major disasters the International Charter (http://www.disasterscharter.org) is activated. The International Charter is a consortium of government agencies (e.g. NOAA) and CRS companies (e.g. GeoEye). A typical activation of International Charter allows organizations involved in disaster response and recovery access to all CRS data acquired in support of the event. The USGS makes the data available via its Hazard Data Distribution System (HDDS) (http://hdds.usgs.gov/hdds2/). In the days following Hurricane Irene in Vermont over 300 CRS scenes were acquired, totaling over 500GB worth of data. Both of the major US-based CRS companies, DigitalGlobe and GeoEye, participate in the International Charter.

5.1.3 Feature extraction, damage mapping, and object-based image analysis

Organizations, such as the Department of Defense, who specialize in damage assessment still primarily employ manual interpretation techniques such as those covered by Kienegger (1992) (United States Army, 2009). Such approaches, while achieving high levels of accuracy this can be extremely time consuming and costly. State transportation departments simply do not have the personnel with either the time or the expertise to handle the vast amounts of CRS satellite imagery that become available following a disaster. In short, interpret massive amounts of imagery is both prohibitive from both a cost and human resource perspective.

Automated classification algorithms long held the promise of saving both time and money. Since the inception of digital remote sensing in the 1970s the most common method for automating the extraction from CRS satellite imagery has been the so-called pixel-based approach. This process is vastly different than manual interpretation. Humans make use of not only the spectral (tone) information in an image, but also the geometric, textural, and contextual information. Pixel-based approaches have come under increased scrutiny due to the relative poor accuracy of the resulting classification when compared to manual interpretation (Olson, 2009). Numerous studies have found pixel-based approaches unsuitable for the latest generation of high-resolution multispectral imagery, particularly in heterogeneous landscapes like urban environments (Chen et al., 2004; Cushnie, 1987; Kontoes et al., 2000; Thomas et al., 2003; Zhou and Troy 2008). Although some advances have been made by incorporating texture into the image classification process (Gong and Howarth, 1990; Puissant et al., 2005) in heterogeneous landscape such as urban areas, the classification accuracy of textural analysis is still relatively low (Chen et al., 2004).

In the case of detecting roadway damage, the pixel-based approach is particularly unsuited because the damaged area is unlikely to have any sort of unique spectral signature. Damage to a road or bridge will be composed of pixels with a wide variety of reflectance values, and many of those reflectance values will be similar to those of pixels of features that are not damage (Figure 7). Furthermore, subtle shifts in the location of pixels between pre- and post-even CRS imagery make pixel-based approaches, which require precise co-registration entirely unsuitable. Damage to roads and bridges is identified using a combination of spectral, textual, geometric, and contextual information from two sets of imagery that likely have minor georegistration errors. Any automated approach to detecting damage must account for these factors.

