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Deliverable 8-B: Final Report

Michigan Technological University

Characterization of Unpaved Road Condition Through the Use of Remote Sensing Project

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Table of Contents

List of Figures

List of Tables

1. Introduction

This report summarizes the three-year “Characterization of Unpaved Road Conditions Through the Use of Remote Sensing” project, agreement number RITARS-11-H-MTU1, funded by the U.S. Department of Transportation (USDOT) Office of the Assistant Secretary for Research and Technology (OST-R, formerly known as the USDOT Research and Innovative Technology Administration or RITA), through the Commercial Remote Sensing and Spatial Information (“CRS&SI”) program. The report covers the project period of August 1, 2011 (its start) through September 30, 2014 (the current end date of the project), which the project team has referred to as the “development and demonstration phase”. It has been a $2,483,814 project, with $1,241,907 of federal funding from the USDOT and $1,241,907 of cost share provided by the project team including applicant, state, and local sources.

The central goal of this project was “to develop a sensor for, and demonstrate the utility of remote sensing platform or platforms for unpaved road assessment”, as described in the project’s Cooperative Agreement between Michigan Technological University and USDOT. To meet this, a diverse and well qualified applied research team developed a working prototype of the modular “Unsurfaced Road Condition Assessment System” (URCAS), with five major components (see Figure 1-1): 1) the Data Collection part, 2) the three-dimensional (3D) data processing part, 3) the Distress Detection Algorithms part, 4) the Extensible Markup Language part, 5) and the Decision Support System (DSS) part. While URCAS has been focused on display and use of the XML road distress data in the Roadsoft geographic information system (GIS) DSS tool, output data can also be used in other standard GIS software.

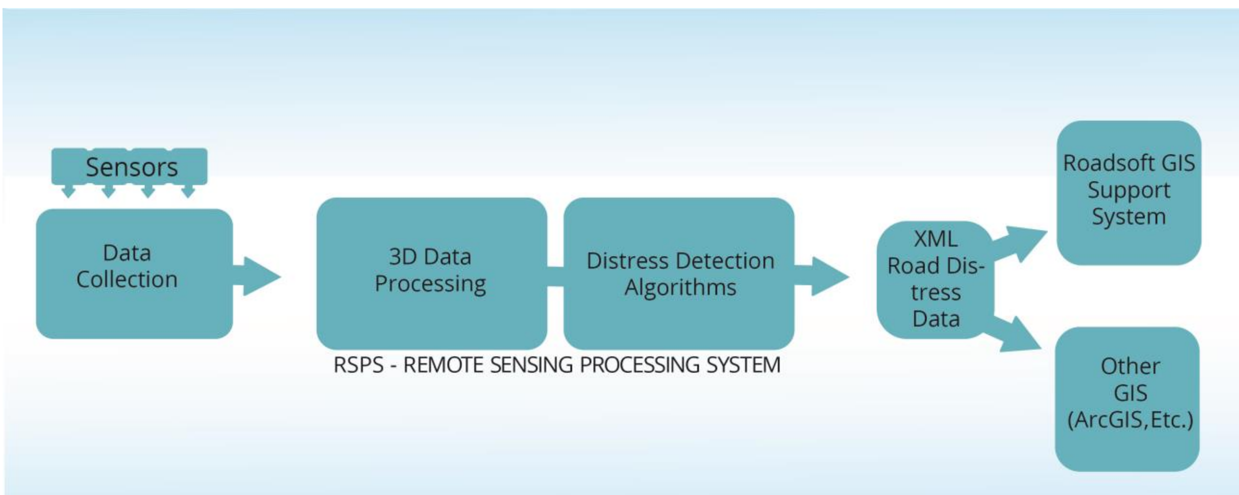


Figure 1-1: The flexible, modular components of URCAS, the Unsurfaced Condition Assessment System, developed as a working prototype for this project.

The work completed to develop this system have been described in a series of submitted reports accepted by USDOT to document project progress, and which are available on the project web page (http://www.mtri.org/unpaved/) under “Tasks and Deliverables”. These reports are reviewed here, with their full contents included as Appendix A so that all project write-ups are included in a single location to serve as final report documentation. The full list of project report deliverables is:

- 1-A: Requirements for Remote Sensing Assessments of Unpaved Road Conditions Report
- 2-A: State-of-the-Practice of Unpaved Road Condition Assessment Report
- 3-A: Remote Sensing the Phenomena of Unpaved Road Conditions Report
- 4-A: Candidate and Recommended Remote Sensors for Unpaved Road Condition Assessment Report

- 5-A: Candidate and Recommended Remote Sensing Platforms for Unpaved Road Condition Assessment Report
- 6-A: A Demonstration Mission Planning System for Use in Remote Sensing the Phenomena of Unpaved Road Conditions
- 6-B: A Demonstration Decision Support System for Managing Unpaved Roads in RoadSoft
- 6-C: Software and Algorithms to Support Unpaved Road Assessment by Remote Sensing Report
- 7-A: Plans for Field Deployment of Recommended System for Remote Sensing of Unpaved Road Conditions
- 7-B: Performance Evaluation of Recommended Remote Sensing System in Unpaved Road Type and Condition Characterization

Also part of this project have been the Quarterly Progress Reports (Deliverable 8-A) with twelve of them having been submitted as of the most recent reporting time period of July 15, 2014. All have been submitted to USDOT and are available on request; they are not included here as their technical content have been included in the various deliverable reports (1-A through 7-B as well). Included as appendices are all the conference proceedings papers written under this project, one of which (Dobson et al. 2013) has been selected for peer-reviewed publication in the Journal of the Transportation Research Board, the Transportation Research Record. Finally, all seven of the outreach articles published about the project form the final appendix, including the four resulting from integration of Outreach Specialist Valerie Lefler, MPA into the project's later stage outreach efforts. Financial report has been regularly sent by the Michigan Technological University Sponsored Programs Accounting Office and approved by USDOT OST-R.

Also included in this final report are several sections with additional detail beyond the project report summaries and their Appendix contents:

- A review of the background behind current unpaved road evaluation methods and the types of distresses that are important to detect and classify for managers of unpaved roads
- A longer description of the Unpaved Road Inventory Algorithm that proved of significant interest to project cost share partners the Southeast Michigan Council of Governments (SEMCOG, the regional planning agency for southeast Michigan), the Road Commission for Oakland County (RCOC) and the Michigan Transportation Asset Management Council (TAMC). This project task was described at various project points as work progressed (see Deliverables 6-A and 6-C in particular) and resulted in seven southeastern counties of unpaved roads mapping that were shared with these partners, providing paved vs. unpaved road designations for the county unincorporated areas for the first time.
- A review of the processes developed and needed for analysis of the collected imagery to produce the road distress information; these were also described in several deliverable reports (Deliverables 6-C and 7-B in particular) and are described here to provide a single location for them.
- A review of demonstrating how results can be integrated into the Roadsoft GIS Decision Support System, updating the initial description detailed in Deliverable 6-B (of July 27, 2012).
- A summary of the outreach efforts and implementation discussions held so far as part of this project, especially after the South Dakota technical demonstration.

All of this documentation supports the project team's central tenet, that after evaluating different unpaved roads evaluation methods, reviewing the state of the practice, evaluating candidate platforms (including manned vs. unmanned systems, as intended), selecting a practical sensor, ensuring effective mission planning, demonstration DSS integration, developing and integrating existing and new software and algorithms, deploying the remote sensing systems, and evaluating their technical performance and data collection costs, we have developed an cost-effective, practical system for assessing the condition of unpaved roads. Our system focuses on a hexacopter unmanned aerial vehicle (UAV), one manufactured in the United States with readily available support and reasonable cost (see Figure 1-2). Commercial implementation of a UAV-based system awaits new regulations due out by September 30, 2015 from the US Federal Aviation Administration (FAA) so that private companies can offer URCAS-type services as third party professional service firms; UAVs have traditionally been restricted to use by public agencies, including public universities.

Figure 1-2: The selected hexacopter UAV, about to collect stereo imagery for evaluating the condition of an unpaved road segment in South Dakota.

Of the two main components of the Remote Sensing Processing System, the 3D Data Processing part took advantage of existing open source tools, with appropriate code written by Michigan Tech Research Institute (MTRI, a research center of Michigan Technological University) research scientist programmers to enable overlapping stereo imagery to be “fed in” and high-resolution (1 cm x,y,z or better) 3D data to “exit” (see Figure 1-3) so that the distress detection algorithms could calculate the density and severity of road distresses. These algorithms were most effective at detecting and categorizing potholes and road crown. Ruts and corrugation (washboarding) could also be assessed, but improvements in their accuracy ratings are needed. The resulting distress data were integrated into the RoadSoft GIS DSS tool as an example of integration with readily available, commercially ready software that transportation agencies could choose to use with this newly available unpaved road asset management data. One of main conclusions shared by attendees of the June, 2014 technical demonstration in South Dakota was that our system seems practical and cost-effective, with several other potential uses (such as haul-road inspection and road geometry evaluations). This final report serves as documentation of how these interested end-users were able to reach this conclusion through a successful demonstration project funded by USDOT.

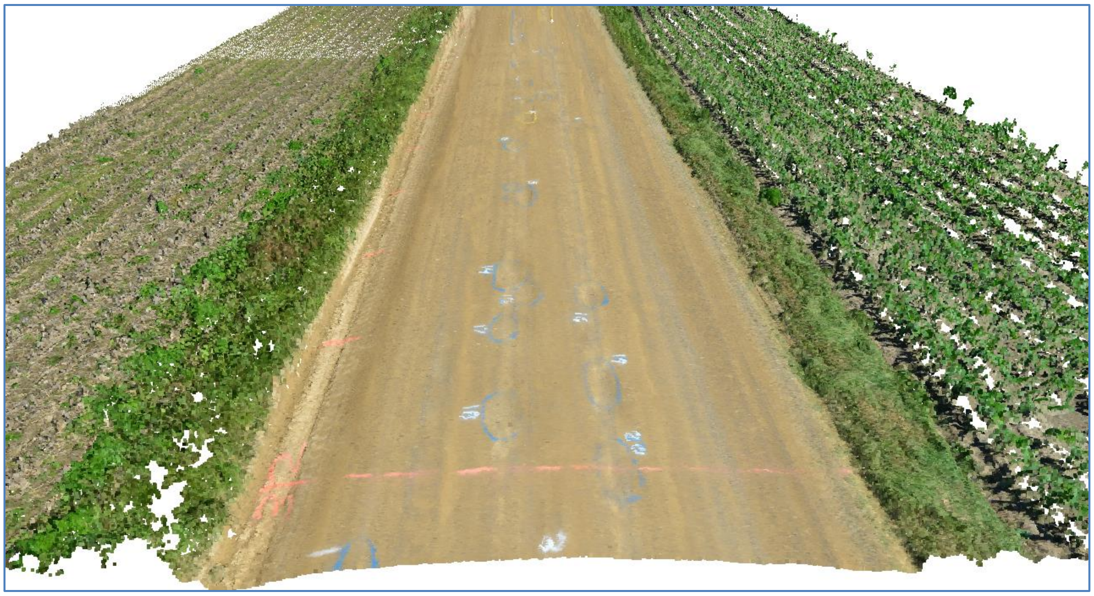


Figure 1-3: An example 3D point cloud generated through the project's image processing tools that was used to detect and calculate road distress densities and severity ratings for this representative road segment *(as shown in Deliverable 7-B)***.**

2. Background

This project effectively used data collected through remote sensing in a decision support system for managing unpaved roads. A significant challenge for managing unpaved roads is the lack of a method or system that provides decision support and provides a method for cost-effective data collection. Previously developed systems provide basic decision support from unpaved road distress data, but data collection costs and quality have limited their effectiveness and adoption by unpaved road managers. It was a goal of this project to overcome these limitations. This project provided an example of cost effective inventory and distress data collection from remote sensing systems using a standard road assessment and inventory technique (Army Corps of Engineers Unpaved Road Condition Index system) and an integrated decision support system.

2.1. Current Evaluation Methods

Many methods for assessing unpaved road conditions exist. These methods range from simple, low-cost visual inspection methods to very complex methods requiring detailed physical measurements. A detailed review of the variety of assessment methods available for unpaved road managers is included in Deliverable 2-A: State of the Practice of Unpaved Road Condition Assessment. The methods outlined in this state of the practice report can be broadly classified as one three general methods: visual, combination (visual and direct measurement), and indirect data acquisition (Brooks et al. 2011a).

The most popular distress identification methods used are typically visual methods: PASER and RSMS for domestic use and THM-12 Standard Visual Assessment Manual for Unsealed Roads internationally (Brooks et al. 2011a). These methods are attractive because they do not involve time-consuming physical measurements and can often be collected inexpensively, however, these methods must be used with caution as due to overall subjectivity of the rating methods (Brooks et al. 2011).

The method chosen for this project is the Department of the Army developed The Unsurfaced Road Condition Index (URCI) because this method provides an objective, repeatable distress identification system that quantifies the extent and severity of seven specific unpaved road defects. URCI is also attractive because it also provides an overall metric that compares overall road quality at a network level.

The Department of the Army developed The Unsurfaced Road Condition Index (URCI) method to manage roads on military facilities and to provide a basis for selecting and prioritizing maintenance activity. Since this method provides maintenance suggestions for specific unsurfaced road conditions, it was ideal for integration with decision support software (DSS) (Department of the Army 1995).

The UCRI method uses a sampling approach that segregating roads into distinct segments or branches that have similar characteristics including structure, traffic volume, construction history and road rank. A combination of a visual assessment of seven specific physical measurements of distresses and two road characteristics quantify the condition of gravel and earth roads. The two road characteristics that are visually assessed can either be collected from a slow-moving vehicle or manually measured. The other five distresses must be measured manually using a wheeled distance meter, surveying tape, or ruler to measure depth. The UCRI method specifies procedures for measuring each distress (Eaton et al. 1987, Eaton et al. 1987, Department of the Army 1995).

A drawback associated with the URCI system is that a significant amount of time is required to collect data using standard field methods with measurement down to half an inch vertical accuracy necessary. The project team selected the URCI system because it can provide high quality data, the required data is for the most part quantifiable, and the distress measurements integrate well with rapid data collection method used in this project.

2.2. Distress Classification

Distress identification methods outlined in Deliverable 2-A: State of the Practice of Unpaved Road Condition Assessment shared many of the same distress types. The primary unpaved road distresses that were common to most systems included the following:

> **Loss of road cross section**: A road cross-section, also referred to as cross slope or crown, is the steepness of the slope of a road from its centerline to the edge of the shoulder (Skorseth et al. 2000, Jones et al. 2003).
>
> **Improper drainage** or road side drainage performance, is based on the suitability of drainage ditches and culverts (if any) present, and the amount of debris and overgrowth (Department of the Army 1995, Jones et al. 2003).
>
> **Potholes** are roughly bowl shaped depressions in the surface of a pavement and are typically less than three feet (0.91 m) in diameter. Water can accelerate pothole growth by collecting in these depressions and weakening the surrounding surface making it susceptible to further damage by traffic (Department of the Army 1995, Skorseth et al. 2000, WCPA 2007).
>
> **Ruts**, also referred to as rutting, are longitudinal depressions in the wheel path of a roadway that are caused by excessive vehicle tire loads. Ruts can fill with water causing it to drain along the road instead of away from the road (Department of the Army 1995, Skorseth et al. 2000). Minimum width of a typical vehicle tire is six to seven inches wide (15.2 cm - 17.8 cm) and can be as large as the wheel path travel area of the lane, approximately 24 inches wide (0.61 m) (Department of the Army 1995).
>
> **Corrugations**, also referred to as washboarding, on an unpaved road are caused by traffic and are compounded by dry conditions and low quality gravel (Skorseth et al. 2000). Washboarding typically results in ridges that have spacing as little as eight inches (20.3 cm) crest to crest, to as large as 40 inches (1.02 m) crest to crest (Department of the Army 1995). Washboarding tends to result in corrugations that have similar crest to crest spacing (period) and depths (magnitude) (Department of the Army 1995).
>
> **Loose aggregate** on a roadway is typically caused by heavy traffic or poor materials and forms linear berms of segregated loose aggregate particles. Typically, loose aggregate berms are six to 24 inches (15.2 cm - 61.0 cm) in width (perpendicular to the road direction) and run longitudinally with the direction of the road for significant distances (Department of the Army 1995).
>
> **Dust**: Fine material loss on a roadway is an indicator of the gravel layer quality. Particles that are most susceptible for loss as dust are responsible for the gravel layer plasticity which is a desirable quality (Skorseth et al. 2000).

The details of measurement and impact of all of these distress on the road rating vary greatly depending on the assessment method used. The URCI method has very specific details measurement of almost all of these main distress and the method quantifies distresses with measurements that are adaptable to remote sensing. URCI provides a mathematical relationship that relates each distress to one another, which results in a system that can be converted into an overall measure of road quality. This combined index is convenient as a network level metric.

Two URCI distresses – loss of road cross section and improper roadside drainage – are somewhat subjective and depend on trained raters comparing field conditions to sketches and non-quantitative verbal descriptions of severity levels. These descriptions lack a specific measurement to define the different distress levels of the system. In Deliverable 6-B: A Demonstration Decision Support System for Managing Unpaved Roads, the project team created criteria for the loss of cross section and improper roadside drainage to define these distressed in measurable terms that still fit with the spirit of the rating system. The new criterial allow these two distresses to be measured by the remote sensing system used for this project.

The only major distress that was not feasible to collect for unpaved roads was dust. Dust was infeasible to collect due to the subjectivity of the rating system and the need to have a dust source such as an automobile (Colling et al. 2012).

3. Summary of Deliverables

The purpose of this section is to briefly review each of the deliverable reports created for this project; all are available on the project website (www.mtri.org/unpaved) but are included here to serve as single-location resource with links to the full reports.

3.1 Deliverable 1-A: Requirements for Remote Sensing Assessments of Unpaved Road Conditions

Available for download at: http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del1-A_RequirementsDocument_MichiganTechUnpavedRoadsr1.pdf

This deliverable detailed and outlined sensor requirements for measurements of unpaved road distresses (e.g. their types, sizes, range of values), sensors and software (e.g. sensor resolutions, size, weight, power, etc.), and operations (e.g. costs, time-constraints, user requirements, etc.). Through development of a remote sensing system, the project team had to keep in mind the requirements set forth by this deliverable and use it as guidance during the duration of the project. Many of the defined requirements were similar to the United States Department of the Army (USDA) Unsurfaced Road Maintenance Management System as defined by USDA Technical Manual # 5-626 of 1995, which served as the basis for integrating unpaved road condition data into easily understandable and actionable information.

In order for the remote sensing system to be efficient and commercially viable, it had to collect distress and inventory data at a rate and cost comparable to traditional methods of land-based assessments in terms of cost-per-mile of data collected. For an efficient processing and output time, data was required to be processed relatively quickly since unpaved road conditions can change quickly (e.g. grading). In addition, in-field data quality checks were suggested to verify that the necessary information was collected before declaring success and moving to a different site. Sensor operations were required to include very little (to no) training or special skills of the operator, while the sensor platform needed to be fast and easy to deploy and could potentially require significant training depending on the platform selection. Remotely sensed data were required to represent at a minimum of 100 feet (30.48 meters) in length as measured down the centerline, with a maximum width perpendicular to the direction of the road of 70 feet (21.34 m).

Phenomenon sensing requirements varied between the different types of distress features that are apparent on unpaved roads. Road types (e.g. gravel pavement, unimproved earth pavement, and paved roads) had to be determined with a goal of obtaining 95% accuracy even though in remote sensing classification 85% is acceptable. Additionally, road width measurements were required to be completed at least every ten feet (3.05 m) and not include ditch or fore slopes. Road cross sections were taken to validate if any crown still existed. A proper crown occurs when the center line of the road is slightly higher in elevation than the edges, which aids in surface water drainage. Crowns can be deteriorated due to traffic, snow plowing, and grading operations, and can lead to accelerated deterioration of the pavement surface. Pothole distress occurs as surface water is collected in depressed areas and weakens the surrounding area, creating a bigger pothole (Figure 3-1). The remote sensing system was required to detect each occurrence of a pothole. Ruts or longitudinal depressions on the surface of unpaved roads are caused by vehicle tire loads permanently deforming the pavement layers. Any ruts detected by the remote system will be binned into one of three categories based on depth. Corrugations are a result of heavy traffic use during dry conditions, forming closely spaced ridges and troughs perpendicular to traffic flow. The area of road experiencing corrugations must be measured by the sensing platform and placed into one of three bins based on the total area. Improper roadside drainage can also significantly weaken an unpaved road and lead to accelerated formation of distress features.

The sensing system was required to detect the presence of standing or running water in a ditched area. Loose aggregate often occurs in the less traveled sections of road and often occur in a distinctive pattern that should be recognized by the sensor (Figure 3-2). Classified loose aggregate sections are measured and placed into one of three bins based on depth of aggregate berms. Lastly, dust can often reduce visibility near unpaved roads but was not a required feature to collect in order to measure the success of the sensor.

Figure 3-1: Potholes on an unpaved road.

Figure 3-2: Loose aggregate on an unpaved road creates a distinctive pattern.

Derived requirements created through the requirements set forth in the preceding paragraph were also imposed on the sensor system. First of all, the Federal Aviation Administration (FAA) requires any aerial vehicle that flies above 400ft (121.92 m) to file formal flight plans. Therefore, the aerial platform and sensor would not fly above this altitude and at the lowest practical altitude. Secondly, the sensor's field-of-view (FOV) had to be at least twice the width of the region of interest (approximately 72 feet, or 22 m). This FOV corresponds to an angle of 11°, which is achieved by using a camera lens with a 75mm focal length. Next, high resolution imagery was required to measure the smallest of distress features that exist on an unpaved road. The required imagery would need to be at least 4 million pixels (4MP), with a consumer grade camera providing 16MP imagery, which provided high enough resolution to capture the features of interest. Finally, speed of image capture must provide at least 50% overlap between images, meaning the camera must capture an image once over 0.4 seconds, or 2.25 frames per second. Additional requirement were to be determined based on experimentally-collected data (e.g. the maximum aperture of the lens will need to be determined based on the illumination and reflectivity of typical scenes, not known at this time).

In summary, Deliverable 1-A defined requirement set upon the different components of the sensor system, platform, and road distresses (Table 3-1). This document helped guide the next steps in the project, including the algorithms needed to analyze distress features, and determine a list of candidate sensors.

Table 3-1: Summary of requirements for a successful unpaved road data collection and asset management system.

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

3.2 Deliverable 2-A: State of the Practice of Unpaved Road Condition Assessment

Available for download at: http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del2-A_State_of_the_Practice_for_Unpaved_Roads_MichiganTech.pdf

The first step in solving any problem is to understand it fully; this ensures that any solution builds upon existing knowledge. Deliverable 2-A is a review of the current state of practice in unpaved road condition assessment and the different methodologies and rating systems used by road assessing agencies. Different methodologies included visual (Pavement Surface Evaluation and Rating (PASER) Road Surface Management System, Standard Visual Assessment Manual for Unsealed Roads, and Subjective Rating System), combined (visual and direct) (Objective Rating System - Central Federal Lands Highway Division, Unsurfaced Road Condition Index), and indirect (Road Roughness Using Accelerometer Technology by Opti-Grade®, Ground Penetrating Radar, Remote Sensing – Unmanned Aerial Vehicles, Survey – Ultralight Aircraft) measurements.

Visual: Pavement Surface Evaluation and Rating (PASER)

Developed to aid road managers in quickly and cost-effectively assess road conditions and guide in road maintenance decision, the PASER system includes two separate systems that are used for unimproved earth and gravel pavements. Visual based assessments are used to classify a pavement into numerical categories based on visible distresses and road attributes. During an assessment, emphasis is placed on the rater's ability to estimate the severity and extent of road features instead of the physical quantitative measurements and completed while driving along a road in a slow-moving vehicle. The unimproved earth PASER system is based on four rating categories (rating of 1 to 4) with a poor rating being assigned a value of 1, and the best rating a value of 5. Categories are based on the presence or absence of five defined characteristics and the extent / severity of four distress types. The gravel PASER system classifies roads into one of five categories (ratings of 1 to 5) with a poor rating being assigned a value 1, and the best rating a value of 5. Categories are based on the presence or absence of three defined road characteristics, and the extent / severity of five distress types.

Overall, PASER systems require minimal equipment for data collections and typically include one to three people per collection, with productivity that is relatively high, and is a well-established condition rating system used in multiple states including Michigan and Wisconsin. PASER rating works best with asphalt, concrete, and sealcoat pavements and is relatively cheap due to the limited amount of specialized equipment and limit amount of field measurements required.

Visual: Road System Management System

The Road Surface Management System (RSMS) aids in creating road network maintenance plans and in the prioritization of road projects. Ratings are assigned to homogenous road segments that have similar construction, maintenance history, and distress patterns. Similar to the PASER method, assessments are conducted from a slowing moving vehicle that stops to allow a rater additional inspection time. Four distress criteria (corrugations, potholes, rutting, and loose aggregate) are classified by their extents and severity. Extents are categorized based on the percent of surface area that is covered, while severity is categorized based on distress depth. Ratings are intended to be used in accordance with a decision tree to help guide potential maintenance options for a road segment. Overall, the Road System Management System is quick to deploy and distress severity and extent criteria to rate road systems are easy to use.

Visual: Standard Visual Assessment Manual for Unsealed Roads

The Standard Visual Assessment Manual for Unsealed Roads (TMH12) standardizes road ratings for maintenance purposes in South Africa provinces. These guidelines can be used nationally to rate entire road networks of gravel roads and provides road managers three levels of assessments (i.e. basic, intermediate, and advanced levels of data collection). Basic level of assessments contains eight distresses (e.g. potholes, corrugations, rutting, loose material, stoniness, erosion, loss of gravel, and dust), which are visually evaluated for their degree of severity. The intermediate level assigns estimated percentage of road cover to each distress. Lastly, the advanced level assigns additional parameters to each distress that will aid a road manager in further road system assessments, project management, or research. Assessments use road segmentations that are defined by physical landmarks such as bridges, intersections, or installed markers. Using this designation allows for easy field identification of segments, but also reduces the homogeneity of segment properties with lengths ranging between 1.5 to three miles long.

Equipment required for assessments is minimal and data are recorded on forms, with a recommended return intervals of once per year. Additional recommendations include keeping daily assessments less than 80 miles per day with speeds below 37 miles per hour. Overall, using this type of visual assessment results in highly detailed and large quantities of data. However, the system can be subjective since it solely relies on the individual's own criteria.

Visual: Subjective Rating System - Central Federal Lands Highway Division

The subjective assessment system includes a visual rating system which evaluates five distress parameters for each segment of road. Segments of roads are rated on five distress types (dust, washboarding, raveling, rutting, and potholing), which are compared to a control segment. Each distress is rated on a scale ranging from 0 – 10, with a rating of 5 representing equal distress levels between the control segment and road segment in question and a rating of less than 5 representing a higher level of distress for the segment in question. Assessments are entirely subjected, but include at least four raters traveling along the same segment with the final score being an overall average of each distress. Overall, while the system produces satisfactory data for a comparative research study, it is not practical as a day-to-day tool due to the fact that ratings are relative to a control segment.

Combination: Objective Rating System - Central Federal Lands Highway Division

This rating system combines both visual and direct measurements of five different distresses (dust, washboarding, raveling, rutting, and potholing) on unpaved roads. Road segments are divided into ½ - one mile long segments, which are further divided into 25 foot segments. An average physical measurement is calculated for each distress using results from each 25 foot segment. This average distress is converted to an eleven-point (0 – 10) scale, then the resulting scores are averaged to create an overall objective rating. Since this system uses precise measurements of distresses, stops are required, which creates a longer time period per assessment. Overall, this system has very well defined rating and measurement criteria, allowing for a higher degree of repeatability.

Combination: Unsurfaced Road Condition Index (URCI)

Developed by the Department of the Army to manage roads on military facilities and to provide a basis for selecting and prioritizing maintenance activity, the URCI has since then gained wide use for local and state governments across the United States for asphalt and concrete pavements. By segregating roads into segments, the road's condition is determined by analyzing representative segments. It combines visual and physical measurements of seven specific characteristics (Table 3-2) and distresses to quantify the condition of gravel and earth roads. Each distress is classified into severity bins (low, medium, or high) and have points deducted from their values based on unique distress curves.

Table 3-2: Distress features and assessment criteria found in the URCI

Road Characteristics and Distresses	Assessment Criteria
Improper Cross Section	Minimal evidence of ponded surface water warrants a low severity rating while large amounts of ponded water or severely depresses cross sections warrant either medium or high severity rating in this category. The length of roadway exhibiting each of the three severity levels of this factor is recorded and used as a measure of density.
Drainage	Drainage features that allow water to pond, are eroded, or are overgrown with vegetation are classified into either low, medium or high severity. The length of roadway exhibiting each of the three severity levels of this factor is recorded as a measure of the factor's density.
Corrugations	Corrugated surface areas are classified into the following three bins: corrugations up to one inch (2.5 cm) deep are low severity, corrugations one inch to three inches deep (2.5 cm - 7.6 cm) are medium severity, and corrugations greater than three inches (>7.6 cm) are high severity. The square area of each bin of corrugated surface is measured to determine density.
Dust	If dust is present but visibility is not obscured, the factor is considered low severity.
Potholes	Potholes are classified as either low, medium or high severity based on a matrix of the frequency of their occurrence and classified into diameter and depth ranges of: less than two inches (5.1cm) , two to four inches (5.1 cm - 10.2 cm), and over four inches (>10.2 cm).
Ruts	Ruts are classified based on their depth in the following three bins: ruts up to one inch deep (2.5 cm) are low severity, ruts one inch to three inches deep (2.5 cm - 7.6 cm) are medium severity, and ruts greater than three inches (>7.6 cm) are high severity. The total surface area is measured for each rutting depth bin for the sample unit.
Loose Aggregate	Loose aggregate berms are classified into three bins: berms of loose aggregate less than two inches deep (<5.1 cm) are low severity, berms of loose aggregate two to four inches (5.1 cm - 10.2 cm) are medium severity, and berms of loose aggregate over four inches (>10.2 cm) deep are high severity.

Visual inspections can occur in a slow moving truck (25 mph) and is recommended to take place approximately four times per year. Direct measurements should be taken using handheld equipment and straight edges to measure depths. Cost ranges from \$0.70/yd^2 for a 25,000 yd^2 area to \$0.10/yd^2 for a

100,000 yd^2 area. No specialized tools are required, but highly detailed measurements are making for a longer collection time period.

Indirect Data Acquisition: Road Roughness Using Accelerometer Technology by Opti-Grade®

The Forest Engineering Research Institute of Canada developed the commercially available Opti-Grade® software to collect roughness data on unsealed roads for management of grading operations of forest industry logging roads. An Opti-Grade® system includes an acceleration systems, GPS unit, and data logging system that is mounted on haul trucks. The acceleration sensor detects the vehicles response to road roughness. Data are used for maintenance analysis through software that interprets the roughness and position data. Schedules are then produced to direct motor graders to roads that require maintenance. This system works well on small road networks that are regularly travelled by instrumented vehicles. However, it is not apparent how well Opti-Grade® performs for larger road networks where frequency of travel by instrumented vehicles is less frequent.

Indirect Data Acquisition: Ground Penetrating Radar (GRP)

Saskatchewan highways are analyzed using data collection methods known as INO Laser Rut Measurement System and the Longitudinal Profiling Systems on urban roads. However, studies suggest that the use of GPR is necessary to acquire additional structural data to aid in decision making. Road materials possess dielectric permittivity properties that are detected by the GPR. Dielectric permittivity properties are collected as a vehicles passes over the road, and this data is compared to reference information to provide information such as moisture content and amount of fines in conjunction with thickness (Table 3-3).

Table 3-3: Gravel road wearing course classification and corresponding dielectric constant values.

Dielectric Value	General Condition/Proposed Treatment
< 8	Dusty material, wearing course erosion. Fines or dust treatment needed.
8 - 12	The wearing course is in the optimum moisture content window with low moisture. Additional gravel and fines for preservation could be added.
12 - 16	The wearing course is in the optimum moisture content window with highest moisture and highest amount of fines. Road drainage should be evaluated. New material could be added with the proper amount of fines.
> 16	Material contains too many fines, water adsorption is apparent. Problems may occur during thaw, surface may be slick during rain. Road drainage should be evaluated.

Additional techniques used with GPR can provide a more complete road analysis. For example a falling weight deflectometer can aid in the calculation of peak deflection and structural index for road segments. Overall, the use of GPR helps accurately measure structural damage allowing a more accurate structural deterioration to be predicted by network models. However, data must be collected on a road section long enough to statistically overcome the variability that is inherent in the road.

Indirect Data Acquisition: Remote Sensing – Unmanned Aerial Vehicles (UAV)

A remote sensing system using a UAV that would support cost effective data acquisition of unpaved road surface distress data was developed by the South Dakota State University. This system was able to collect high resolution imagery and measure distress features using point extraction techniques and threshold algorithms. Imagery was process to reconstruct a 3-D road surface model. Although the study showed promise, it did not serve as a complete evaluation of the capabilities of a UAV to assess unpaved road conditions. