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Characterization of Unpaved Road Condition Through the Use of Remote Sensing Project – Phase II

Deliverable 8-D: Final Report

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1. Executive Summary

Building on the success of developing a UAV based unpaved road assessment system in Phase I, the project team was awarded a Phase II project by the USDOT to focus on outreach and implementation. The project team added Valerie Lefler of Integrated Global Dimensions (IGD) who is an outreach specialist, and Woolpert Inc. which is an architecture, engineering, and geospatial services firm to assist in the second phase. As part of the new focus on outreach and implementation, the original Phase I name for the system, URCAS (Unpaved Roads Condition Assessment System), was changed to AURA (Aerial Unpaved Road Assessment) after input from the project's Technical Advisory Committee (TAC).

The first objective of the project team was to review and update the requirements, sensors and platforms. Since it had been over three years between defining these parameters and the start of Phase II, the project team needed to re-evaluate the AURA system as technology is quickly advancing. Through a brief investigation, the results were published through Deliverable 5-B: "Review and Update on the AURA [URCAS] Requirements, Sensors, and Platforms". The project team found that the Bergen Hexacopter and Nikon D800 components selected in Phase I were still the preferred components for the AURA system due to their flexibility, low cost, and high resolution.

The use of fixed-wing UAVs as an alternative to using multi-rotor systems was also investigated. Fixed-wing UAV data was provided by Jarlath O'Neil-Dunne of the University of Vermont. All imagery was collected using a Sensefly eBee which carries a point and shoot camera. The imagery and was processed through commercial Structure from Motion (SfM) software and compared to previous results obtained from the Bergen Hexacopter carrying a Nikon D800. Figure 1-1 shows an example comparison of the hillshades of the 3D models generated at the same scale.

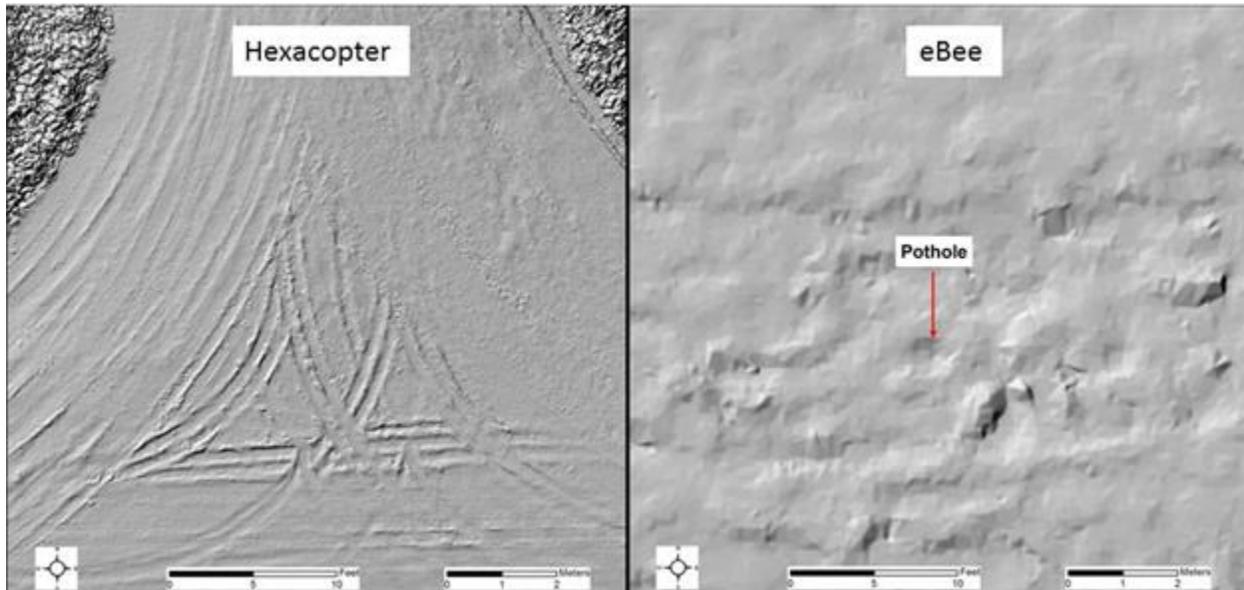


Figure 1-1: A comparison between the level of detail between DEMs generated from the Bergen hexacopter-based system and an eBee-based data collection system. Both hillshade representations are at the same scale and the pothole pointed out in the eBee hillshade is 67cm in width.

Imagery collected from the eBee with its built-in camera had a lower resolution than imagery collected from the Hexacopter with the attached Nikon D800 camera. For conducting detailed condition assessments of unpaved roads as defined in Deliverable 1-A: "Requirements for Remote Sensing Assessment of Unpaved Road Conditions", a multi-rotor system carrying a high resolution DSLR is the

only system capable of providing the resolution required. Fixed-wing UAVs are better suited to long duration collects and for collecting imagery for visual inspection.

A major component of Phase II was two field demonstrations, building from a well-received technical demo in Phase I held in Sioux Falls, SD. The first technical demonstration in Phase II was in Salina, Kansas on June 10, 2015 at the University of Kansas - Salina and the second demonstration was held in Rapid City, South Dakota on October 20, 2015 as part of the 30th Regional Local Roads Conference hosted by the North Dakota Local Technical Assistance Program (LTAP). These were focused on bringing together local transportation officials and companies to demonstrate the AURA system developed by the project team as well as demonstrate the usefulness of UAVs for the asset management. Figure 1-2 shows the project team demonstrating a data collection of an unpaved road using the AURA system in Rapid City, SD.



Figure 1-2: Field demonstration in Rapid City, SD as part of a pre-conference workshop for the 30th Regional Local Roads Conference.

Important software updates were made to the Remote Sensing Processing System (RSPS) developed in Phase I of the project. One update included a blurred image filter which removes blurred imagery before being processed for 3D reconstruction, improving the 3D output quality. Another was the ability to run the distress detection part independently of the 3D processing. The separation of the two components of RSPS was done in response to commercialization discussions with companies which already have their own 3D processing software and some UAVs (especially fixed-wing UAVs) have 3D processing software included in their purchase. By separating the two components, the user is able to input their own 3D point cloud to RSPS and the same distress detections analysis “damage report” XML outputs are generated as in the original version.

Using new imagery from SEMCOG, the project team updated the unpaved roads inventory maps from Phase I. The original imagery used was collected in 2010 and the latest imagery analyzed was collected in 2015. By adapting the algorithm used previously, updated maps were generated for the SEMCOG counties using the updated imagery, and compared to PASER data. These updated maps show that the unpaved roads inventory algorithm can be rapidly applied to generate the basemap needed to know where paved vs. unpaved roads are located. A peer-reviewed article describing this algorithm has been submitted to Photogrammetric Engineering and Remote Sensing and has been resubmitted for publication after incorporating reviewing comments.

As part of Phase II, commercialization discussions were held with several firms, including one interested in offering AURA system analysis of unpaved roads to end users through an online web-based processing system. The market for high-resolution, UAV-enabled sensing of unpaved road condition is still developing. The technical capability has been demonstrated through this project that meets all requirements defined by the Technical Advisory Committee. A mandate to collect sub-inch resolution assessment of all unpaved roads in a state or the country does not yet exist. Nonetheless, several firms

expressed strong interest in working with the Michigan Tech team on using the AURA system commercially, especially for assessment of shorter “haul roads” that must be in sufficiently good condition for goods such as mining and dairy products to reach markets along these rural, typically unpaved roads. The project team is continuing to search for U.S. and international opportunities for the AURA system to reach day-to-day usage for unpaved road assessment, and is committed to doing so beyond the formal conclusion of the project. The technology has reached the stage of being implementation ready – the right opportunities just need to be applied for, won, and completed.

Acknowledgements

As Project lead Principal Investigator, I would like to personally thank the Program Manager at USDOT for this project, Caesar Singh, P.E., for providing insight and guidance throughout the duration of this project, from 2011 to 2016. My associate Co-Principal Investigators during Phase I and II, Chris Roussi (of MTRI) and Dr. Tim Colling, P.E., (of the Michigan Tech Center for Technology and Training), and Phase II Co-PI Rick Dobson provided critical inspiration, technical expertise, software coding, data collection, and engineering input that made the AURA system possible. Valerie Lefler, MPA, provided professional outreach help that made it possible for a much wider audience to learn about the capabilities and need for our automated unpaved road assessment system. The project team was invaluable throughout, with David Banach, Ben Hart, Joe Garbarino, Sam Aden, Brian White, Dave Dean, and Michelle Wienert helping in Phase II. Project interns who helped with data collection and demonstrations provided significant project help, especially with data collection, and are now part of the tech-savvy workforce that can help solve future transportation problems. The Phase II Technical Advisory Committee (TAC) members and their representatives, including Carmine Palombo (Southeast Michigan Council of Governments/SEMCOG and State of Michigan Transportation Asset Management Council/TAMC), Ann Burns (SEMCOG), Ed Hug (SEMCOG), David Huft (South Dakota Department of Transportation), Jay Carter (Road Commission for Oakland County), Ken Skorseth (South Dakota LTAP), Nelda Buckley (Kansas Department of Transportation), Nick Verret (Parish of Natchitoches – Louisiana), and Roger Surdahl (USDOT Federal Highway Administration - Central Federal Lands) continued to provide valuable input through two Phase II TAC meetings and other discussions. This was a team effort, and I appreciate everyone's help.

– Colin Brooks, October 5th, 2016.

Disclaimer

The views, opinions, findings and conclusions reflected in this report are the responsibility of the authors only and do not represent the official policy or position of the USDOT/OST-R, or any State or other entity.

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2. Introduction

This report reviews the second phase of the “Characterization of Unpaved Road Conditions through the Use of Remote Sensing”, which was focused on implementation and commercial readiness of the Aerial Unpaved Road Assessment (AURA) system. Under the leadership of Principal Investigator (PI) Colin Brooks, through the efforts of the research team, and with guidance of U.S. Department of Transportation (USDOT) program manager Caesar Singh and the project’s Technical Advisory Committee, the AURA system is now commercially ready for rapid, repeatable assessment of unpaved road condition in an asset management environment.

The second phase builds from a 2011-2014 effort that included describing the state of unpaved road assessment technologies, determining needed resolution and functionality through the help of a Technical Advisory Committee (TAC), testing two unmanned aerial vehicle platforms, comparing to manned fixed wing options, applying a high-resolution digital camera, and developing an end-to-end software system to create the needed three-dimensional (3D) data and detected road distresses. Associate PI Tim Colling provided in-depth expertise on gravel road assessment, and the capability to integrate road distress data into a decision support asset management environment. Associate PI Chris Roussi provided the engineering, hardware testing, and software development capabilities necessary to develop a successful AURA system. A peer-reviewed Transportation Research Record paper (Dobson et al. 2014) overviewing the Phase I analysis and accomplishments was submitted and accepted for publication.

In Phase II, project efforts resulted in commercialization discussions with seven companies in the U.S. and one in South America who expressed interest in offering AURA services for unpaved road assessment on a commercial basis. The project team is looking with the most interested companies in opportunities to bid AURA system capabilities for a paid project. Haul road monitoring at mining sites and assessing roads along potential pipeline projects have emerged as two of the main commercial opportunities. The project team is committed to continuing commercialization efforts, as sufficient momentum has been built and ceasing efforts at the end of Phase II would not seem sensible. Second Phase partners Woolpert Incorporated of Dayton, Ohio proved a valuable addition through their help in arranging a test of AURA system capabilities at a working gravel mining site in Ohio. This helped demonstrate that the AURA system can provide the data to assess haul road sites. The attribute of haul roads that lends itself to the AURA system is that frequent assessment of road condition is needed to see if roads are passable for the mining product’s transport along the road network. The AURA system produces centimeter-resolution 3D models of road surfaces with automated detection and severity rating of ruts, potholes, and washboarding, plus calculation of percent crown. In the U.S., a requirement to produce this level of data for unpaved roads does not yet exist in most localities. However, major unpaved roads such as haul roads must remain open, and the AURA system can produce the data needed to monitor road condition and suitability for traffic.

An outreach professional, Valerie Lefler of Integrated Global Dimensions, was added to the team for the second phase to help improve and extend the project’s outreach efforts. Ms. Lefler significantly helped the project by producing outreach videos, helping organize demonstration events, tracking down and communicating with potential commercialization partners, and helping generate new flyers to share with interested companies and agencies.

This second phase report starts with an overview of Phase I, then has summaries of all seven deliverables created for Phase II, continues with an update on applying the unpaved roads inventory algorithm, and then describes improvements made to the processing software. All of these milestones, outcomes, and deliverables have helped improve the capabilities and commercial readiness of the AURA system. With UAV technology developing rapidly, and newer more flexible rules on UAV operations coming out of the federal government, the AURA system is ready to help assess unpaved roads in the U.S. and beyond.

Summary of Phase I

During the initial three-year Phase I assessment of this analysis, the project team’s goal was to develop and test the ability of a UAV and remote sensing to assess, identify, and quantify unpaved road distresses (such as potholes, ruts, and washboarding). This goal was accomplished through the development of the Aerial Unpaved Road Assessment (AURA) system, which contained five major components including 1. data collection, 2. three-dimensional data processing, 3. distress detection algorithms, 4. extensible markup language (XML) distress data, and 5. a decision support system (DSS) (Figure 2-1). The initial step in development of the AURA system included an in-depth review into current unpaved road assessment techniques, including those that involve visual, a combination of visual and direct measurements, or indirect measurements (e.g. remote sensing methods and technologies). The Pavement Surface Evaluation and Rating (PASER) system (a visual method) allows road managers to quickly and cost-effectively assess road conditions that can guide road maintenance decision and classifies a pavement into numerically labeled categories based on the type, extent, and severity of distresses and includes assessment of road attributes such as drainage, surface material makeup, and ride. Additionally, PASER data for the seven counties that compose the Southeast Michigan Council of Governments was used as “ground-truth” data for the Unpaved Roads Inventory Algorithm (Section 5). The Unsurfaced Road Condition Index (URCI) (a combination of visual and direct measurements method developed by the U.S. Army) was used as the basis for assigning distresses into category bins based on each distress feature’s severity for AURA. Lastly, remote sensing (an indirect method) was used as the basis of this project.

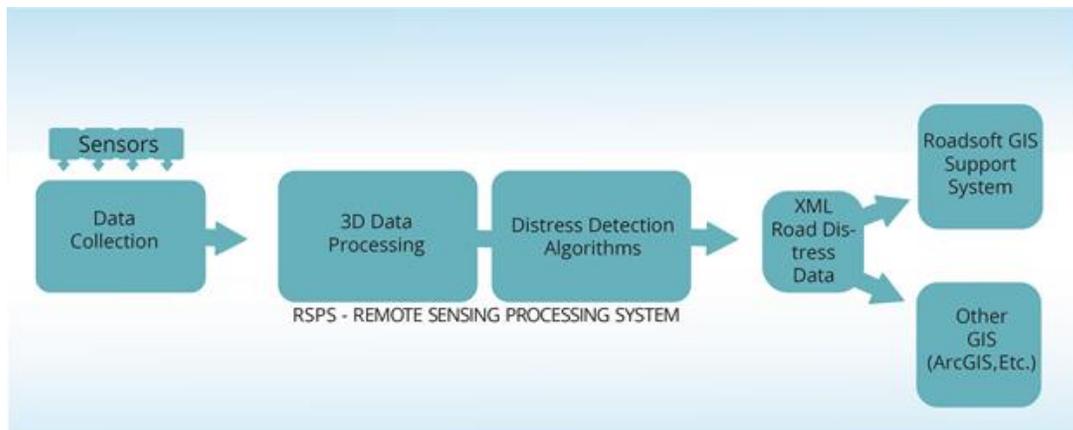


Figure 2-1: The flexible, modular components of AURA developed as a working prototype for this project.

In order to assess roads via indirect methods, a Bergen Hexacopter UAV was selected as the primary data collection platform (Figure 2-2) after an initial test with a single-rotor UAV. This platform was chosen due to ease of control, simple maintenance, its ability to collect up to 20 minutes of data per flight with a DSLR camera load, fairly compact size with folding arms for easy packing, ability to quickly transfer from one data collection location to the next, cost (approximately \$5,400, U.S.-made status, and ability for safe and efficient flights that follow FAA rules and guidelines). Based on defined requirements (such as the sensor had to be remote controllable and contain a certain field-of-view, focal length, resolution, and frame rate), the 36-megapixel Nikon D800 was selected as the optical sensor with a 50 mm f/1.4 prime lens. Through the use of these select sensor and lens, the project was capable of collecting aerial imagery of 1cm resolution from 30m altitude for multiple unpaved road segments located for study and demonstration sites in southeast Michigan, Iowa, Nebraska, and South Dakota (Figure 2-3).



Figure 2-2: The selected hexacopter Bergen Hexacopter UAV.



Figure 2-3: High resolution imagery collect from approximately 30m.

Overlapping aerial imagery collected by the UAV were processed by a software toolset called the Remote Sensing Processing System (RSPS) consisting of both custom developed and existing open source tools and scripts, allowing the overlapping stereo imagery to be reconstructed into a point cloud, digital elevation model (DEM), and eventually a three-dimensional model of the unpaved road segment, in which the density and severity of road distresses could be quantified and binned (Figure 2-4).

Categorization of distress features such as potholes and road crown were most effectively identified, with ruts and washboarding also being detected, but requiring further accuracy improvements. Quantified distress data were integrated into the RoadSoft GIS DSS tool, a commercially ready software that transportation agencies could choose to use with this newly available unpaved road asset management data (Figure 2-5).

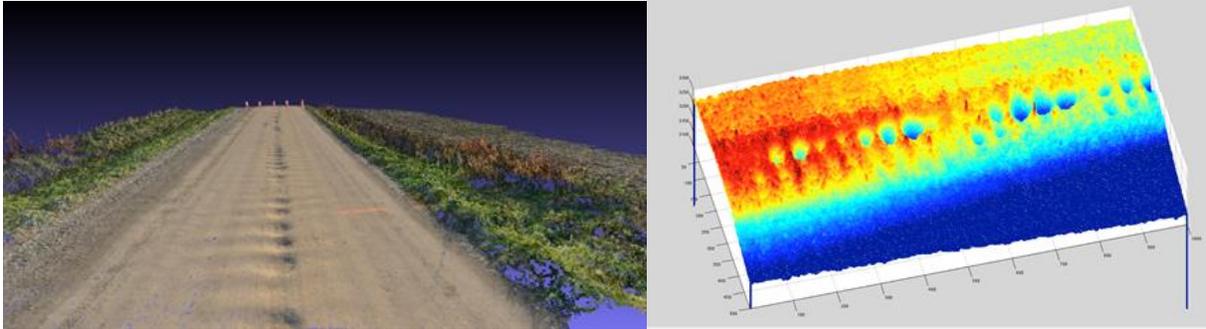


Figure 2-4: A 3-D point cloud generated through the project’s algorithms and the corresponding height map where potholes and their depths can be seen.

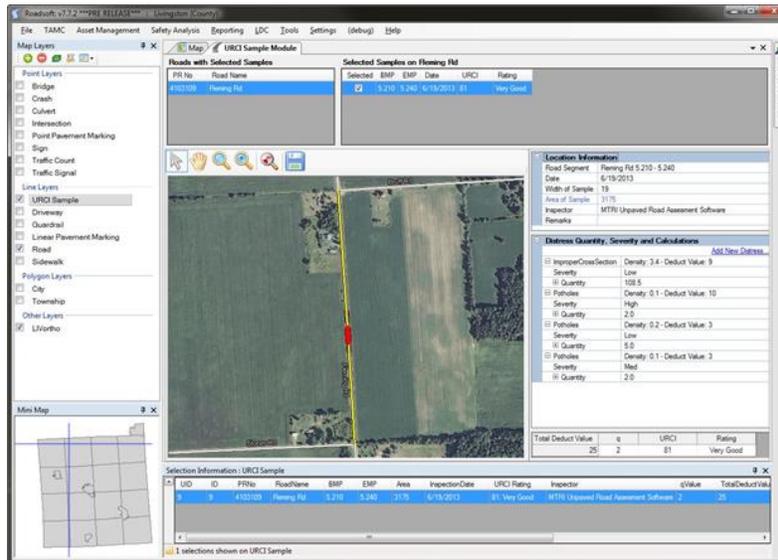


Figure 2-5: Assigning road sampling locations to a network of representative roads in the DSS.

Additionally, as part of Phase 1, an algorithm that automatically classifies paved vs. unpaved roads from aerial imagery was developed and implemented on the SEMCOG region, including Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne counties. The benefits of conducting this analysis was twofold and included developing the ability to assess the mileage and condition of unpaved roads on a comprehensive, repeatable and cost-effective manner for road commissions and to automatically define where unpaved roads that can be assessed by AURA are located. Using one foot (30cm) resolution four-band aerial imagery provide by SEMCOG, the Michigan Framework Roads network (buffered by 30ft / 9.1m), and an algorithm created within eCognition, the category of road (paved vs. unpaved) was assigned to every road segment (with a National Functional Classification (NFC) of 4 (Minor Arterials), 5 (Major Collectors), 6 (Minor Collectors) and 7 (Local)) within each county. Additional categories such as shadow and vegetation were also used in this analysis as both occur either within the 30ft buffer. The sections that were classified as unpaved are exported and merged together to create a data layer for use within GIS software. Ground truth PASER data was then used to verify if the classified unpaved road segments are actually unpaved. Lastly, based on error matrices generated for different automated unpaved road detection percentages, county-wide maps with each road being labeled as paved or unpaved were generated (Figure 2-6). The percentage that matched the PASER data most closely was selected as the overall value.



**Livingston County
Accuracy Assessment
25% coverage**

| | Users | Producers | Overall |
|---------|-------|-----------|---------|
| Unpaved | 83.8% | 72.1% | 87.2% |
| Paved | 88.4% | 93.8% | |

| | Mileage |
|------------------|---------|
| Paved | 1289.4 |
| Unpaved | 894.1 |
| Total Mileage | 2183.5 |

Figure 2-6: Map of unpaved roads (represented in green) in the Livingston County MI road network and its accuracy assessment based on 2010 SEMCOG aerial imagery.

Reports describe all details of the Phase I part of this project have been posted to the project web page at www.mtri.org/unpaved.

3. Summary of Deliverables

The purpose of this section is to briefly review each of the deliverable reports created for this project. All reports are available on the project website (www.mtri.org/unpaved) but are also included here with links to the full reports.

Chapter 1: Review and Update on AURA Requirements, Sensors, and Platforms

Deliverable 5-B is available for download at:

http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del_5B_URCASupdate_requirementsensorsplatforms_Final.pdf

Deliverable 5-B Supplemental is available for download at:

http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del_5B_Supplemental_FixedWingEval_Final.pdf

During Phase I of the project, four deliverables were published to define the requirements for the AURA system to assess unpaved roads. These deliverables are requirements definition (Deliverable 1-A), assessment methods (Deliverable 2-A), sensor selection report (Deliverable 4-A), and candidate and recommended remote sensing platforms (Deliverable 5-A). All of these deliverables were submitted from 2011 - 2012 and with the availability of newer and more advanced sensors and platforms by 2014, it was necessary to revisit the initial analysis for the system. This deliverable reported on these technology advances and made recommendation on how the project team should proceed in Phase II.

The requirements of the system remained mostly the same from Phase I of the project as outlined in Deliverable 1-A. Table 3-1 shows a summary of the updated requirements for a successful unpaved roads data collection. The new table now includes platform and sensor specific details which include flying altitude, resolution, field of view, and image capture speed. These were determined in Deliverables 4-A and 5A and tested in Phase I of the project.

Table 3-1: Updated Summary of requirements for unpaved roads collection.

| Number | Name | Type | Definition |
|--------|----------------------|----------|---|
| 1 | Data Collection Rate | Sensor | The systems must collect data at a rate that is competitive with current practice (to be determined, TBD) |
| 2 | Data Output Rate | System | Processed outputs from the system will be available no later than 5 days after collection |
| 3 | Sensor Operation | Sensor | “easy”, little training required |
| 4 | Platform Operation | Platform | Training needed TBD, based on platform choice |
| 5 | Reporting Segment | System | <100ft x 70ft, with location precision of 10ft. Map position accuracy +/- 40ft |

| | | | |
|----|---------------------|----------|--|
| 6 | Sample locations | System | Specified by the user a map waypoints |
| 7 | Inventory | System | A classified inventory of road types is required prior to system operation. This will consist of 3 classes: Paved, Gravel, Unimproved Earth |
| 8 | Surface Width | System | This is part of the inventory, and may also be estimated by the system measured every 10ft, precision of +/- 4" |
| 9 | Cross Section | Distress | Estimate every 10ft, able to detect 1" elevation change in 9', from center to edge. |
| 10 | Potholes | Distress | Detect hole width >6", precision +/-4", hole depth >4", precision +/-2". Report in 4 classes: <1', 1'-2', 2'-3', >3' |
| 11 | Ruts | Distress | Detect >5" wide x 10' long, precision +/-2" |
| 12 | Corrugations | Distress | Detect spacing perpendicular to direction of travel >8" - <40", amplitude >1". Report 3 classes: <1", 1"-3", >3". Report total surface area of the reporting segment exhibiting these features |
| 13 | Roadside Drainage | Distress | Detect depth >6" from pavement bottom, precision +/-2", every 10ft. Sense presence of standing water, elevation precision +/-2", width precision +/-4" |
| 14 | Loose Aggregate | Distress | Detect berms in less-traveled part of lane, elevation precision +/-2", width +/-4" |
| 15 | Dust | Distress | Optional – measure opacity and settling time of plume generated by pilot vehicle |
| 16 | Flight Altitude | Platform | ~400' (max) |
| 17 | Field-of- View | Sensor | 11 degrees |
| 18 | Resolution | Sensor | 0.5", (4 MP pixels for this geometry) |
| 19 | Image Capture Speed | Sensor | 2.25 frames per second |

Since the system requirements did not change, the resolution requirements for the sensor remained the same. The project team chose the Nikon D800 which is a 36.3 MP DSLR camera during Phase I. With that sensor resolution the resolution of the collected imagery from 25m flying altitude is 0.4cm. After processing the imagery through SfM algorithms, the resulting point cloud has a resolution of 0.9cm (roughly 1/3in). This is well below to the required 1” (2.5 cm) resolution requirement defined in Deliverable 4-A.

A review of potential multi-rotor platforms other than the Bergen Hexacopter was conducted for Deliverable 5-B. This included other multi-rotor configurations, shown in Figure 3-1, as well as different manufacturers. After review of these systems it was determined that multi-rotor platforms from Bergen RC were preferred as the manufacturer based on performance, price, and outstanding customer support. The Bergen Hexacopter remained at the preferred choice for a platform, but a new Bergen Quad-8 with heavier lift capabilities would also be a good potential option. This platform is slightly larger than the Hexacopter but its advantages include greater redundancy in case of motor failure, heavier lift payload, and longer flight times when carrying the same payload as the Hexacopter.

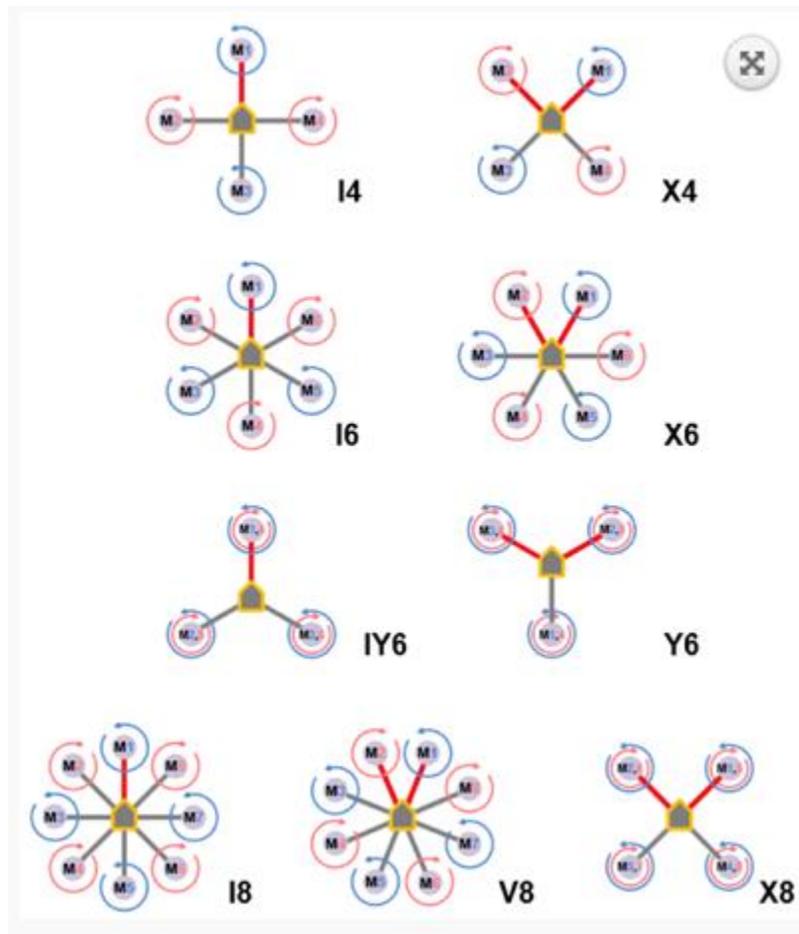


Figure 3-1: Possible multi-rotor prop configurations.

The Nikon D800 is the camera that was chosen as the sensor to be used during the first phase of this project. This was done because it has a full frame (“FX”) sensor with the highest digital single lens reflex (DSLR) camera resolution (36.3MP) at that time. It is capable of being remotely triggered as well as having an internal interval timer to continuously capture imagery at user defined rate. Through testing of

the camera it was determined that the interval timer on the camera allowed for a maximum frame rate of 1 fps while an external controller enabled up to 2 fps. While the camera is rated from up to 4 fps continuous shooting, the camera ran into buffer issues when collecting unpaved road data at 3 to 4 fps.

For deployment to collect unpaved roads imagery a 50mm prime lens was attached in order to achieve the desired FOV. The total weight of the camera and lens is 1.2kg which the Bergen hexacopter platform is more than capable of carrying. For the first phase of the unpaved roads project, this camera was proven to be able to collect the necessary resolution and quality of imagery needed for the 3D models and distress detection.

Since choosing the Nikon D800 to be the sensor for the system in early in the Unpaved Roads project, Nikon has introduced an upgraded version named the D810 (see <http://www.nikonusa.com/en/Nikon-Products/Product/dslr-cameras/D810.html>), also at the \$3k price point. This camera has the same resolution of 36.3MP as the D800 but is capable faster continuous shooting which would allow for faster collection speeds. The new camera is now also 20g lighter than the D800 which would help slightly with increasing flight times for the UAV platform.

Fixed-wing UAV Evaluation

The supplemental report was focused on evaluating fixed-wing UAVs for assessing unpaved roads. This report reviewed and compared the practicality of using fixed-wing UAVs but more importantly it evaluated unpaved road imagery collected from these platforms and compared the results to those from the Hexacopter platform recommended by the project team.

Fixed-wing UAVs are available in a variety of sizes and capabilities. These range in size from small hand launched varieties like the eBee to the larger catapult launched types. For rapid deployment assessment of unpaved roads and for operating in smaller areas, hand launched UAVs were focused on. Due to their small size and payload capability these UAVs are generally restricted to carrying only point and shoot cameras with lower resolution sensors and smaller lenses.

The major advantage of fixed wing UAVs is that they have longer flight time when compared to multi-rotor systems. They are usually powered by a single motor as opposed to four or more on multi-rotors. They are also more efficient in with respect to staying aloft. Multi-rotor systems have to be continuously creating downforce greater than their weight through their propellers to maintain flight. Fixed-wing UAVs only have to create enough force to push it through the air while the wings create the lift. This requires significantly less power to accomplish and therefore greater flying times with smaller batteries. The project team evaluated two fixed-wing UAVs, the Lehmann LP-960 and the Sensefly eBee.

The Lehman LP-960 is a fixed-wing UAV owned by Michigan Tech with a flying wing design and has a wingspan of 1m and 0.5m long (3ft and 1.5ft respectively) and weighs 1250g ready-to-fly with a camera (Figure 3-2). Depending on what “extras” it is purchased with (such as extra batteries), it costs approximately \$10,000 (the base kit is currently €6990 or about \$7940 at current exchange rates from its European manufacturer). It has an endurance of up to 25 minutes and can fly in winds up to 25kt (29mph). It is designed to carry a maximum payload capacity is 350g (12oz) which Lehmann recommends as Sony point and shoot cameras or a GoPro. The camera is triggered by the LP-960 using an infrared (IR) remote mounted over the cameras sensor and captures imagery at one frame per second.



Figure 3-2: Lehman LP-960 wing and ground control station.

The UAV is hand launched (Figure 3-3) and can be remotely piloted or fly pre-programmed GPS-based waypoints. During takeoff the LP-960 needs roughly 30m / 100ft from the launch point to stabilize and ascend to an altitude which is over nearby trees or other obstacles which could be near the launch site. When using the waypoint capability, after launch the LP-960 ascends to the desired altitude and then flies to the starting waypoint. After the mission is complete, the LP-960 flies to towards the designated landing point. The motor shuts off manually which initiates a landing in which the UAV would glide in to land. A clearing which is at least 90m / 300ft long is needed for landing safely.



Figure 3-3: Lehmann LP-960 being hand launched and manually controlled.

The LP-960 is designed to carry Sony point and shoot cameras such as the Sony NEX-5T with a 16MP resolution, Sony a6000 with a 24MP sensor, and the Canon PowerShot S110 with a 12MP sensor (the Michigan Tech team has the Sony NEX-5T, which Lehmann Aviation described as their preferred sensor). The highest image ground pixel resolution possible at an altitude of 55m / 180ft by the Sony NEX-5T is 1.3cm, the Sony a6000 is estimated to be less than 0.9cm and the Canon PowerShot S110 is 2cm. Actual resolution will depend on the ability of the UAV to maintain its altitude as wind will impact its flying characteristics and quality of the imagery. The Digital Elevation Model (DEM) derived using the RSPS typically has a maximum resolution of twice the resolution of the input (i.e., images with 2 cm ground pixel resolution have the possibility of being turned into a 3D DEM model with 4 cm x,y,z resolution). This is done as a method to minimize processing time while still achieving accurate models of the road surface, and not exceeding the resolution capabilities of the collected imagery.

The waypoint capability is limited to a “mow-the-lawn” collection style. This is where the operator designates an area to be surveyed and the OperationCenter software (that comes with the LP960) calculates the flight path needed to complete the survey with overlapping imagery (Figure 3-4). Flying altitude is determined by the software based on an imagery resolution selection and type of camera flown. In the example below the camera is a Sony NEX-5T set to a 16mm focal length and a desired ground pixel resolution of 1.6cm. The flying altitude for this collection would be roughly 55m / 180ft. The collection area is set to a wide area over the unpaved road since the software is using Google Earth for the background imagery, and the georeferencing of Google’s product can be off by several meters (the Michigan Tech team has seen Google Earth imagery be displaced from its true location by 10m / 33ft in some locations). This wider area but still focused collection area enables full collection of the road while allowing for some error in the Google imagery as well as some inaccuracy from the GPS on the UAV itself.

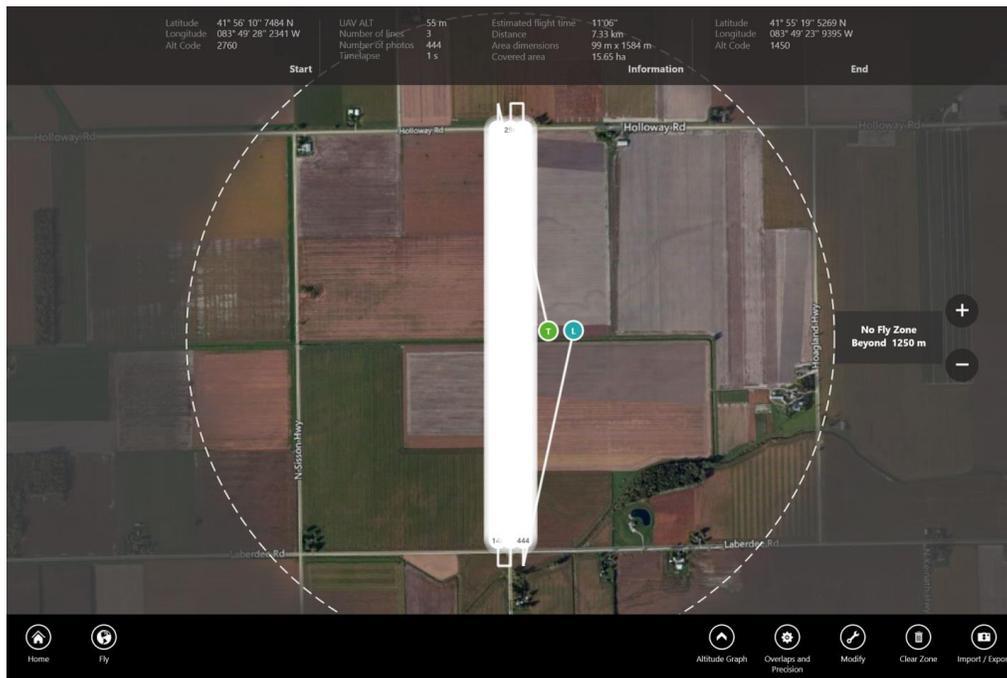


Figure 3-4: Final flightpath for the proposed collect of Piotter Hwy near Britton, MI.

The Sensefly eBee is a flying wing design similar to the Lehmann LP-960 (Figure 3-5). Sensefly is another European company and part of the Parrot group. It has a 1m wingspan and weighs 730g (1.6lbs). It has an endurance of up to 40 minutes and can fly in winds up to 24kt (28mph or 44kph). It is designed to carry point and shoot cameras and can operate with the Sony WX220 (18MP) or the Canon PowerShot

S110 (12MP). An option for the eBee is RTK (Real Time Kinematic) GPS capability for increased positional accuracy of imagery location tagging. The cost of an eBee RTK is \$51,000 with 3D processing software.



Figure 3-5: Sensefly eBee (Photo Courtesy of Jarlath O'Neil-Dunne, University of Vermont)

Like the Lehmann, the eBee is hand launched and comes with its own mission planning software. They are both light weight systems, but to launch the Lehmann the operator needs to do a short run and throw it upward into the air. The eBee is a slightly lighter system and is launched with a quick throw from a standing position. The eBee flight panning software called eMotion. Similar to the OperationCenter software, eMotion allows the user to select the area to be mapped, the desired resolution and the takeoff and landing points of the UAV. Google Earth imagery is also used as the base map within the software to aid in visualizing the data collection. This software also allows the operator to make changes to the flight plan while the eBee is flying.

Both fixed-wing platforms are capable of carrying the same type of camera in a similar fashion. A point-and-shoot camera is mounted inside the UAV. This is different than the Bergen Hexacopter where the camera is mounted to and stabilized by a two-axis gimbal. The gimbal counters roll and pitch movements of the hexacopter while in flight so that the camera is always pointed at nadir. The hexacopter itself is stabilized through a GPS IMU (Internal Measurement Unit). The GPS is used to hold the UAV's x, y, and z position when there is an absence of inputs given by the controller, as well as to fly programmed waypoints. The IMU keeps the hexacopter level while in flight and provides input for the gimbal. As a mission is being flown, wind gust will tend to push the hexacopter off course and the GPS IMU will correct this action by changing the roll orientation to maintain a straight flight path. This action is corrected by the gimbal to keep the camera pointed at nadir.

Fixed-wing UAVs like the eBee also have a GPS IMU but they do not have a gimbal to stabilize the camera. Like the multi-rotor systems, the eBee will automatically adjust its orientation to maintain the flight path programmed by the operator. As the UAV is being buffeted around by gusting winds and correcting for those actions, the camera is moving with the aircraft without any correction. Depending on the severity of the wind gust, the camera is sometimes quickly jerked while a picture is being taken. Since it is not mounted to a gimbal this could cause motion blurring in some frames.

The type of camera used on the UAV also makes a difference in the quality of imagery. Larger multi-rotor systems like the Bergen Hexacopter can carry a DSLR while the eBee is restricted to smaller point and shoot cameras. There are differences in sensor and lens quality as well as operational differences between the two camera types. The Nikon D800 currently used on the AURA allows for full manual operation. Prior to a collect, the operator manually sets the camera shutter speed, aperture and focus to ensure properly exposed imagery while minimizing motion blur with the lighting conditions during the flight. Some point and shoot cameras have limited capability with full manual settings as well as setting the focus. Point and shoot cameras on fixed-wing systems typically are set to shutter priority and auto focus. This could lead to image blurring issues as light conditions change leading to the aperture

changing, leading to changes in depth-of-field. The auto focus feature could cause blurring issues as it will tend to focus on larger objects such as tree tops, buildings or other parts of the image area and not always the road surface. Depending on the depth-of-field and where the camera is focusing in the field of view, the road surface may be out of focus and therefore blurred.

Most fixed-wing UAVs are also sold with SfM software and cannot be purchased separately. This significantly adds to the cost of the UAV. By comparison a Bergen Hexacopter ready to fly costs \$5,400, while an eBee RTK system cost \$51,000. The RSPS already contains SfM algorithms which generate the 3D point cloud and therefore it is not necessary to purchase it with a UAV. However, the project team recognized that many companies that might offer unpaved road assessment using the AURA system might already have their own SfM software and may prefer to continue using that.

Imagery was collected from an eBee by Jarlath O'Neil-Dunne from the University of Vermont and sent to the project team to assist with this report. The imagery was processed through Pix4D to assess image and 3D model quality. Figure 3-6 shows example output from the processing of eBee imagery. Three large potholes are clearly seen in the orthoimage (mosaiced and terrain corrected image from the collected imagery), but only one is seen in the Digital Elevation Model (DEM) or the Hillshade representation of the DEM. This pothole is 67cm / 26in diameter and 10cm / 4in deep.

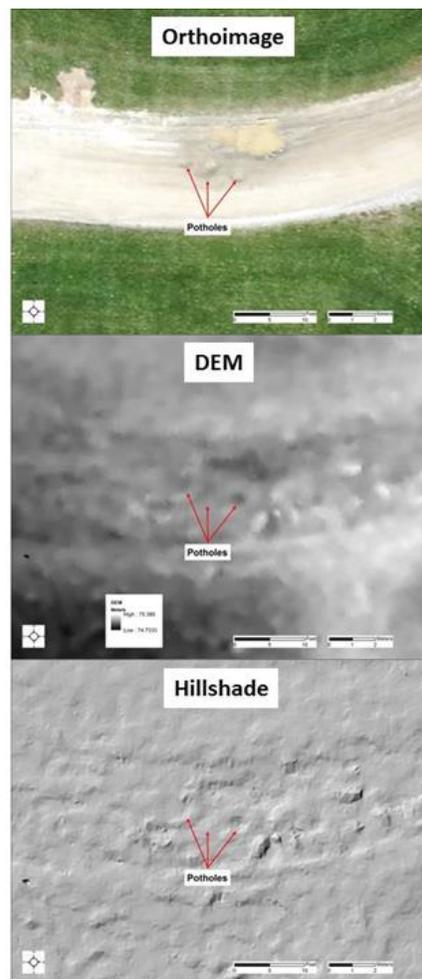


Figure 3-6: Detail of potholes on an unpaved road in Shelburne, VT. The orthoimage and DEM were generated in Pix4D and the hillshade was generated in ArcGIS from the DEM. Both the orthoimage and DEM are processed to a resolution of 3.3cm.

Based on these results, the project team determined the detection ability of the eBee system and compared it to the Hexacopter based system and compared them in Table 3-2. This table illustrates that fixed-wing system, which use small point and shoot cameras, are not capable of capturing the high resolution imagery needed to meet the unpaved road assessment resolution requirements defined earlier in the project. Fixed-wing systems do offer an advantage in longer duration flight and therefore would be more useful in collecting large sections of road and using the imagery for visual inspection purposes.

Table 3-2: Comparison of Detection ability between the eBee and Hexacopter systems.

| Distress | Hexacopter (cm) | eBee (cm) | Comments |
|------------------|-----------------|-----------|--------------|
| Crown | 1 | 10 | z-axis |
| Pothole Diameter | 3 | 67 | x and y axis |
| Pothole Depth | 1 | 10 | z-axis |
| Rutting Diameter | 3 | 67 | x and y axis |
| Rutting Depth | 1 | 10 | z-axis |
| Corrugation | 1 | 10 | z-axis |

Form this analysis of the highest resolution DEM which was processed to the resolution of the input imagery (3.3cm) the smallest sized pothole that can be detected from imagery collected from an eBee is 67cm in diameter and 10cm deep. There were other potholes shown in the orthoimage but could not be differentiated from the road surface in the DEM. Figure 3-7 shows a comparison of the hillshade representations of a DEM from the current AURA system and the eBee.

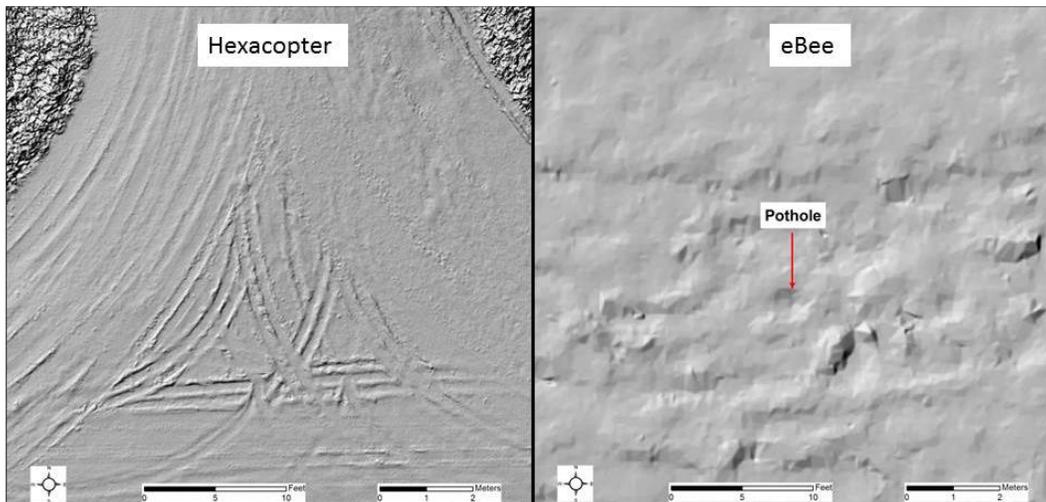


Figure 3-7: A comparison between the level of detail between DEMs generated from the Bergen hexacopter-based system and an eBee-based data collection system. Both hillshade representations are at the same scale and the pothole pointed out in the eBee hillshade is 67cm in width.

While current FAA regulations restrict UAVs to within line of sight operation, this could be taken advantage of in the future when longer-distance styles of collection are offered, this could be done through the new FAA waiver process. An alternative to the eBee fixed-wing system is the Tempest fixed wing UAV aircraft from UASUSA (<http://www.uasusa.com/products-services/aircraft/the-tempest.html>). It has the capability to fly a 4.5kg (10 lbs) payload for up to 1.5 hours. While larger than the eBee (3m or 9.8ft wingspan), it is still easily transported with removable wings and is still hand-launched. The major advantage of this system is that it is capable of carrying the high-resolution Nikon D800 payload that is currently used by the AURA system to evaluate sub-inch road distresses. This would allow for centimeter / sub-inch 3D reconstructions of the unpaved roads from a fixed-wing UAV. This ability would be extremely useful when new regulations allow for beyond line of sight operations as it could collect high resolution imagery over several miles of road in a single flight; a linear data collection distance of at least 40 miles / 64 km has been estimated, with 60 miles / 97 km possible.

Chapter 2: Extension of GIS DSS Tools to a Nationwide Assessment Tool for Unpaved Roads

Deliverable 6_D is available for download at:

http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del6-D_ExtensionofGISDSSTools_fin.pdf

During the Phase I demonstration flights, there was a considerable amount of interest from the participants. However, the interest to collect further data or to use the data in conjunction with the Decision Support System (DSS) software did not materialize as well as the project team had originally hoped. Anecdotal information from interacting with agencies at field demonstration sites revealed that, while unmanned aerial vehicle (UAV) technology was interesting and alluring to participants, many agencies were still struggling with the concept of asset management for unpaved roads. Conversations with agency staff revealed that few, if any, participating agencies have business processes set up to use condition data in their decision-making process for unpaved roads but, rather, relied on professional judgment to drive decisions. The idea of data-driven decisions appeared to be a new concept for most of the demonstration participants at our various field efforts.

From these interactions the project team developed a webinar to introduce the concepts of asset management and how a DSS could be useful. The project team developed and presented a two-hour introductory webinar on asset management concepts in light of the capabilities of the AURA system. This webinar intended to raise the awareness of the benefits for using asset management systems and the associated data gathering, helping to create demand for AURA system capabilities. The webinar would also then be available to help with outreach to any future groups interested in how road asset management and the AURA system fit together to meet their unpaved road data needs.

The project team developed a webinar with five learning objectives:

- 1) *Participants will be able to outline the three phases and six steps of a general asset management process.*
- 2) *Participants will be able to relate asset management core concepts to everyday activities.*
- 3) *Participants will be able to articulate the six uses of condition data for asset management purposes.*
- 4) *Participants will be able to describe the applications of the AURA systems to their peers.*
- 5) *Participants will be able to articulate the differences between the worst-first strategies for project selection versus a mix-of-fixes asset management strategy.*

Advertising for the webinar relied on a targeted electronic mailing campaign. Participants who had provided their contact information at an AURA system field demonstration received the advertisement for the webinar via e-mail. A second mailing advertising the webinar included contacts from the Michigan Local Technical Assistance Program (LTAP) mailing list and a third marketing effort involved advertising the webinar in the e-mail newsletter, "Transportation Tomorrow," which is created and distributed by Valerie Lefler of Integrated Global Dimensions (IGD) and is produced by Integrated Global Dimensions. This newsletter is distributed to over 20,000 transportation professionals worldwide.

The webinar was held on June 2, 2016 and presented by Co-Investigator Tim Colling and project PI Colin Brooks using Adobe Connect web conferencing system. There were 26 participants who attended the webinar, of which, 85% of them were from Michigan. Table 3-3 shows a list of attendees by state. During the two hour webinar, the participants were also given multiple feedback quizzes to foster interactivity between the audience and instructors while collecting data for the project.

Table 3-3: Webinar attendees by home state.

| Registrant Home State | Registrants | Percent of Total |
|------------------------------|--------------------|-------------------------|
| Alabama | 0 | 0% |
| Arkansas | 1 | 4% |
| Connecticut | 1 | 4% |
| Kentucky | 0 | 0% |
| Michigan | 22 | 85% |
| Montana | 0 | 0% |
| Nebraska | 2 | 8% |
| North Dakota | 0 | 0% |
| South Dakota | 0 | 0% |
| Total | 26 | 100% |

The presentation first introduced the audience to the concept of asset management and its importance before discussing the capabilities of the AURA system and then how a DSS could help in road management planning. Throughout the presentation, participants were asked questions to foster interactivity between the audience and instructors while collecting data for the project. The questions were focused on determining the types of positions and familiarity with asset management as well as how asset management may be used in their agency. These results are summarized in Deliverable 6-D. The webinar is available to help interested parties in learning more about the need for asset management and decision support for unpaved roads at <http://mtu.adobeconnect.com/p8czppjifce/> and is also linked to through the www.mtri.org/unpaved website.

Chapter 3: AURA Remote Sensing Processing System Software Adaptation for Commercial Readiness

Deliverable 6-E is available for download at:

http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del_6E_AURA_SoftwareAdaptation.pdf

The AURA system's Remote Sensing Processing System (RSPS) provides the capabilities to ingest, process, and analyze input images to create 3D road reconstructions that are automatically analyzed for unpaved road distress density and severity. Improvements were made to RSPS which included automated screening for poorly focused images and automated removal of these images from the processing stream, therefore improving the overall 3D reconstruction. In addition, the RSPS software was packaged for delivery and availability to commercialization partners.

Blurred Image Removal

The images collected from our airborne systems sometimes exhibit degradations due to collection artifacts. Blurring is the most common image artifact, and can be caused by the motions of the aircraft or camera-stabilization system, camera mis-focus, or a combination of those. In preparing for a collection, an attempt is made to select parameters that minimize these errors (e.g. slow flight velocities, selecting a large depth-of-field, and short exposure times), but sometimes wind-gusts, equipment errors, or other effects can still result in image blurring (Figure 3-8).



Figure 3-8: Sample images from Petersburg Rd collect, showing varying amounts of motion blur.

The blurring affects the feature-detection step of the 3D reconstruction, either changing the locations of the image features (in the presence of slight blurring), or completely destroying them (in severe cases). These features are used in calculating the camera locations and trajectory, and in determining the 3D locations of features in the scene. When these features are incorrect, the 3D point-cloud is incorrect; measurements of road distresses can only be as accurate as the starting 3D reconstruction.

For the detection of blurred imagery, the Vollath Correlation metric was selected as it measures local pixel correlation. In an image with increased blurring neighboring pixels become highly correlated and therefore there is less difference to distinguish them apart. Figure 3-9 shows the histogram generated from the Vollath Correlation of 200 images. Qualitatively, images with a VC >20 appear to have small enough motion effects that they can be used in the reconstruction. This value also happens to be near the peak in the distribution.

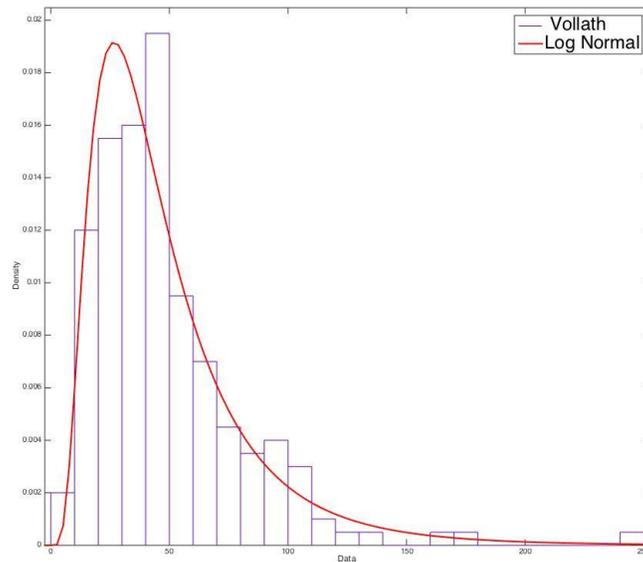


Figure 3-9: Histogram showing distribution of Vollath Correlation metric on Petersburg Rd data

Example 3D reconstructions using this metric and various threshold values are shown in Figure 3-10. In this case, 16 images (without regard to their focus) were used to reconstruct a small section of road (left). Then, a reconstruction spanning the same section of road was formed in which images with $VC < 20$ were excluded (4 images excluded, right). Note that the image on the left (16 images used, some of them blurred) tends to show, qualitatively, more surface variation (“noise”), as well as more gaps in the reconstruction. The image on the right (12 images, $VC > 20$) is less “noisy”, and more “filled in” overall, but has gaps where the excluded images failed to fill in surface detail. In general, though, using fewer (but “better”) images produces a qualitatively better reconstruction.

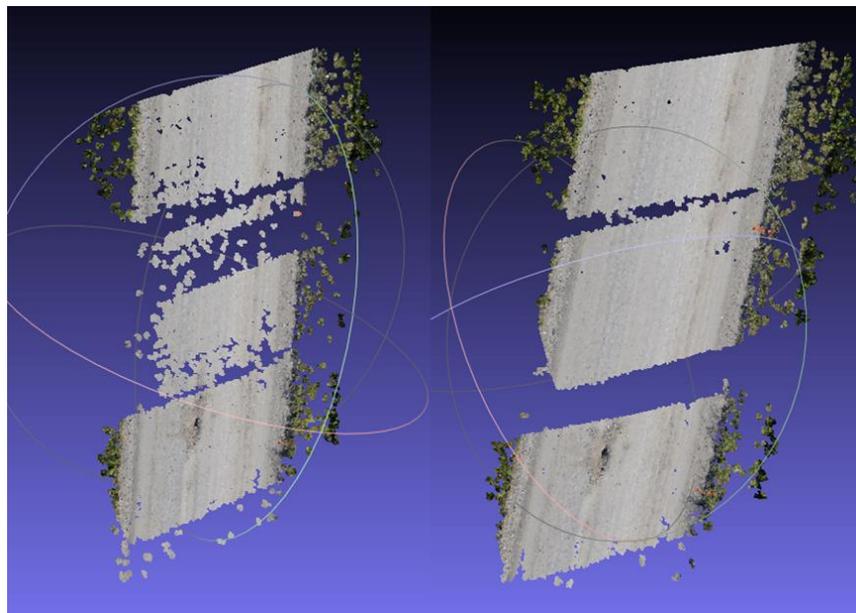


Figure 3-10: Dense point clouds reconstructed from 16 sequential images (left) and 12 images with $VC > 20$ (right).

The addition of the blurred image filter greatly improved the 3D point cloud generation within RSPS and resulted in improved distress detection. For a comparison, Figure 3-11 shows a comparison of height maps generated from processing all of the imagery as opposed to removing blurred imagery first. The height field which results from all of the imagery being processed contains substantial (and unrealistic) height variation, as well as no detected potholes (even though there was a 15cm-deep pothole in the scene). Using only images that were deemed properly focused ($VC > 20$) for reconstruction, the segmented road surface was much larger and more uniform. The pothole detection locations and sizes are indicated with circles. The largest pothole was combined during processing with a nearby pothole and measured slightly larger than actual size, although the declared depth (14cm) was accurate.

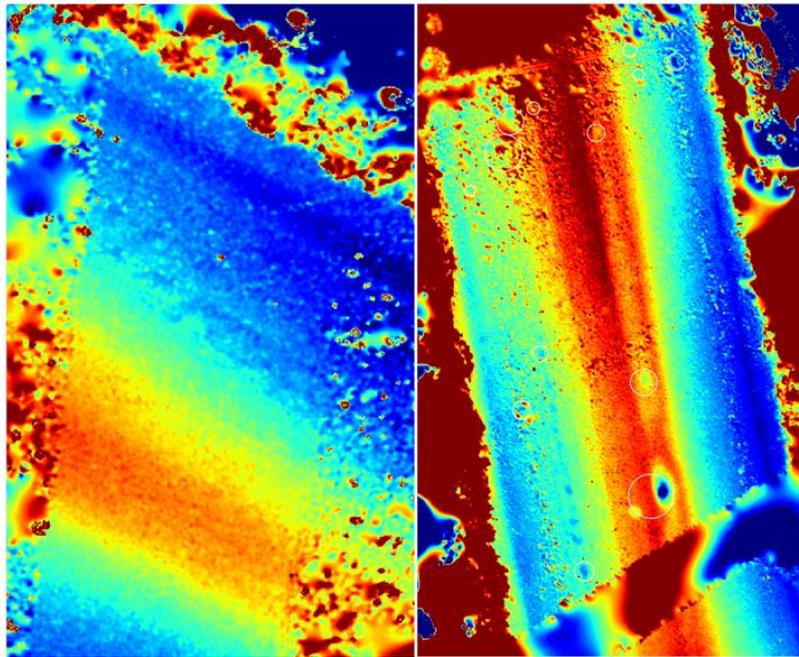


Figure 3-11: Comparison of height maps of segmented road surface using all images (left) and after removing blurred images for reconstruction.

Examples of the road cross sections are shown in Figure 3-12. In the cross section of the height field from all of the imagery, it is difficult to distinguish the edges of the road. The pothole in which the cross section goes through is only 3cm deep when ground truth data recorded it to be 15cm. With the blurred images removed the quality of the height field is improved and shows clearly the road crown, and the pothole depth (14cm at this point, versus 3cm in the original measurement), which is much closer to the true value.

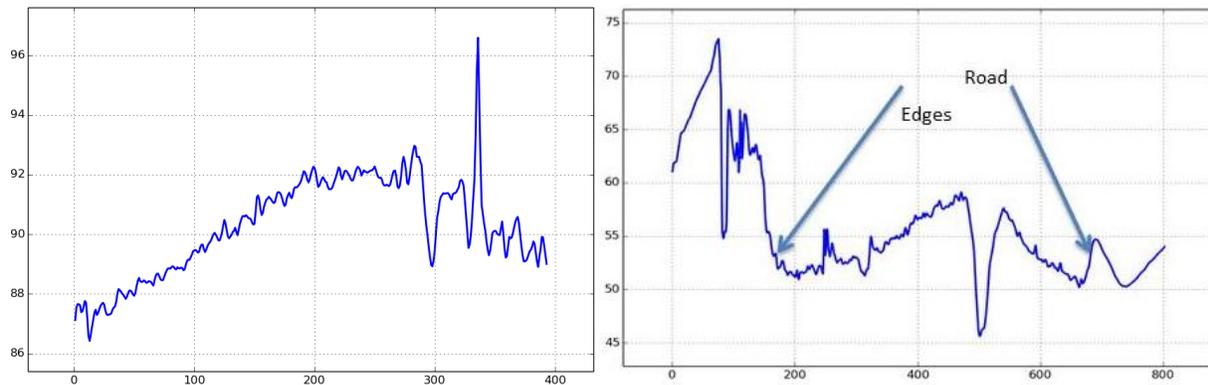


Figure 3-12: Road cross-sections using all images (left) and focused images (right).

RSPS Commercial Packaging

Part of the Phase II analysis was on improving the RSPS algorithm workflow, making the software more prepared for commercial use. Implementing the RSPS algorithm in Unix using Bash offers several advantages. Bash scripting allows the entire processing workflow to be customized to suit specific objectives, such as only performing select processing functions, creating a certain output type, or processing non-standard input types. For instance, if a 3D point cloud had already been generated with outside software, then only the latter tools bundled in the MeasureRoad Bash script would need to be called. Alternatively, if a user has an aerial imagery dataset needing visualization as a 3D point cloud, Bash would only run the initial tools bundled in the patch-based multi-view stereo software (PMVS) process.

Once fully installed and set up, a full list of the available processing functions is available in `$URDIR/trunk/imageProcessing/bin`. These top-level functions build processing pipelines out of lower-level utility functions contained in `$URDIR/trunk/imageProcessing/src`. The lower-level utilities are programs written in C, Python, and Bash, and provide all the basic functionality packaged in the AURA processing workflow. Improvements could come in the form of broadening and refining the functionality of these top-level tools so as to optimally implement the lower-level functions and maximize their applicability in different scenarios.

One particular bottleneck in the processing workflow is in the exclusive reliance on entropy to distinguish the unpaved road from the areas in the photographs that are not part of the road. Depending on the specific details of the area surveyed, users may prefer this classification to be performed by taking more or different criteria into account, such as color or shape. Adding this functionality would be integrated by replacing computations in how the road mask is created, and the entire damage assessment would still be able to run to completion. While the AURA system is a fully integrated software suite that performs the specific task of damage assessment of unpaved roads when given a set of aerial imagery, its constituent parts may also be employed by discerning users for access to a wider range of geospatial processing abilities.

Chapter 4: Field Demonstrations

Deliverable 8-C is available for download at

http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del_8C_AURA_FieldDemoReport_fin.pdf.

A main objective of Phase II of the project was to conduct field demonstrations as part of outreach and implementation of the AURA system. Field Demonstrations were based on the successful field demonstration held in Sioux Falls, SD during Phase I of the project. This format begins with an opening presentation by the projects Primary Investigator (PI) which introduces the audience to the project, the development of the Aerial Unpaved Road Assessment (AURA) system, and its condition assessment capabilities. This is followed by taking the participants to a representative section of unpaved road for a live demonstration of the system. During the live demonstration the participants were able to see the collection of condition assessment data for an unpaved road as well as learn how the Unmanned Aerial System (UAS) is set up and flown. After the field demonstration the participants are brought back to the meeting location to have a round table discussion with the project team.

Phase II field demonstrations were performed in Salina, Kansas on June 10, 2015 and in Rapid City, South Dakota on October 20, 2015 as part of the 30th Regional Local Roads Conference. The second demonstration also included the project team staffing a vendor booth during the remainder of the conference for further outreach and commercialization efforts. Most of the participants at the field demonstrations were from local road agencies, which provided valuable input from the potential end users of the AURA system. The project team also received interest from multiple companies for licensing AURA. Descriptions on commercialization efforts are reported in Deliverable 10-A: “Commercialization Report on AURA for Day-to-Day Operations”.

AURA Demonstrations

An important component of the outreach effort for this project was the AURA field demonstrations. These demonstrations allowed transportation officials and businesses to learn about the project and see the AURA system collect data. The format of the demonstrations was developed with the help of IGD and consisted of an introductory presentation, field demonstration, presentations on data processing and integration with a DSS, and a round table discussion. During the second phase, the project team performed field demonstrations in Salina, KS and Rapid City, SD.

Salina, Kansas

The demonstration in Salina, Kansas was held on the campus of Kansas State University – Salina (KSU). There were 55 participants in attendance from various sectors of the transportation industry ranging from local roads managers to survey inspectors to state DOT staff. These included 23 city or County representatives, 15 academic representatives, nine from the private sector, and eight from Kansas state DOTs. The research team also asked Kurt Carraway, UAS Executive Director at KSU to join with the project team for the demonstrations and round table discussions. Since KSU has a strong aviation and UAS background it was important to include them as a partner in the technical meeting. Figure 3-13 shows the project PI Colin Brooks giving the introductory presentation.



Figure 3-13: AURA demonstration introductory presentation being given by the project PI.

After the introductory presentation the attendees were taken to a representative unpaved road. Figure 3-14 shows the attendees learning about how the AURA platform is flown and collects data. The field demonstration allowed the attendees to get more familiar with operating UAVs and how they can be used for unpaved roads assessment in practice. This included both a demonstration of the capabilities of the UAV but also data collection of a segment of unpaved road.



Figure 3-14: Demonstration attendees observing the Bergen hexacopter collecting unpaved road data with project member answering questions.

Like the previous demonstration at the end of Phase I, the project team collected data on unpaved roads prior to the AURA demonstration. This was done as a precaution if the weather prevented the team from conducting the field demonstration component and to present to the audience 3D models of Kansas distresses which were collected the day before. This helped with illustrating the rapid assessment capabilities of the system. 3D models and descriptions of the data processing were included in the data processing presentation (Figure 3-15).



Figure 3-15: 3D point cloud on a section of unpaved road from the demonstration site illustrating the project team's capability to make crown measurements.

The afternoon was wrapped up with a round table discussion. The audience was most interested in using this system as a service rather than maintaining in-house. Additionally, the audience was also interested in other applications such as pavement inspection, bridge inspection, drainage channel inspection and several others. Figure 3-16 shows the round table discussions being held as part of this demonstration, and Figure 3-17 shows part of the technical data collection demonstration and attendees who saw the demo.



Figure 3-16: The round table discussion included Colin Brooks (Michigan Tech – project PI & Senior Research Scientist), Dale Phillips (Barton County, KS Road and Bridge Director), and Kurt Carraway (Kansas State – Salina UAS Flight Operations Manager) answering questions during the afternoon discussion panel,



Figure 3-17: Outdoor demonstration photos from Salina, KS

Rapid City, SD

The final AURA demonstration took place in Rapid City, SD on October 20, 2015. This demonstration was done as part of the North Dakota LTAP 2015 Regional Local Roads Conference in which the project team also staffed a vendor's booth. There were over 60 attendees from state and local road commissions, Federal Highway Administration, US Forest Service and Bureau of Indian Affairs, and nine companies at the technical demo. Fourteen of the attendees were from the private sector and ten Native American tribal representatives. Figure 3-18 show project PI Colin Brooks giving the introductory presentation at the Best Western Ramkota Hotel conference room.



Figure 3-18: Colin Brooks presenting an overview of the USDOT Project and AURA system.

As with the previous demonstration the attendees were taken to a representative unpaved road after the introductory presentation. Figure 3-19 shows the attendees being shown another UAS platform demonstration. This was important to show that other less expensive platforms can be used for a quick visual assessment of unpaved roads. The project PI flew a DJI Phantom Vision 2 which the camera is controlled by and sends video to the users' cellphone.

After the live demonstration, the attendees and presenters returned to the Ramkota Hotel, where Associate PI Dr. Tim Colling of the Michigan Tech Transportation Institute and Center for Technology and Training, gave a review of integrating AURA system data into the RoadSoft GIS decision support system. Participants were able to learn about how high-resolution unpaved road condition data could be effectively integrated into unpaved road asset management. Co-PI also shared examples of processed data collection results, including 3D data of roadways and samples of the University of Vermont's road data collected via fixed wing UAS. Figure 3-20 shows audience members learning about these capabilities.



Figure 3-19: Project PI Colin Brooks shows field demonstration attendees how to control the camera of a Phantom Vision 2.



Figure 3-20: Audience members at the Rapid City, SD demonstration learning about AURA system capabilities.

The project team arrived in advance of the demonstration to collect data of unpaved roads for the data processing presentation. A unique feature of the location where the demonstration was held was the Stratobowl. This location allowed the project team to collect data on an unpaved road which was not straight. Additionally, there was significant elevation difference and trees lining the road but not covering the surface. Figures 3-21, 3-22, and 3-23 show the 3D point cloud generated from the Stratobowl.



Figure 3-21: 3D point cloud of the Stratobowl collect.



Figure 3-22: Original 3D point cloud of the Stratobowl collect before the trees were removed from the model.



Figure 3-23: 3D point cloud of the Stratobowl collect after the trees were removed from the model.

The project team also participated in the conference through presenting and staffing of a vendor's booth. The project PI also presented the progress of the project to the main conference on the opening morning to the main session with approximately 300 attendees (Figure 3-24). This allowed for a broader audience

to learn about the project and the AURA system. The vendor's booth also allowed from other conference attendees to learn about the AURA system and the application of UAVs for unpaved road assessment (Figure 4-25).



Figure 3-24: The project PI presenting on the unpaved roads project at the conference.



Figure 3-25: Discussing the potential of the AURA system for the assessment of unpaved roads.

As an outcome of these events the project team was able receive feedback from the participants. In the form used in Kansas the research team asked the participants to list what they would use the AURA system for, however in South Dakota a list of the use cases that were identified in Kansas and asked them to check off which ones they would use the system for. This improved consistency in the answers as well. For example, you can see in Figure 3-26 almost 65% of those individuals who completed the survey indicated that they would use the AURA System for Unpaved Roads Condition Monitoring. In addition, we can see the range of how often they indicated they would use the system - ranging from 5+ to 12 times. However, some individuals did not read the question well, that they put “high” or “multiple times” in the frequency answer box, thus indicating that we could have been more specific in frequency of use in the future.

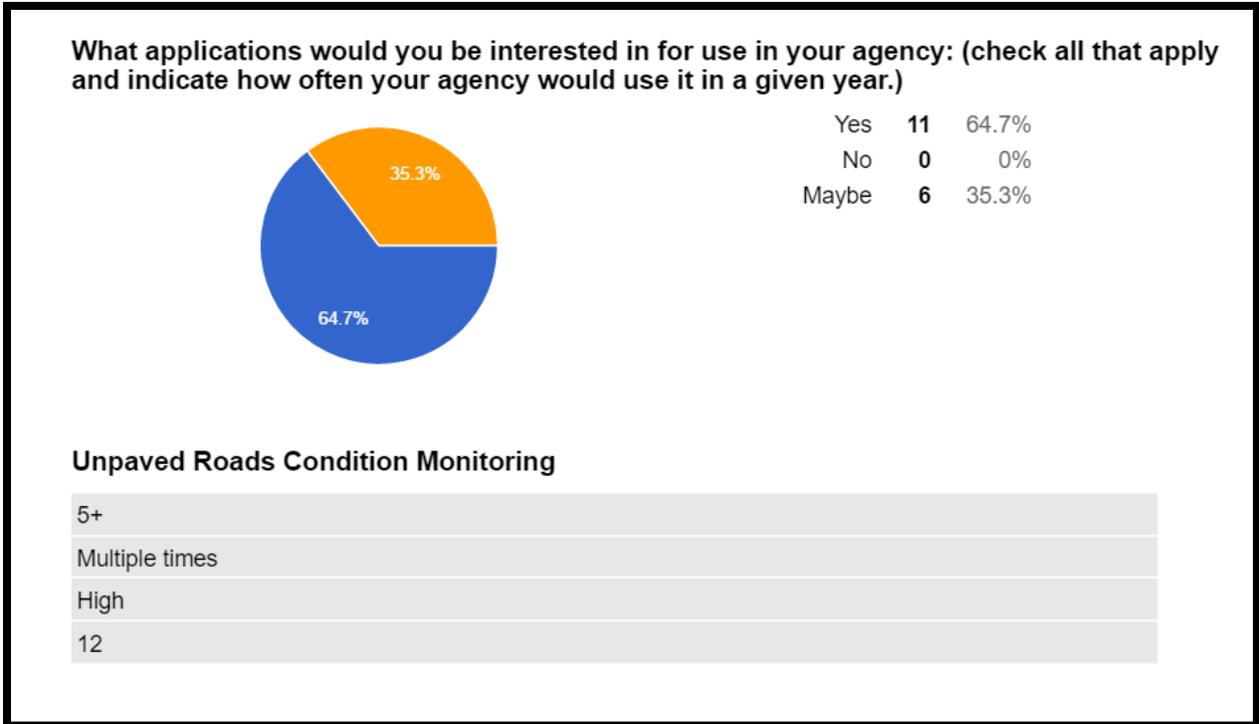


Figure 3-26: Response to Survey Question for South Dakota Demonstration

Another question which was asked was related to commercialization potential. Figure 3-27 lists how “likely” the AURA system would be used as rated by demonstration participants, and the most common results were by a landslide a rating of 6 or 7. This indicates that the MTRI team was able to demonstrate the purchase value of AURA. However, what are the barriers of adoption that they are facing in making the purchase? The private sector companies who were the most interested in purchasing were still either working through the UAS Certificate of Authorization process or they wanted features that were not available instantly on demand. It is noteworthy that since the Rapid City demonstration, three firms have discussed offering AURA services from their bases in Ohio, Nevada, and Arizona. With new Federal Aviation Administration rules (“Part 107”) having become effective on August 29, 2016, it is now significantly easier for companies to offer UAS-enabled services.



Figure 3-27: Commercialization Potential South Dakota

The nature of the early adopters who typically attend technology demonstrations, they want to seek to understand not only the product in its intended form, but also look for new and innovative ways to use the technology. In addition to using AURA on unpaved roads, the demonstration participants identified the following use cases:

- Highway Road Monitoring
- Site Surveying
- Stock Pile Quantities
- Airfield Pavement Condition Inspection
- Bridge Inspection
- Levee Inspection
- Landfill Monitoring
- Work Zone Analysis
- Weather Event (Tornado, etc.) Documentation
- Haul Road Monitoring
- Crash Investigation
- Inventory of Roadway Features
- Road Safety Audit
- Selection Road Weather Information System (RWIS) Site Locations

While these are not the primary functions of AURA, if these reasons give enough use cases for AURA, they can do gravel road monitoring and it improves the value proposition – especially for the private sector.

When it comes to price, the question came up at both demonstrations “what does it cost” and while the price of the equipment was available, the price to buy AURA and put it in the truck with the software CD that day was not available, because it depends on the needs of individual projects and different agencies. The call to action was missing from the demonstrations in order to push the sales. This was a take away for future demonstrations that involve commercialization that the price to buy and rent should be clear and there should be incentives for purchase such as hours of free tech support, or a session of free training that normally runs \$2,500 (for example) to set up the system. The guarantee or return policy should also be available.

Chapter 5: Professional Outreach & Commercialization

Deliverable 9-A is not available at this time as it was just submitted the sponsor by 9/30/2016. It will be added the project web page once available.

Deliverable 10-A is available for download at:

http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del_10A_Commercialization_AURAsystem_fin.pdf

One of the main objectives of this project was to commercialize the AURA system. As part of this effort, the project team conducted a commercialization field test. This effort was conducted with the assistance of Woolpert Inc. as part of the research team. The commercialization field test was held at an active quarry near Sidney, Ohio, where there were two sites with unpaved roads were to be evaluated (Figure 3-28). There were multiple platforms tested including the Bergen Hexacopter, Kespry quadcopter, Vireo fixed-wing, and the Surrogate Unmanned Aerial System (SurrUAS).



Figure 3-28: An overview of the commercialization test field sites near Sidney, OH.

The southern site contained a haul road that was approximately 0.5 miles in length. This section of haul road contained “control potholes” to allow for objective measurements in the three-dimensional image products produced by each of the platforms (Figure 3-29). The smallest pothole measured 6” (diameter) x 3” (depth). The second pothole measured 12” x 6”. The third pothole measured 18” x 6”. All potholes were dug to be cylindrical in shape. As seen with the earlier assessment of the fix-wing UAVs, different sensors from other platforms may not produce the same results as the AURA system. This could be a difference in resolution, imagery sharpness, or collection stability.

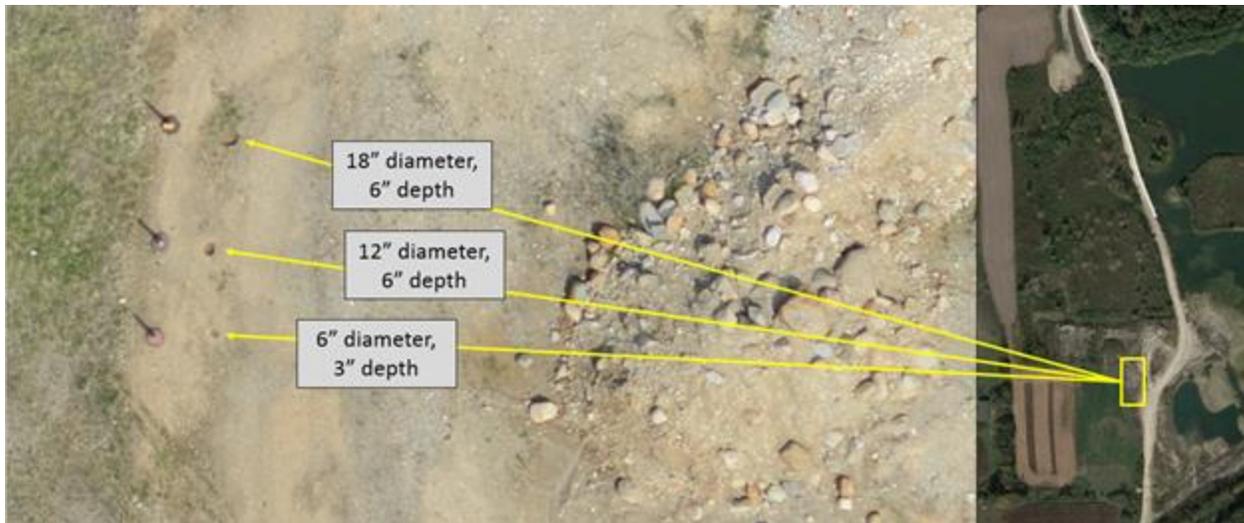


Figure 3-29: Overview of control potholes made at the southern test site.

The platforms were selected as each are representative of the systems that could be used for future commercial collects. The Bergen Hexacopter has been the main data collection platform used by the project team as part of the AURA system and was used as a comparison for the other data collected. With the ability to carry a Nikon D800 DSLR, this setup has proven to collect high resolution imagery which produces highly accurate results. In the case of the AURA system the accuracy is within 1% of measured ground truth measurements.

Kespry is a quadcopter which carries an integrated 20MP Sony Alpha SLR camera. Unlike the Bergen Hexacopter, Kespry flies a predetermined flight path which is a typical “mow the lawn” style aerial surveying method. The flight plan is setup and the UAV is controlled using an iPad. Flight altitude and speed are determined by the app and is based on the desired image overlap and resolution. Kespry data was processed through Kespry Cloud in which the user uploads the imagery to the website and a 3D model and orthoimage are generated and made available for download.

A fixed-wing system was also tested which is owned by Woolpert Inc. The Vireo is a hand launched UAV carrying a 10.5MP camera. Like the Kespry and other fixed-wing systems, it flies a pre-programmed flight path based on the user defined area and resolution requirements. This system did encounter issues with acquiring adequate data for the demonstration. The flight planning software did not allow the user to adjust the frame rate of the camera. Thus, forward-lap was insufficient to process the imagery as altitude was decreased to increase ground sample distance of the resulting imagery.

The SurrUAS is the only platform which was not a UAV. It is instead a manned fixed-wing aircraft (Cessna 182) which flies a camera setup more comparable to the UAVs. This system also flew a Nikon D800 DSLR but since it is a manned aircraft, flew at a higher altitude than the AURA system. Collected imagery was processed through SimActive’s Correlator 3D to generate 3D models and an orthoimage.

The project team also compared point clouds generated using RSPS and commercial software such as Agisoft PhotoScan. This comparison was done in part to ensure that the point clouds generated between different 3D processing software was comparable, which could be used as future input for RSPS. Since most commercial software uses the same SfM algorithms to produce the point clouds, the resulting product was discovered to be the same. The main difference between the software packages were options for how to process the data (resolution, ground control, etc.) and processing time.

Based on field testing, the project team recommended continuing to using multi-rotor UAVs for the AURA platform. The Vireo fixed-wing UAV was not able to collect the high-resolution and quality data

needed for 3D processing and assessment of the unpaved roads. Similar data collection issues that were reported previously in Deliverable 5-B: “Review and Update on AURA System Requirements, Sensors, and Platforms – Supplemental Report” were encountered. The multi-rotor systems and SurrUAS collected data with similar results, which can be used by potential commercial partners (Figure 3-30).

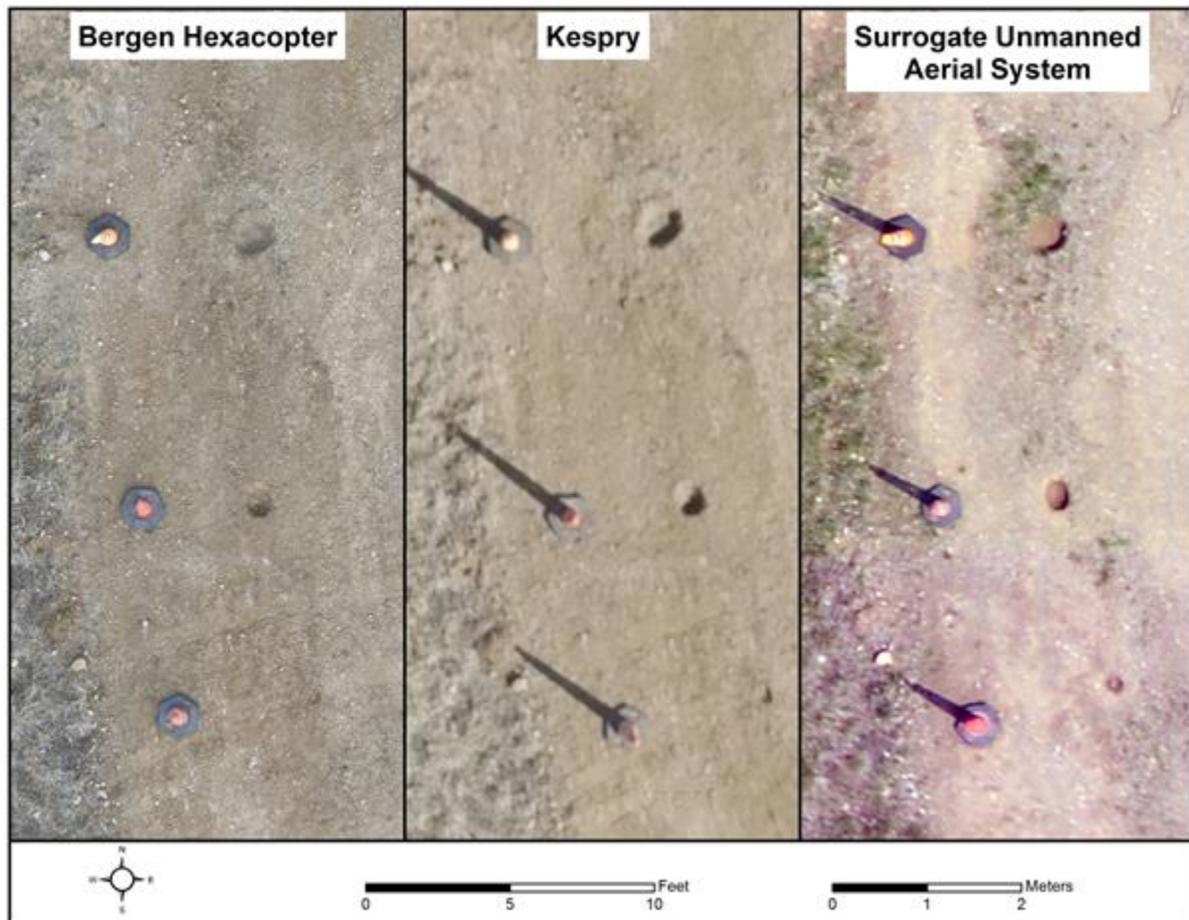


Figure 3-30: A comparison of the output orthoimages from the Bergen Hexacopter (Left), Kespry (Center), and the Surrogate Unmanned Aerial System (Right).

The fixed-wing UAS has inherent disadvantages for commercializing the AURA system developed by MTRI. First and foremost, a fixed-wing platform requires significant forward velocity (relative to a rotary wing) in order stay aloft. This is ideal for larger, rectangular collections where the UAS can utilize its speed to “mow-the-lawn” efficiently. However, for ultra-high-resolution corridor mapping and 3D modeling, a slower, more agile system is ideal. A fixed-wing also requires a cleared (and soft) area for landing. Unpaved roads are often located in areas surrounded by dense tree lines or other unsuitable terrain where this is not possible.

A multi-rotor UAS is better suited for high-resolution corridor mapping. Although the run-times are half that of a fixed-wing at about 20 minutes, the stable, agile, and heavier-lift nature of the platform make up for this shortfall. Having additional battery packs helps limit the impact of this battery life. The image products produced from the Kespry, Bergen Hexacopter, Vireo, and Altavian (used in previous collects) confirm this.

The RSPS was developed by project team during the first phase of the project. This software was originally designed to process overlapping imagery captured by a UAV and provided an XML file which

characterizes the detected unpaved road distresses in a “damage report”. Processing is completed in two parts, first a 3D model is reconstructed using Structure from Motion (SfM) algorithms and second the model is then run through a series of distress detection algorithms developed by the Michigan Tech team. As mentioned in recently submitted Deliverable 5-B-Supplemental report evaluating fixed wing options, UAS (such as the Kespry) can be purchased with a variety of often tightly-integrated commercial SfM software or the aerial services firm may already have SfM software with their easy to use interfaces. Because of this the project team is working to separate the two parts of the RSPS so the distress detection component can operate as a stand-alone software and can process any 3D point cloud generated from other software.

Many UAS manufacturers have tightly integrated software (Kespry and Sensefly eBee systems, for example) that creates a 3D image product automatically for the user. If burdened with another image processing solution, this may detract from the AURA system from an end-user perspective. For commercialization, we have recommended that the AURA system accept industry-standard 3D image products (LAS and PLY files, for example), and produce actionable intelligence from them with its distress algorithms. As part of closing project activities, the Michigan Tech team is developing examples of how 3D point cloud outputs from SimActive’s Correlator3D, ESRI’s new Drone2Map software (which uses Pix4D), and Agisoft Photoscan can be run through the RSPS distress detection and severity algorithms.

These steps are designed to improve the opportunities for commercialization by enabling a third-party service partner to use their own SfM software, but then use the RSPS distress algorithms through a software licensing agreement. Software licensing is designed to produce a small revenue stream to the Michigan Tech inventor team who would dedicate the funds to answering questions from AURA system users (i.e., providing support) and help enable future improvements to the software, such as developing a user-friendly interface to the distress algorithms component.

As a step in demonstrating that the distress detection algorithms can work with any point cloud with suitable resolution, Figure 3-31 shows the same stretch of a Phase I study site (Piotter Hwy in southeast Michigan) processed with the AURA system’s Structure from Motion implementation (top) and via the commercial AgiSoft Photoscan (bottom). Both software solutions produce a sufficiently dense point cloud appropriate for analyzing with the RSPS distress algorithms that can then be used to produce the XML “damage report” of that road segment. This is a significant advancement towards commercialization.

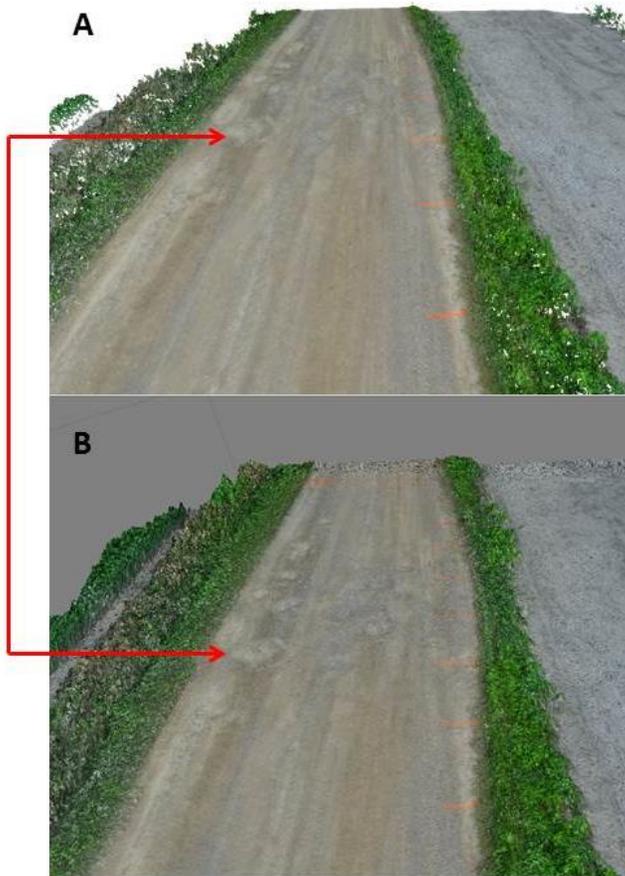


Figure 3-31: A comparison of the point clouds generated by the RSPS (A) and Agisoft PhotoScan which is a commercially available SfM software (B). The red line identifies the same pothole on each point cloud.

Since the point clouds generated from other SfM software is similar in quality to those produced by RSPS, the distress detection portion of the algorithm characterizes the distresses with the same accuracy. Figure 3-32 shows an example XML “damage report” output from the section of Piotter Hwy shown above. The project team has completed work on separating the RSPS software so the distress detection portion will function as a stand-alone software able accept 3D point clouds from any commercial SfM software, which should help with commercialization efforts.

```

<!--potholes-->
  <Type Distress="84">
    <Severity>H</Severity>
    <Quantity>1</Quantity>
    <Units>count</Units>
  </Type>
<!--potholes-->
  <Type Distress="84">
    <Severity>M</Severity>
    <Quantity>0</Quantity>
    <Units>count</Units>
  </Type>
<!--potholes-->
  <Type Distress="84">
    <Severity>L</Severity>
    <Quantity>0</Quantity>
    <Units>count</Units>
  </Type>
<!--potholes-->
  <Type Distress="84">
    <Severity>N</Severity>
    <Quantity>1</Quantity>
    <Units>count</Units>
  </Type>
</DistressTypes>
</inspection>
</inspections>

```

Figure 3-32: An example of the XML output from RSPS run on the Plotter Highway point cloud and categorizing detected potholes into severity categories. For example, one high-severity (“H”) pothole was detected in this stretch.

It should be noted that the UAV results from the Sydney, OH site were processed through the AURA system’s remote sensing processing system after completion of this report, and are now available. An example of the intermediate products depicting where ruts could be detected is shown in Figure 3-33.

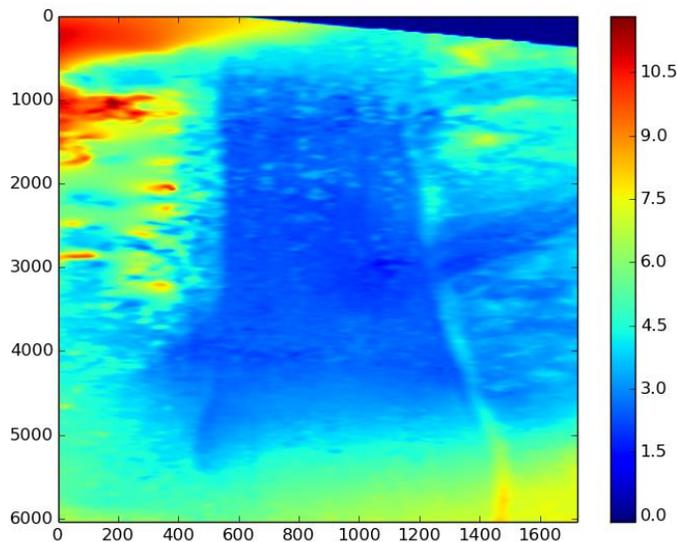


Figure 3-33: An example of the intermediate analysis results from RSPS run on the commercialization example at the Sydney, OH site coordinated by Woolpert showing ruts.

Outreach and Commercialization Efforts

One of the first efforts to enhance outreach and commercialization effort was to give the platform a name and a brand such that people could easily identify the platform and technology. While not “mind blowing” or “rocket science”, the challenge is that often in academia and research and development (R&D), the name of the system becomes non-germane and they cannot remember it. When IGD started working with the MTRI project team the name of the system was:

URCAS - Unpaved Road Condition Assessment System

The problem with URCAS was many individuals did not know if the vowels in the acronym were strong or soft and when used in the sentences listed above it created some interesting variations that were not identifiable or meaningful. Thus we went through the process of naming the system working with the project team and identifying commonly used terms that were words we could turn into the new project team that had meaning and was easy to say. After 2-3 revisions, the final option was selected, with input from the project’s Technical Advisory Committee (TAC).

AURA - Aerial Unpaved Road Assessment system

The MTRI project team also worked to develop a logo that could identify the project as well as tied back to the University – the Michigan Tech colors of deep yellow and black were utilized (Figure 3-34).



Figure 3-34: The newly designed AURA logo.

The project team also created three online portals of information regarding AURA. Being able to engage an audience visually through online portals to reduce travel time and encourage self-discovery was a major focus for this project. Our target audience for the AURA system in public agencies typically have very small travel budgets, thus being able to learn about the system remotely was incredibly valuable in reaching the largest audience possible.

These online portals include a YouTube Channel, SlideShare, and SmugMug (photo sharing site). Early in the project we experienced several issues related to state DOTs not being able to use social media outlets like YouTube or SlideShare due to security walls in the agency, however, as FHWA and other federal agencies began to distribute more and more information in this manner the restrictions on such channels reduced dramatically.

The YouTube channel has ten videos posted which were all created during Phase II of the project. Figure 3-34 shows a screenshot of the AURA System channel on YouTube. As of September 29, 2016 the YouTube channel received 427 views, 897 minutes of watch time (almost 15 hours) and the average video watch duration was 2.06 minutes.

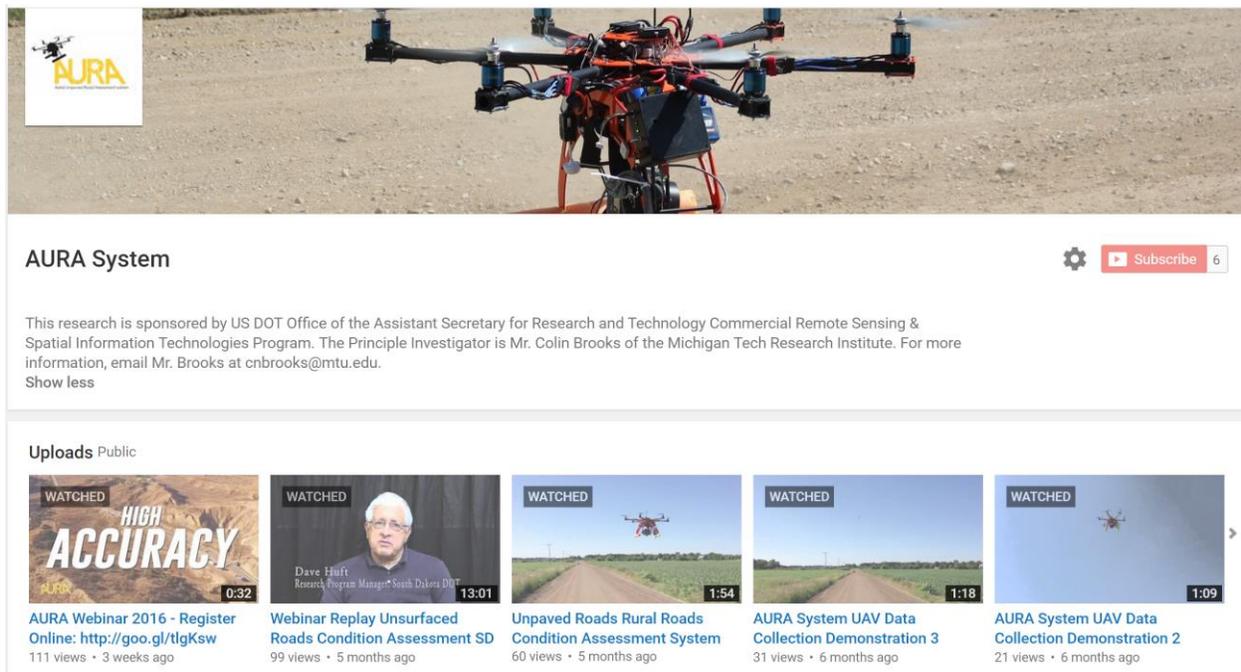


Figure 3-35: Screenshot of the AURA channel on YouTube.

In reviewing the metrics from the videos that were uploaded on the system, the Webinar Replay from the Evergreen Webinar was the most watched by far with a total of 597 minutes. The webinar utilized in the Evergreen format during the Phase I outreach was more of a motion picture with several different speakers, visuals, and music arrangements that totaled about 15 minutes in length. The remaining videos which averaged less than 100 minutes watched were predominately flat without narration and specific speakers.

In addition, the geography and user base was able to be captured in the analytics, where we could see about 87% of the interest was domestic, with some interest in Canada, Brazil, Australia, and South Africa. Audience demographics could be captured as well, through individuals who watched the video while they were logged into a social media or other platform that the YouTube analytics could capture. When looking into the domestic states that are interested in the technology based upon video viewership the following states were the most engaged. Figure 3-35 displays a breakdown of the viewers by state and includes Watch Time, Views, and Average View Duration. Arizona, Nebraska, Kansas, and Texas all had over 50 minutes of watch time on the videos. Most of the views however were generated in Nebraska with 75 and the next highest viewing state was Kansas with 30 views. Viewers from Mississippi had the highest average view duration with over five minutes learning about the AURA system.

| Geography | Watch time (minutes) ↓ | Views | Average view duration |
|-------------|------------------------|-----------|-----------------------|
| Arizona | 86 (11%) | 28 (7.6%) | 3:03 |
| Nebraska | 84 (11%) | 75 (20%) | 1:07 |
| Kansas | 72 (9.2%) | 30 (8.2%) | 2:24 |
| Texas | 50 (6.4%) | 18 (4.9%) | 2:46 |
| Oklahoma | 45 (5.7%) | 11 (3.0%) | 4:02 |
| Iowa | 44 (5.7%) | 27 (7.4%) | 1:38 |
| Colorado | 36 (4.6%) | 12 (3.3%) | 2:59 |
| Minnesota | 36 (4.6%) | 9 (2.5%) | 3:58 |
| Mississippi | 29 (3.7%) | 5 (1.4%) | 5:50 |

Figure 3-36: A breakdown of the AURA channel video views by state.

As part of the outreach the project team also uploaded three of the PowerPoint presentations from the technical demonstration for the 30th Annual Region Local Road Conference and was able to see significant traction with almost 1,000 views of the presentation outside of that one time in the conference meeting room. In total it took less than 20 minutes to upload the presentations and for the extension of 812 direct additional views (as of 9/29/16) of the information is very powerful and an amazing return on investment for the project team and faculty. Figure 3-37 shows a screenshot of the presentations the project team has made available through SlideShare.

The screenshot displays the SlideShare profile for Michigan Tech Research Institute - AURA System. The profile includes a 'Follow' button and statistics: 3 SlideShares, 1 Follower, and 0 Clipboards. Below the profile, there are three presentation thumbnails with their respective titles and view counts:

- AURA: Asset Management & Deci...**: 11 months ago, 268 views
- AURA: Aerial Unpaved Roads As...**: 11 months ago, 284 views
- AURA: Aerial Unpaved Roads As...**: 11 months ago, 281 views

Figure 3-37: Screenshot of the presentation available through SlideShare.

Picture sharing is also an important component of the online presence of AURA. As part of this outreach the project team created a photosharing website using SmugMug. SmugMug allows for branding of the photo site as well as captures metrics related to views. It is more of a business sharing site than a social media outlet such as Flickr. We created 17 albums containing 612 images in total for workshop participants or online viewers to access and share with colleagues and co-workers (Figure 3-38).

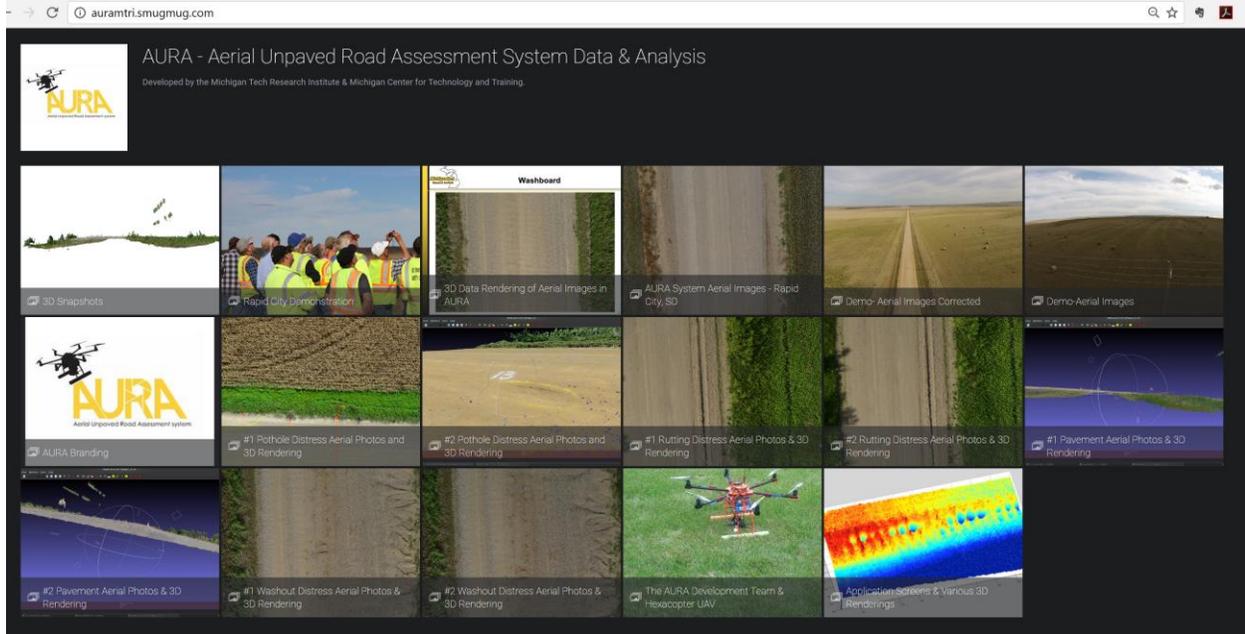


Figure 3-38: Screenshot of the AURA SmugMug photo sharing webpage.

Overall the viewership statistics are not as detailed as the YouTube channel but in total there were 7,618 views on the photo sharing site, which is the most of our social media promotion efforts. Many spikes in activity were directly related to when technical demonstrations were held as well as follow-up outreach and advertising for the in-person webinars. The folder “Rapid City Demonstration” is the most popular folder with 3,944 views as of September 29, 2016.

Another method of outreach used by the project team was two online webinars. IGD also facilitated two live webinars that were held on September 8 and September 22, 2016 led by the PI, Mr. Colin Brooks. To encourage attendance at the webinar, IGD sent out an email announcement to 9,737 domestic and international transportation professionals on our proprietary listserv. Figure 3-39 shows the email announcement which was sent out by the project team.

AURA - Latest Technology in Drone Asset Management - Webinar Registration - Space is Limited

Sent Tuesday, September 6, 2016

[View as plaintext](#)

Good morning,

We're excited to announce that we're holding a new webinar to discuss the advancements in our Aerial Unpaved Road Assessment (AURA) Technology and how you can finally access it for your organization. (check out the promo video below!)

AURA has evolved over the past 4 years and we're excited to share with you:

- our most recent updates to the platform and technology
- new changes in the FAA regulations that will *make it easier* **
- how you can gain access to the technology and equipment for your organization

The webinar is being held [September 8, 2016 at 2 PM EDT](#) and if that date does not work in your schedule, we are holding a encore presentation [September 22 at 2 PM EDT](#).



This research is sponsored by US DOT Office of the Assistant Secretary for Research and Technology Commercial Remote Sensing & Spatial Information Technologies Program.

If you liked the promo video and want to learn more:

- Please feel free to check out our [YouTube Channel](#) to see the system and some of the sample output.
- Additional images can be viewed on our [photo-sharing site](#).
- Read the [Field Demonstration Report](#).
- Read the [Commercialization Report](#)

Before the webinar or at any time, if you have any questions about the AURA system, please don't hesitate to contact me.

Best regards,

Colin

Colin Brooks
Senior Research Scientist

Figure 3-39: The email announcement which was sent out ahead of the September 8, 2016 webinar.

Aweber was used to track how many of the email recipients opened the email as well as tracked how many clicked to learn more about AURA. This service also tracks emails which were forwarded to other individuals and how many were viewed. From the email that went out to the almost 10,000 individuals, there were 1,892 individuals who opened the email and that in total there were almost 800 clicks to learn more about the information linked in the body of the email.

There were 60 individuals from over 20 states/countries who registered for the webinar. Between both days, there were 33 attendees for the September 8 Webinar and 15 for the September 22 Webinar.

Combined there was approximately an 80% attendance retention from those who signed up to those who actually attended the webinar. IGD utilized Go To Meeting as the webinar platform and it does not track the list of attendees in the software, so when a participant would log into the webinar, did not track exactly who it was by name, especially if they used their organization name or initials as the log-in name.

IGD was also involved in other outreach efforts through the Phase II portion of the project. In April of 2016, outreach specialist Valerie left sent an email out to 50 contacts in the UAV industry, looking for AURA commercialization partners around the country. This resulted in two companies contacting PI Colin Brooks to discuss commercial applications of the AURA system. Darling Geomatics of Tucson, Arizona and AboveNV of Reno, Nevada discussed the system's capabilities with the team based on the email "blast"; AboveNV staff also saw PI Brooks present at the 2015 UAS Symposium hosted in Reno by the American Society for Photogrammetry and Remote Sensing (ASPRS). Darling Geomatics was interested in the capabilities of AURA to evaluate representative sections of unpaved roads along a potential pipeline site in South Dakota. A presentation was made to a company needing evaluation of road condition along a pipeline route. However, the company expressed doubt that UAV-based optical sensing could produce results with the same resolution as vehicle-based LiDAR. Despite many graphics and outputs being shared that demonstrate the sub-centimeter resolution that can be created with UAV-based 3D sensing, the traditional vehicle-based LiDAR solution was chosen. Michigan Tech continues to communicate with Darling Geomatics to look for future opportunities to bid on a commercial basis.

AboveNV is looking for opportunities to assess unpaved road condition for federal and state agencies in Nevada and elsewhere in the region. The company is interested in the AURA system because of its capability to create high-resolution and automatic assessment of 3D modeled road surfaces. Potential projects are being investigated for the right proposal to bid on together.

After presenting at the 30th Regional Local Roads Conference in Rapid City, SD, three companies expressed interest in potentially using the AURA system. Discussions went furthest with the North Dakota office of RDO Integrated Controls, who sell UAVs and related processing software. RDO's interest is selling and licensing AURA system software to end users, which is not a direction this project has taken, as its strength is in road asset management processes. However, the project team is looking for opportunities to convert the existing AURA system software into "shrink wrapped" software with a user-friendly interface. If a funding source is found for that work, PI Brooks will get back in contact with companies such as RDO so that the AURA system software analysis tools can be sold as a software solution.

A licensing agreement for commercial use of the AURA system has been signed with Grupo Engemap of Assis, Brazil. Representatives of "Departamento Nacional de Infraestrutura de Transportes" (DNIT), the Brazilian Department of Transportation, saw Phase II Co-Investigator Rick Dobson present on AURA system capabilities at the 2015 Transportation Research Board workshop on Sensing Technologies for Transportation Applications (hosted by PI Brooks). Engemap staff contacted PI Brooks based on DNIT's recommendation. After a series of email and Skype discussions, terms were agreed to that make Engemap the exclusive provider of AURA system capabilities in South America. Michigan Tech will provide support as Engemap bids on, wins, and completes projects involving unpaved road assessment. While the economy is struggling and the political situations is in flux in Brazil, Michigan Tech and Engemap expect to start working together on paid projects within the next year.

Phase II partner Woolpert's task leader Aaron Lawrence arranged for a demonstration of AURA's capabilities for automated assessment of haul roads for a gravel mining site in Ohio. Based on working together, Michigan Tech and Woolpert are looking for projects to bid on together where frequent, high-resolution, repeatable, and objective unpaved road condition assessments are needed. Both groups expect that haul road monitoring will be a good opportunity for commercial implementation of the AURA system and will continue working together on this past Phase II.

After completion of the commercialization report, PI Colin Brooks reached out to PrecisionHawk (<http://www.precisionhawk.com/>), a company focused on enabling wider commercial use of UAVs through an online, third party service provider model. They were one of the first companies to obtain permission to collect data beyond normal visual line-of-sight rules under the FAA’s Pathfinder Program (<http://media.precisionhawk.com/topic/precisionhawk-release-phase-1/>). Collectors of UAV imagery can upload their data they have flown and have it automatically processed into orthoimagery and 3D products for customer end use. PI Brooks was intrigued by their “AlgoMarket” focus where developers of analysis algorithms can have their analysis tools made commercially available (see Figure 3-40 and <https://www.datamapper.com/algorithms>). Developers get a certain percentage (around 15-20%) of revenue while PrecisionHawk helps create demand through promotion of the algorithm to their customers. To PI Brooks, this seems like an ideal combination – PrecisionHawk is dedicated to growing demand for web-based processing of UAV data, and software tool developers can get their algorithms into the hands of end users more easily through online access to their analysis tools. PI Brooks is continuing discussions with PrecisionHawk about having them be the commercial providers of the AURA system algorithm around the country, with the help of Michigan Tech’s Innovation and Industry Engagement staff. Based on promising discussions as of early October 2016, commercial offering of AURA system analysis is intended to begin in early 2017.

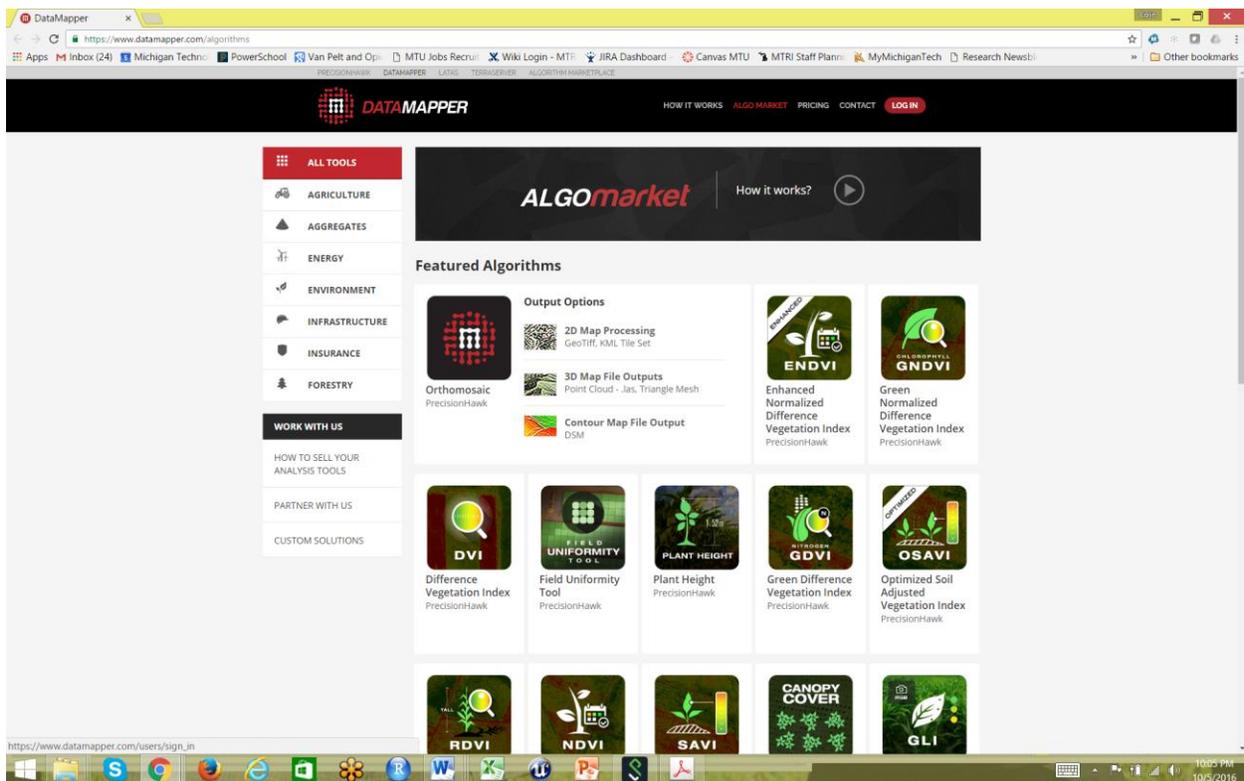


Figure 3-40: A view of PrecisionHawk’s “AlgoMarket” web page, where PI Brooks is working to make the AURA system analysis capabilities commercially available to third party providers and local/state agency end users of unpaved road assessment data.

Chapter 6: Unpaved Roads Inventory Algorithm

As part of this second phase of funding, an updated unpaved road mapping analysis using the unpaved roads inventory algorithm developed during the first phase of funding was conducted for six of the seven SEMCOG counties, including Macomb, Monroe, Livingston, Oakland, St. Clair, and Washtenaw counties. Wayne County was not mapped beyond a small test area as a majority of the county is classified as incorporated and therefore included minimal amounts of unpaved roads. It is important that local governments and transportation agencies are knowledgeable of the total mileage and locations of unpaved roads as the agencies are responsible for a large part of this unpaved infrastructure. These agencies need to be able to cost-effectively assess the condition of their infrastructure on a periodic basis in order to effectively manage their unpaved roads, and to optimize maintenance resource allocations. However, most local transportation departments do not have specialized equipment to measure road surface conditions, instead relying on occasional, visual evaluation of road condition. Unpaved roads typically have low traffic volumes and therefore consequently may receive less time and attention from local agencies that have limited funding and human resources. These limitations often prevent thorough evaluations of unpaved road condition, even though timely identification of road damage is extremely important. These unpaved local roads have an important role to play in connecting farmers to markets, school buses to school children, and residents to their homes.

During the first phase of this project, four band (red, green, blue, and infrared), 1ft (30cm) resolution 2010 (“leaf-off”) aerial imagery collected by SEMCOG was used as the basis in developing an unpaved roads inventory algorithm that was capable of detecting and classifying a road as being paved or unpaved. Additionally, the 2011 Michigan State-Framework road network GIS dataset was used to define where roads were located throughout each SEMCOG county. It is important to note that only roads with a defined NFC of 4 (Minor Arterials), 5 (Major Collectors), 6 (Minor Collectors), or 7 (Local) were used in the analysis as these types are typically either paved or unpaved as compared to other NFC roads labeled as 1 (Interstates), 2 (Other Freeways), and 3 (Other Principal Arterials), which are nearly always paved. The GIS road dataset was buffered by 30ft (9.1m), since the “centerlines” of the road were not always accurately positioned along the center of the road segment.

Classification of the road segments was conducted in Trimble’s eCognition software and was based on a developed algorithm that classified a road segment as paved, unpaved, shadow (roads with a shadow casts on the segment), or vegetation (typically along the edge of a road where neighboring vegetation or grass meets the road). Image classification was a multi-step process that used several eCognition routines. Chessboard segmentation was used to create an area that would contain a road (the Framework road centerline layer). Quadtree segmentation was run on the area of the potential roads, segmenting the potential road area into a grid based on color differences within the object. The process runs recursively until there are no further significant changes in any resulting square. A multi-resolution segmentation region grow process was then run to combine spectrally similar areas into objects. Spectral difference segmentation then merges objects according to a user defined mean layer intensity value (Figure 3-41). Road segments that were classified as unpaved were exported to a GIS shapefile and were compared to the overall length of the original road segment. Therefore, if more than a particular percentage (10%, 15%, 20%, 25%, or 30%) of the segment was classified as unpaved, then the entire segment was classified as unpaved. The total mileage of unpaved and paved roads for each of the six counties analyzed during phase one of the project can be found in Table 3-4.

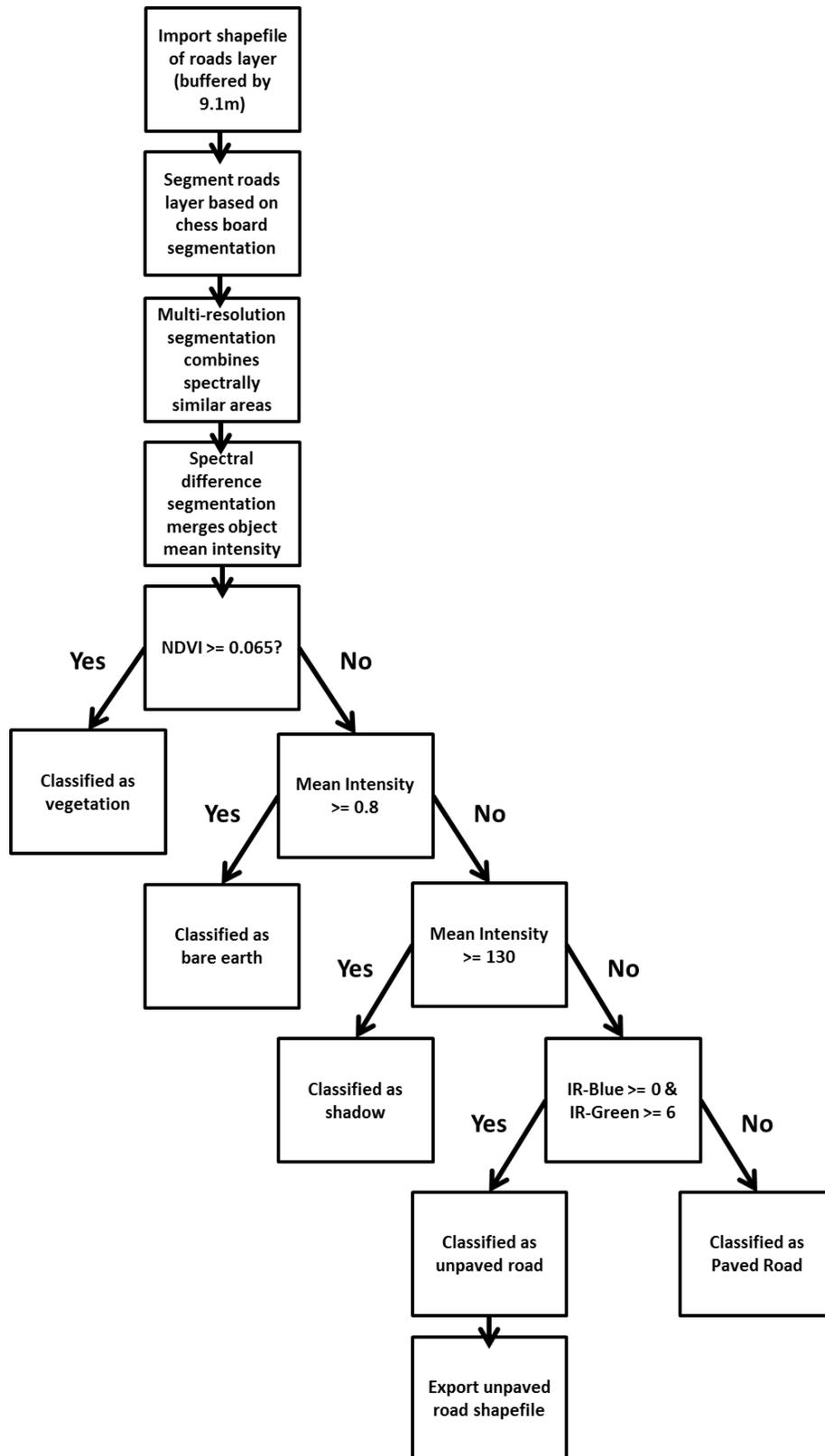


Figure 3-41: The eCognition unpaved vs. paved road classification process.

Table 3-4: 2010 total unpaved vs. paved mileage as defined by the unpaved roads inventory algorithm

| County | % Unpaved Coverage | Total Mileage (miles) | Paved (miles) | Unpaved (miles) |
|------------|--------------------|-----------------------|---------------|-----------------|
| Monroe | 30 | 1,741.9 | 1,390.0 | 352.9 |
| Oakland | 25 | 3,642.1 | 2,948.2 | 693.9 |
| Macomb | 20 | 2,166.4 | 1,847 | 319.4 |
| Livingston | 25 | 2,183.5 | 1,289.4 | 894.1 |
| St. Clair | 15 | 1,959.8 | 1,222.4 | 737.4 |
| Washtenaw | 20 | 2,339.8 | 1,434.9 | 904.9 |

During this phase of funding, the unpaved roads inventory algorithm was used to update the total mileage of unpaved roads for the same SEMCOG counties using four band (red, green, blue, and infrared), 1ft / 30cm resolution 2015 (“leaf-off”) aerial imagery collected by SEMCOG. In order to create an updated road network classification, a similar methodology described above was used. However, some updates were required in the unpaved roads inventory algorithm due to the use of the new 2015 imagery. First of all, the individual 2,500ft x 2,500ft (762m x 762m) tiled 2015 SEMCOG aerial imagery had to be mosaicked together into a four-by-four grid, creating new 10,000ft x 10,000ft (3,048m x 3,048m) aerial images, improving image processing speed significantly. Next, the 2015 Michigan State-Framework road network GIS dataset was used to define where roads were located throughout each SEMCOG county. Similar to the 2010 imagery analysis, only roads with a NFC of 4, 5, 6, or 7 were classified as paved or unpaved. The 2015 GIS road dataset was also buffered by 30ft / 9.m since the “centerlines” of the road were not always accurately positioned along the center of the road segment.

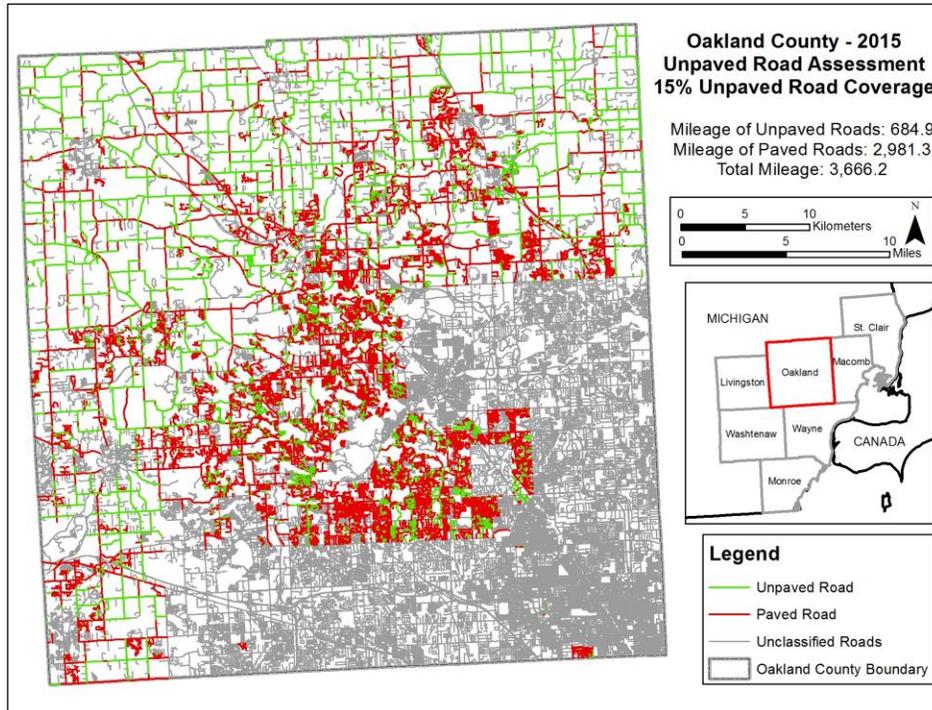
For the classification processing algorithm, the normalized difference vegetation index (NDVI) values were higher in the 2015 aerial imagery (different for each county) as compared to the 2010 aerial imagery, which was valued at 0.065. If the polygon was not classified as vegetation, it was passed on to the shadow classification. If the road segment passed the shadow classification value, the segment was passed on to the paved vs. unpaved classification. Phase I analyses of band relationships showed a strong correlation between positive values in the infrared minus green (IR-Green) calculation to the presence of an unpaved road. Therefore, this relationship was used for this analysis and was tested using a receiver operating characteristic (ROC) curve; a graphical plot that depicts the performance of a binary classifier, in our case whether a road is paved or unpaved. The ROC curve displays the fraction of true positives (TP) out of all positive results (pd) plotted against the fraction of false positives (FP) out of all negative results (pfa) for any IR-Green value. Plotting an ROC curve aided in determining the best value range for

the IR-Green parameter by selecting a value that maximized the number of true positives (ρ_d) while minimizing false positives (ρ_{fa}).

Once unpaved roads were identified and exported from eCognition, polygons that were classified as unpaved were imported into ESRI ArcGIS as a standard ESRI shapefiles and intersected with the overall county road network. Each eCognition unpaved road segment in this shapefile was compared to the overall length of the original segment. Depending on the specified percentage (10%, 15%, 20%, 25%, or 30%), if a road segment contained that percentage or more of unpaved road the entire segment was classified as unpaved. The total mileage of unpaved and paved roads for each of the six counties analyzed using 2015 aerial imagery (Figure 3-42 and Figure 3-43) can be found in Table 3-5.

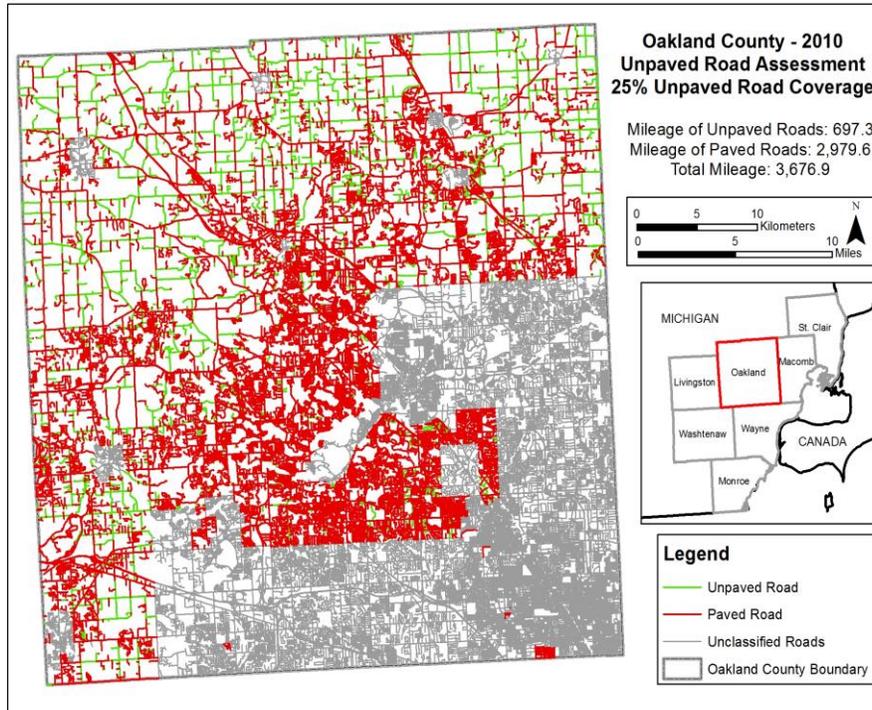
Table 3-5: Total mileage of paved and unpaved roads for each county analyzed using 2015 aerial imagery.

| County | 2010 Total Mileage (miles) | 2015 Total Mileage (miles) | 2010 Paved (miles) | 2015 Paved (miles) | 2010 Unpaved (miles) | 2015 Unpaved (miles) |
|---------------------|-----------------------------------|-----------------------------------|---------------------------|---------------------------|-----------------------------|-----------------------------|
| Livingston (subset) | 411.6 | 386.9 | 246.8 | 143.4 | 164.8 | 243.5 |
| Macomb (subset) | 151.1 | 128.1 | 100.2 | 47.2 | 50.9 | 80.9 |
| Monroe (subset) | 606.5 | 576.4 | 207.9 | 286.0 | 398.6 | 290.4 |
| Oakland | 3,642.1 | 3,666.2 | 2,948.2 | 2,981.3 | 693.9 | 684.9 |
| St. Clair (subset) | 447.3 | 436.1 | 304.3 | 308 | 143 | 128.1 |
| Washtenaw | 2,339.5 | 2,296.2 | 1,434.6 | 1,421.6 | 904.9 | 874.6 |



| | Users | Producers | Overall 94.3% |
|---------|-------|-----------|--------------------------------|
| Unpaved | 88.7% | 74.6% | |
| Paved | 95.2% | 98.2% | |

Figure 3-42: Map of unpaved roads (represented in green) in Oakland County based on 2015 aerial imagery.



| | Users | Producers | Overall |
|---------|-------|-----------|--------------|
| Unpaved | 83.6% | 62.2% | 89.4% |
| Paved | 90.5% | 96.7% | |

Figure 3-43: Map of unpaved roads (represented in green) in Oakland County based on 2010 aerial imagery.

Similar to the initial analysis, Pavement Surface Evaluation and Rating (PASER) data for each of the counties will be used to assess the algorithm’s classification accuracy. Error matrices will be calculated for each coverage value (every 5 % from 10% to 30%) with generally the coverage value with the best overall accuracy being chose to represent the roads for each county. Coverage values will be varied from one county to the next due to the differences in geography – some areas had significant tree cover over the roads, limiting the view of the roads and making classification less accurate; others were more open, which generally improved classification accuracy. Results from the accuracy assessment indicated that the user’s accuracy in detecting unpaved roads for Livingston (subset), Macomb (subset), and Oakland counties were all above 85%, indicating that the unpaved roads algorithm performed well. However, the accuracy assessment indicated that the user’s accuracy in detecting unpaved roads for Monroe (subset), St. Clair (subset), and Washtenaw counties were all at 65% or lower, indicating that the unpaved roads algorithm did not work was well in these counties. The algorithm could be refined for these three counties to try and increase the user’s accuracy. Overall accuracies for the counties ranged between 64.4% and 94.3%, Monroe (subset) and Oakland counties, respectively (Table 3-6)

Table 3-6: Accuracy values for each county.

| County | User's Accuracy (unpaved roads) | Overall Accuracy |
|---------------------|--|-----------------------------|
| Livingston (subset) | 85.5% | 79.5% |
| Macomb (subset) | 96.2% | 88.6% |
| Monroe (subset) | 49.2% | 64.4% |
| Oakland | 88.7% | 94.3% |
| St. Clair (subset) | 65.1% | 67.8% |
| Washtenaw | 48.6% | 70.6% |

During the analysis, some processing challenges were experienced and were very similar to the challenges faced during the previous analysis. Due to data availability and timing restrictions, the 2015 unpaved roads inventory algorithm was processed for two full SEMCOG counties (Oakland and Washtenaw) and subsets of four more SEMCOG counties. The subset regions of analysis were chosen based on the presence of both paved and unpaved road segments and covered at least a quarter of each county. In order to compare the 2015 results of paved and unpaved roads to the 2010 results, the 2010 data was also clipped to the same area of coverage.

Additionally, as experienced by the original analysis, this update analysis also contained a State Framework GIS roads layer with variable road network centerline accuracy when displayed over the high resolution aerial imagery. Some road centerlines aligned very closely to their associated feature in the four band high resolution aerial imagery while other road segments within the same roads dataset did not align well. This may be a function of scale of which the roads are digitized.

Another challenge encountered related to the spectral similarities in the four band aerial imagery between some types of road surface materials. Concrete / old macadam and crushed limestone (which is a component of both) roads are spectrally very similar, which can lead to misclassifications of the type of road (paved vs. unpaved). The spectral similarity between bare soil and natural aggregate (such as locally sourced river sand and gravel) is another potential source of misclassification (Figure 3-44). This becomes less of a problem when the classification is constrained to a known road network and a small buffered area around the roads, as was done for this project. SEMCOG staff noted some issues with the quality of the 2015 imagery vs. the 2010 imagery that may have also impacted accuracy results.



Figure 3-44: Example of RGB aerial photography being analyzed with image processing to map the location of unpaved vs. paved roads in SE Michigan as a mission planning input.

A = unpaved road dominated by natural aggregate; B = unpaved road dominated by crushed limestone; C = paved asphalt road.

As seen in the initial assessment, a significant challenge was the presence of shadows from trees, which obscured the road making it difficult to classify the type of road that passed under the canopy. This is a known issue for remote sensing processes where forest cover limits surface visibility. Therefore, the "percent coverage" rule (whereby only a certain percentage of a road segment needed to be called unpaved for the entire segment to be labeled as such) was included in the analysis to address this problem.

The results of the classifications could potentially be used to aid road commissions in determining the locations of paved and unpaved roads (as was the case with the analysis containing 2010 aerial imagery). For example, the 2015 unpaved road dataset for each county was placed into Roadsoft, a roadway asset management system that collects, stores, and analyzes data associated with transportation infrastructure (www.roadsoft.org) (Figure 3-45). Currently, over 400 road agencies and consultants incorporate Roadsoft into their practice in order to manage assets. Additionally, according to a 2015 National Cooperative Highway Research Program (NCHRP), 27 states (including Michigan) are currently practicing this process along primarily low-volume roads that were paved when construction prices were low. However, due to the age and condition of these low-volume paved roads and the price to keep these roads paved, these road segments are converted to unpaved (Fay et al, 2015). With the two county-wide and two subset county datasets, road commissions now have access to information pertaining to where individual road segments may have changed in road type within the past five years, including the conversion of paved roads to unpaved.

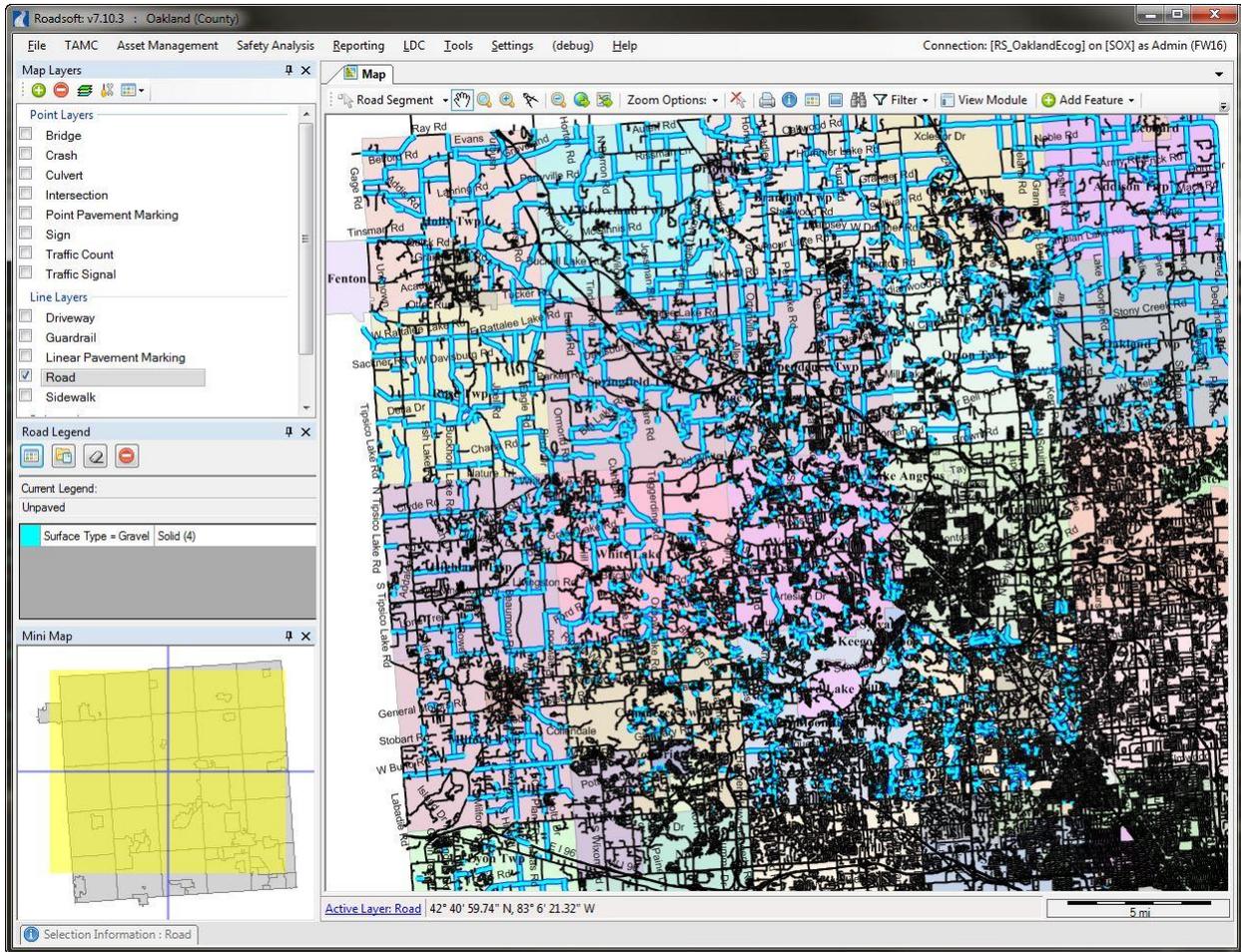


Figure 3-45: The 2015 unpaved roads dataset for Oakland County (as detected by the algorithm) is placed into Roadsoft – the project’s representative roadway asset management software suite.

Chapter 7: Conclusions

The second phase of the Unpaved Roads project has resulted in a commercial-ready system available for implementation in the U.S. and beyond. Companies in Ohio, Nevada, and Arizona have expressed interest in using the AURA system on a commercial basis and are looking for the right projects to bid on. After being contacted by PI Brooks, an online UAV data processing and algorithm services company, PrecisionHawk, is in negotiation with Michigan Tech to offer AURA system analysis of unpaved roads across the U.S. and elsewhere. Working with Woolpert Inc. has produced a commercial-ready example of using the AURA system on haul roads for a gravel mining site in Ohio. A webinar is now available explaining how asset management of unpaved roads needs a user-friendly decision support system to manage data and make decisions on road repair. Two end-of-project national webinars have raised the profile of AURA system capabilities with potential end users and service providers across the U.S.

Seven additional reports provide details on meeting requirements, the value of multi-rotor vs. fixed wing systems, the need for road asset management tools, commercial readiness, field demonstrations, professional outreach efforts, and commercialization potential. Field demonstrations were held in Salina, Kansas and Rapid City, South Dakota with strong attendance by a mix of companies and transportation agencies from local to state levels. In Phase II, project results and capabilities were shared with the National LTAP/TTAP Conference, the Transportation Research Board Annual Meeting, Michigan DOT meetings, the Innovations in Transportation Conference in Iowa, the American Planning Association conference in Arizona, and the 2015 ASPRS UAS Symposium in Reno, Nevada. There is no shortage of information about the AURA system and its capabilities that anyone interested in unpaved road assessment can easily find and that will continue to be available online.

In June of 2016, the FAA released new rules (“Part 107”) on commercial use of UAVs that enable easier operations without the need for special exemptions and having a licensed pilot on staff. This should make adoption of UAV-based sensing capabilities in the U.S. much easier. There are still issues that make adoption of the AURA system challenging, the primary one of which is no standard operations beyond line of sight. However, a new “waiver” process is coming into force in August of 2016 allowing groups to apply on a case-by-case basis to go beyond what is allowed by the new 2016 rules. PI Brooks believes that the most practical way forward to standard evaluation of unpaved roads by UAVs is to fly many miles of road at one time with a high-resolution camera, making data collection cost and time efficient. As new rules come forward, PI Brooks is dedicated to making the AURA system widely available and commercially implemented.

4. Publications

Peer-Reviewed:

Dobson, R.J., T. Colling, C. Brooks, C. Roussi, M.K. Watkins, D. Dean (2014). Collecting Decision Support System Data Through Remote Sensing of Unpaved Roads. *Transportation Research Record: Journal of the Transportation Research Board*, 2433, 108-115.

Brooks, C.N., D. Dean, R. Dobson, C. Roussi, J. Carter, A. VanderWoude, T. Colling, D. Banach. (In final review). Identification of Unpaved Roads in a Regional Road Network using Remote Sensing. Submitted to *Photogrammetric Engineering and Remote Sensing*.

Other publications:

Dean, D. B., Brooks, C. N., Roussi, C., Colling, T., Oommen, T., Havens, T. C., Ahlborn, T. M., Dobson, R., & Kueber, M. J. (2014). Transportation infrastructure assessment with high-resolution remote sensing. *ASPRS 2014 Annual Conference Proceedings*.

Brooks, C. N., Colling, T., Roussi, C., Singh, C., Dean, D. B., and Watkins, M. (2014). Implementing assessment of unpaved road condition with high-resolution aerial remote sensing. *TRB 2014 Annual Meeting Proceedings*.

Dobson, R.J., Brooks, C., Roussi, C. and Colling, T. (2013). Developing an unpaved road assessment system for practical deployment with high-resolution optical data collection using a helicopter UAV. In *IEEE 2013 International Conference on Unmanned Aircraft Systems (ICUAS) Proceedings*, pp. 235-243.

Dean, D. B., Brooks, C. N., Dobson, R. J., Roussi, C., Colling, T., and Singh, C. (2013). Applications of UAV-capable systems for post-disaster damage assessment of transportation infrastructure. *CaGIS/ASPRS 2013 Specialty Conference Proceedings*.

Brooks, C. N., Ahlborn, T. M., Harris, D. K., Roussi, C., Colling, T., and Singh, C. (2012). Remote sensing of transportation infrastructure: Bridges and unpaved roads. *ASPRS Annual Conference 2012 Proceedings*.

5. References

Dobson, R., Colling, T., Brooks, C., Roussi, C., Watkins, M. and Dean, D. (2014). Collecting Decision Support System Data Through Remote Sensing of Unpaved Roads. *Transportation Research Record: Journal of the Transportation Research Board*, (2433), pp.108-115.

Fay, L., Kroon, A., Skorseth, K., Reid, R., & Jones, D. (2015). *Converting Paved Roads to Unpaved*. National Cooperative Highway Research Program (NCHRP) Synthesis 485, 98 pgs.

Appendix A: Reports

Deliverable 5-B: Review and Update on URCAS Requirements, Sensors, and Platforms

Available for download at:

http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del_5B_URCASupdate_requirementsensorsplatformforms_Final.pdf

Deliverable 5-B: Review and Update on AURA System Requirements, Sensors, and Platforms – Supplemental Report

Available for download at:

http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del_5B_Supplemental_FixedWingEval_Final.pdf

Deliverable 6-D: Extension of GIS DSS Tools to a Nationwide Assessment Tool for Unpaved Roads

Available for download at: http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del6-D_ExtensionofGISDSSTools_fin.pdf

Deliverable 6-E: Adaptation of AURA Remote Sensing Processing System Software to Include Additional Features and for Commercial Readiness

Available for download at:

http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del_6E_AURA_SoftwareAdaptation.pdf

Deliverable 8-C: Transportation Agency Field Demonstration Report

Available for download at:

http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del_8C_AURA_FieldDemoReport_fin.pdf

Deliverable 9-A: Professional Outreach for Implementation to a Nationwide Audience Report (*This was submitted to the sponsor on its due date of 9/30/16 and will be posted once it has been reviewed by the Program Manager*).

Deliverable 10-A: Commercialization Report on AURA for Day-to-Day Operations

Available for download at:

http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del_10A_Commercialization_AURAsystem_final.pdf