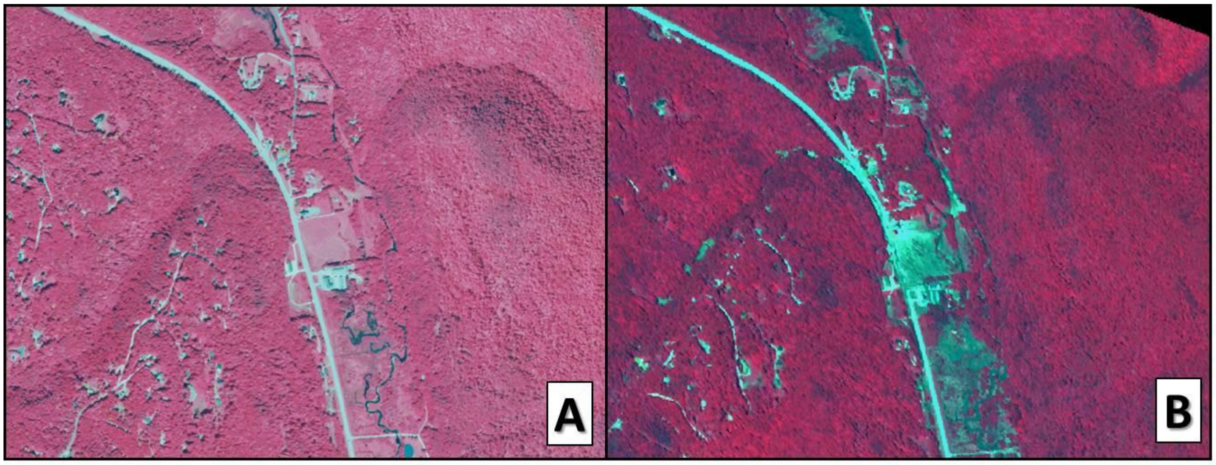

Figure 7. Images of Route 100 in Vermont both pre (A) and post (B) Hurricane Irene. The pixels for the damaged area in the center of (B) have no distinct spectral signature, and many are practically spectrally identical to other paved surfaces or the silt-laden water.

To deal with the complexities of high-resolution imagery with pixel sizes that are frequently smaller than real-world objects (e.g. half meter), an automated approach must classify objects rather than pixels (Blaschke, 2010; Walker and Blaschke, 2008). Object-based image analysis (OBIA) has emerged as the most promising and widely used technique to the automated extraction of information from high-resolution CRS imagery. OBIA, which attempts to replicate aspects of human cognition, allows spectral, geometric, and contextual information to be brought into the feature extraction process, overcoming the limitations of pixel-based approaches (Hay and Castilla, 2006). OBIA techniques also provide a framework for the direct integration of thematic GIS data sets (e.g. roads), and can be built on top of expert systems that can be designed in such a way that they are flexible enough to adjust to differing sensors and image characteristics (Smith and Morton, 2010). Expert systems also have the advantage that they do not inherently require “training data,” for each run, something that is difficult to obtain during a crisis situation (Buchanan, 1983). OBIA techniques have repeatedly shown to be a robust and accurate approach to feature extraction (Geneletti and Gorte, 2003; Laliberte et al., 2004; Shackelford and Davis, 2003). OBIA approaches been found to be an excellent method for classifying even fine-scale objects such as individual trees, houses, and driveways (Troy and Zhou, 2007; Zhou and Troy, 2008) (Figure 8).

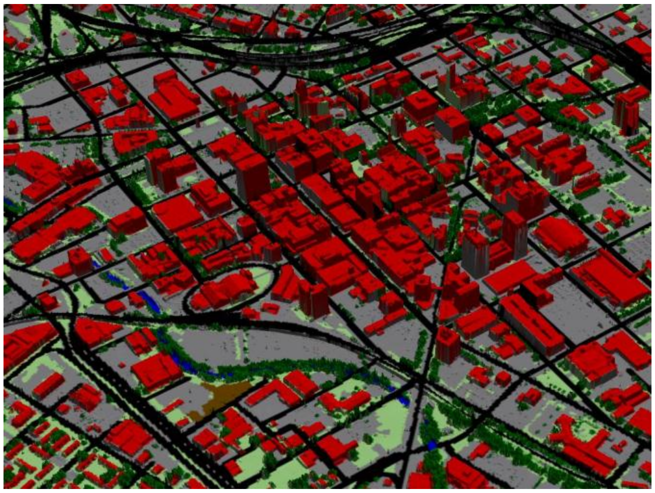

Figure 8. Example output from of a feature extraction for Syracuse, NY developed by the proposal team. OBIA techniques were applied to high-resolution CRS data to extract both natural and man-made features with over 94% accuracy.

OBIA's greatest strength is its ability to incorporate contextual information that permits feature extraction from local (e.g. neighborhood), semantic, cultural, geometric, and geographic relationships (Divvala et al., 2009) (Figure X). OBIA techniques also provide a way to overcome the limitations associated with existing vector and raster data models. Data fusion OBIA approaches data have been successfully used to identify roadways (Hinz and Baumgartner, 2003), land use (Ban et al., 2010), and buildings (Tullis and Jensen, 2003). In a OBIA workflow, segmentation algorithms are used to group pixels into objects. Like pixels, image objects have spectral properties (mean band values), but unlike pixels they have spatial (shape, size, texture) characteristics and are topologically aware (i.e., each object “knows” its neighbor objects). Image objects can also be organized hierarchically to reflect relationships between sub- and super-objects.

5.2 Background on flooding and road infrastructure

5.2.1 Increasing flood frequency

Flood disasters have increased in prevalence with the ever-increasing number of streams and rivers that are out of equilibrium. The equilibrium of a stream can be affected by both changes in hydrology and changes in the hydraulics of a water channel. Changes in hydrology can increase the amount of stormwater runoff and decrease the amount of time it takes stormwater to reach a stream or river, therefore increasing the likelihood of flash flooding. Vegetation clearance and new development serve to increase impervious surface which in turn increases the velocity of runoff.

Changes in river channel morphology and hydraulics can increase the speed at which the water flows through a channel, increasing its destructive power. Straightening, steepening, dredging, armoring, and damming can all alter river and stream hydraulics, in turn endangering roadways. Straightening and steepening a water channel generally occurs as a result of building a roadway, railroad, city or town adjacent to a river. Dredging and damming serve to deepen the water channel. Armoring refers to the use of rip-rap, or large rocks, to stabilize an embankment for erosion control. If that particular embankment becomes stabilized through the use of rip-rap, while that river section may be protected, now downstream embankments become the target for erosion. All of these actions serve to speed up the flow of water, steepen embankments, and increase erosive activity.

One of the most significant factors behind flooding is the isolation of a stream or river from its floodplain by new developments and clearing of vegetation. Ideally, the floodplain occupies about six times the width of the water channel (for low gradient sections), and is fully vegetated with trees and bushes which help stabilize the soil. In addition to providing protection against floods, the floodplain also allows for the water channel to shift slowly over time, an act that is also referred to as meandering, in an effort to obtain equilibrium.

Inarguably, all of these changes in hydrology and hydraulics have been occurring for years. In Vermont, for example, nearly three-quarters of streams have lost connectivity with their historic floodplains (Friends of the Winooski River,, 2012) and nearly half of historic wetlands have been lost or severely impaired (Vermont Department of Fish and Wildlife, 2010).

All of this is compounded by climate change, which is expected to increase the intensity of precipitation events in many areas, including parts of the United States (Groisman, Knight, et al 2005). Higher rainfall totals per storm event lead to more flooding as the ground becomes more saturated, water velocities increase and streams overflow their banks. All of this can lead to significant road damage.

Hence, as watersheds become increasingly impervious, streams become increasingly engineered, and climate change intensifies precipitation in certain areas, there is a growing need to develop frameworks to quickly and effectively respond to what is likely to be more frequent and routine storm damage to road networks.

The extent to which roadways can be damaged from flooding was amply illustrated by Tropical Storm Irene, which dumped massive quantities of rain over southern Vermont in August 2011. Over 500 miles of state highway and 200 state-owned bridges were damaged, including 34 bridge closures. 13 communities were stranded due to impassable roads. Over 2,000 road segments and nearly 300 bridges were closed on town road networks. At least 300,000 tons of fill was required to repair roads, and probably significant more than that (State of Vermont, 2012). An event of this magnitude illustrates how extensive post-flood recovery and reconstruction can be and, consequently, how important actionable information is.

5.2.2 Current state of practice for flood damage response

In 2003, the Homeland Security Presidential Directive (HSPD-5) made it mandatory for all Federal departments and agencies to adopt and implement the National Incident Management

System (NIMS) when preparing for or recovering from natural disasters such as flooding. Therefore, following a natural disaster, if a state requests support from the Federal Emergency Management Agency (FEMA), they are required to adopt the NIMS. The NIMS is a guideline of best practices for incident management. Some states, like California, have created their own Emergency Plans which use the NIMS framework.

The process to rebuild infrastructure through an Incident Command System (ICS) is complex. An Operations Team deploys people to inventory the damage. They communicate with a Planning Team if the initial field inspection warrants the need for coordination with other entities such as utility companies, inspectors, environment hazard specialists, etc. The Logistics Center is tasked with acquiring and distributing the resources needed to rebuild the waterways and infrastructure including construction equipment, fill materials, pavement materials, rip-rap for stabilizing embankments, etc. When flooding occurs, the Operations Team will inspect the areas adjacent to the damaged site to determine the pavement structure, drainage design, slope between the roadway and waterway, roadway alignment, etc. and will attempt to rebuild the road back to the way it was. One of the decisions the Operations Team must make is whether to rebuild damaged roadways back to their existing condition or re-align them. The likelihood of repairing to the original condition depends on the criticality of the road link (whether its loss will result in major detours or isolation of communities), the permitting that would be involved, and whether the flood event fundamentally changed the surrounding terrain morphology. When hundreds of such road damage events might have occurred after a major storm, an automated decision support tool summarizing information about each damaged area could be of help save Operations Teams time and money by allowing them allocate resources more efficiently.

5.2.3 Current state of practice for roadway design

Road beds utilize a complex layered design that must be taken into account when repairs are made. Each layer requires a different fill material. A significant challenge for engineers in the field after flooding is determining what types of fill to use in different layers and how deep each layer should be. These choices vary based on a large number of factors, including site characteristics and road usage.

The 1993 AASHTO Guide for Design of Pavement Structures provides the basic guidelines used by states to develop their roadway design standards. There are three types of pavement structures. Rigid pavement design is used for bridges, Aggregate Surface pavement design is used for gravel roads, and Flexible pavement design is used for most everything else.

The pavement structure design is generally split into three strata. The top stratum is the surface course and generally consists of multiple layers, called lifts, of asphalt concrete. The asphalt concrete is applied in layers to allow for future resurfacing over the entire lifespan of the roadway (typically 40 year lifespan, with resurfacing expected at about 20 years). The top layers of the surface course can be removed and reapplied, while the bottom layers remain intact. The second stratum is the base course and generally consists of dense graded crushed stone or other coarse aggregate. The base course enables the load on the surface course due to traffic to be spread across the entire roadbed. The third stratum is the subbase course which generally consist of earth borrow materials to bring the road up to grade. Earth borrow will provide a solid ground to build the road upon. The subbase course can also include a layer of stone fill or sand borrow above the earth borrow. Stone fill is generally used in conjunction with drainage designs, such as underdrains. Sand borrow is generally used as a buffer to make sure that the earth borrow is placed below the frost depth.

The depth of each strata depends on design variables, performance criteria, material properties, pavement structural characteristics, and reinforcement variables (see, for instance, AASHTO's Guide for Design of Pavement Structures, 1993). Design requirements tend to vary based on the design life (e.g. 40 years), traffic volumes (existing and future), traffic speed, project location (e.g. frost depth), road type (e.g. interstate or local road), road width (number of lanes), and pavement type (e.g. flexible or rigid).

The current state of practice for determining the pavement design for state roads in Vermont is to contact the Pavement Department at the Agency of Transportation. A pavement design engineer will use the basic information for design life, traffic volumes, traffic speed, project location, road type, road width, and pavement type to input the standard design requirements for Vermont into a program called DARWin, which is also used in many other states. The standard design requirements for Vermont are adopted from the 1993 AASHTO Guide for Design of Pavement Structures, but are fine tuned for the conditions experienced in Vermont, for example the freeze-thaw process. The pavement design engineer will then communicate the DARWin results back to the roadway design engineer. Local and town road pavement designs are generally standardized. The roadway designs have to conform to state standards for minimum width and depth, but can be designed in access of the minimums.

5.3 Anticipated benefits from proposed approach

Both of the project objectives will significantly aid incident managers in responding to flooding events by helping them save time and money while resulting in a more efficient allocation of resources and higher quality of repairs. Below is a discussion of some of the specific benefits by objective.

Objective 1 (automate the detection of damaged road infrastructure from high-resolution CRS satellite imagery) will drastically reduce the efforts of the Operations Team needed to perform initial field inspections, which in turn reduces the need for communicating the results of those inspections to the Logistics Center. This also allows for the Operations and Planning

Teams to begin the process to rebuild the roadways sooner. The work performed by the Logistics Center to compile the information from each site and communicate it to the whole ICS and community at large would be reduced significantly. Being able to understand the extent of the damage following a flooding event is essential to setting priorities, deploying resources, and rebuilding the infrastructure. The faster incident managers have this information, the faster they can restore the roadways and the more information they can communicate to the public. In the case of Vermont after Tropical Storm Irene, there were hundreds of people deployed for weeks and months just to inventory all of the damage. If this process had been automated, it would have freed up resources for other recovery related tasks and facilitated the flow of information. Most states do use GIS maps and online applications to communicate road damage and closures throughout the ICS and to the community. However, in most cases, this process is manual and very time consuming.

Objective 2 (estimating the amount of materials needed to fill damaged areas using stereo imagery acquired from UAVs) will greatly benefit incident managers and engineers. The current practice for estimating the amount of material needed to fill a damaged area is to either have a field engineering "eye-ball" the amount or, in the case of larger roadway washouts, perform a very basic survey of the area. In rare cases, like Vermont Route 107 where the entire roadway was destroyed, full field surveys are performed. A full field survey could take weeks to perform, download the data, and quantify the fill requirements. Basic field surveys or "eye-balling" the amount of fill uses only cursory data combined with basic rules of thumb and gut instincts to estimate needed fill volumes (e.g. if a roadway is missing a section that is approximately 20 feet deep, by 15 feet wide, and along approximately 200 feet of roadway, 60,000 cubic feet of fill materials would be needed). This can result in considerable inaccuracy in orders for truckloads of construction materials, a problem that is compounded by the fact that different fill grades cost different amounts, multiple types of fill are likely to be needed, and a single truckload can only contain one type of fill at a time (personal communication, William Ahearn, VTrans, February 2012).

The use of UAVs to estimate the amount of materials needed to rebuild the roadways would reduce the cost, effort, and time required if the entire roadway was washed out and a full survey was necessary. For sites experiencing smaller amounts of damage, the UAVs would drastically increase the accuracy of the estimate. Typically, after a flood disaster with widespread damage, there is a tendency for state DOTs to order more fill material than needed (and particularly more of the high-grade fill), because without complete knowledge about the damage, engineers and surveyors have to be conservative and err on the side of caution. Having more complete information would reduce this tendency and consequently save money.

Inventorying the damaged sites following a flooding event and estimating the amount of materials needed to rebuild the infrastructure are two processes that occur in the first initial steps of a recovery plan. Improving these processes through the use of technology has a trickle-down effect that allows all the following steps to occur faster and more efficiently. Time is not a luxury that anybody has after a natural disaster when so many people are relying on the state to rebuild the infrastructure so they can get back to work and school; have access to necessities such as food, water, and electricity; and have access to hospitals, fire departments, and ambulances. Better information can restore this access quicker.

5.4 Simple cost benefit analysis

Given our current state of knowledge, it is not possible to conduct a precise cost-benefit analysis of the technology. However, there are numerous indications that return on investment would be highly positive for this technology. First, governments are already spending large amounts of money on remote sensing imagery without gaining actionable information from it, leaving the full value of the imagery unexploited. Following Hurricane Irene in Vermont we estimate, based on sensor, area, and published costs, over $200,000 of CRS satellite imagery was acquired. Due to the aforementioned challenges in extracting information from this imagery, the return on the investment was quite low. Furthermore, the lack of timely and accurate information on road closures, delayed repairs, resulted in inefficient travel, and even delayed emergency response personnel. The damage detection decision support system we propose to develop will increase the return on investment on CRS satellite imagery in addition to improving the efficiency of both travel and repair following a disaster. In terms of the potential reduction in costs due to more efficient use of construction materials, there is great potential. Inaccurate fill estimates can result in overcharges on the order of $20 to $100 per ton and, given that an emergency like Tropical Storm Irene required well over 300,000 tons, the potential savings readily become apparent.

6. Key Personnel and Facilities

6.1 Credentials, capabilities, and technical background of each team member and organizations

6.1.1 Organizations

Transportation Research Center

The UVM Transportation Research Center (TRC) is a hub for innovative and interdisciplinary research, education and outreach on sustainable transportation system solutions. Since its founding in 2006, the TRC has attracted over $6.5 million to UVM in new external grants, funded 67 graduate students with $28K stipends, hosted over 3,200 people at its events, and created 12 new courses. The TRC also serves as the host of the National University Transportation Center (UTC), funded by the U.S. Department of Transportation, as well as the Vermont Clean Cities Coalition, funded by the US Department of Energy and the

Vermont Department of Public Service. This year the TRC became the coordinator of the New England Transportation Consortium (NETC) for the six new England state DOTs.

Spatial Analysis Laboratory

The Spatial Analysis Laboratory (SAL) is an applied research facility located in the Rubenstein School of Environment & Natural Resources at the University of Vermont (UVM). The SAL specializes in ecosystem assessment, biodiversity analysis, ecosystem services, land-cover mapping, transportation modeling, planning for conservation lands, scenario modeling of land use change, high-resolution remotely sensed data analysis, defense applications, web-based mapping, and the development of new applications for natural resource management. The SAL has been internationally recognized for its expertise developing object-based approaches to extracting information from multi-billion pixel data sets. The SAL maintains a robust suite of hardware and software dedicated to the processing and analysis of geospatial data.

6.1.3 Personnel

Dr. Austin Troy, PhD

Dr. Troy will serve as PI. He is the Director of the University of Vermont (UVM) Transportation Research Center and the UVM Spatial Analysis Lab (SAL). Dr. Troy is an Associate Professor in the Rubenstein School of the Environment and Natural Resources at the University of Vermont with a secondary appointment in computer science. His research has addressed many aspects of spatial analysis, remote sensing, dynamic spatial modeling, and spatial econometrics. In particular, he has conducted research and published on object-oriented remote sensing, integrated land use and transportation modeling, and use of GIS in decision support related to the management of ecosystems. He is also Principal and Co-founder of Spatial Informatics Group, LLC, a geographic and environmental consulting group.

Jarlath O’Neil-Dunne

Mr. O’Neil-Dunne will serve as Co-PI. He is a Faculty Research Associate and Assistant Director of the University of Vermont’s Spatial Analysis Laboratory. He and his team have been internationally recognized for their expertise in developing and deploying object-based systems capable of extracting information from massive amounts of high-resolution remotely sensed data for urban planning, defense, and natural resource applications. Mr. O’Neil-Dunne is a former intelligence officer whose last assignment was the geospatial team lead for a group specializing in infrastructure analysis for select Middle Eastern countries. He is also the director VermontView, a state affiliate of the AmericaView program.   During Hurricane Irene Co-PI O’Neil-Dunne coordinated all image acquisition, processing, and exploitation activities for Vermont.

Amanda Hanaway-Corrente

Amanda Hanaway-Corrente is a licensed Professional Engineer employed at the University of Vermont (UVM) Transportation Research Center (TRC) as the New England Transportation Consortium (NETC) Coordinator, which enables the collaboration between the Research Section at the Vermont Agency of Transportation (VAOT) and the Departments of Transportation in Massachusetts, Connecticut, Rhode Island, New Hampshire, and Maine. She also represents the UVM TRC as the VAOT Research Advisory Committee (RAC) Liaison, and as such has served on the RAC Region 1 Planning Committee for the 2012 AASHTO Research Advisory Committee and TRB State Representatives Annual Meeting with members from the Research Section of the Departments of Transportation in Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont. Amanda was also named Vermont's 2011 Young Engineer of the Year.   Her professional engineering license is in the field of transportation engineering as she has designed many roads, roundabouts, and parking lots.

James Sullivan

Jim Sullivan began his career as a Research Analyst at the UVM Transportation Research Center after completing the Master’s Degree program in Civil and Environmental Engineering at UVM in May 2009. Prior to his degree program at UVM, Jim worked in the private sector in consulting for 13 years and he currently holds a professional engineering license. His consulting experience includes project management and engineering related to RCRA and CERCLA compliance, groundwater and surface water pollution assessments, remediation design, and construction management.

Sean MacFaden

Sean MacFaden is a research specialist with the UVM Spatial Analysis Laboratory. He has 18 years of experience in geospatial technologies, including GIS and remote sensing applications for wildlife habitat mapping, biodiversity assessment, conservation lands, forest characterization, and watershed-scale analyses of pollutant loading. Most recently, he has used object-based image analysis (OBIA) techniques in conjunction with high-resolution imagery and LiDAR to map land cover in a variety of urban and suburban settings, including multiple tree canopy assessments (UTC) for cities and counties in the United States

Ernest Buford

Ernest Buford is a research specialist and systems administrator at the UVM Spatial Analysis Lab. He has over 15 years experience in geospatial analysis, server and network administration, and general systems administration. He is also skilled in setting up map server technologies and enterprise databases.

6.1.4 Prior Experience Managing Similar Projects

Both Dr. Troy and Mr. O’Neil-Dunne bring years of experience managing large and complex projects in academia, the private sector, and the military. Both have served as PI on large federal grants in the past for a number of agencies. Both have served as consultants as well for a wide array of clients. Mr. Sullivan and Ms. Hanaway-Corrente bring extensive engineering experience in both the private and academic sectors and leverage very strong relationships within a wide network of state DOTs. The Transportation Research Center and the Spatial Analysis Laboratory have strong track records of performance on working on transportation related and commercial remote sensing projects.

6.1.5 Collaborations and Partnerships

Trimble

Trimble Geospatial offers a full range of mobile mapping systems, airborne systems, and photogrammetry & digital surface modeling solutions. Trimble will be providing matching funds to the project in the form of software and consulting time.

GeoEye

GeoEye is a leading source of geospatial information and insight for decision makers and analysts who need a clear understanding of our changing world to protect lives, manage risk and optimize resources.. GeoEye will provide matching funds to the project in the form of satellite imagery.

Vermont Agency of Transportation

VTrans' mission is to provide for the movement of people and commerce in a safe, reliable, cost-effective and environmentally responsible manner. VTrans will serve as a partner on the project, providing guidance and feedback.

6.1.6 Equipment, materials, and facilities

Together, the SAL and TRC have much of the requisite equipment, materials, and facilities for this project. The exceptions are: 1) UAVs, 2) laptops to support UAV operations, 3) software licenses for select packages, and 4) satellite imagery. UAVs and laptops to support the UAV operations will be purchased as part of this project. Trimble will provide software licenses to both eCognition and Inpho as part of their matching contribution. GeoEye will provide access to additional satellite imagery as part of their matching contribution.

7. Other Related Proposals

Not applicable. We have not submitted any proposals related to this one.

8. Review Panel Recommendations

Several issues were raised during our presentation at USDOT headquarter in Washington, DC. We believe we have addressed these in the proposal and have provided a brief summary below.

Lack of decision support. The weakness of our presentation is that it was heavily focused on the technology and short of the decision support system. In this proposal we have outlined our workflow and provided details on the decision support tools that will result from it, the primary one being a web-based portal.

Region specific. Concerns were raised that focusing the project in Vermont would limit its utility to other state transportation departments. Thanks to the generosity of GeoEye we will have access to their vast holdings of commercial satellite imagery. This will allow us to deploy the system, potentially in response to a disaster that occurs during the course of the project.

Deployment and validation. In our presentation we did not present a clear plan for deploying the system or validating the results. In this proposal we have outlined the deployment plan and provided information on the validation/accuracy assessment.

Matching funds. At the time of the presentation Trimble was the only source of matching funds. Since that time we have added matching funds from both GeoEye and the University of Vermont.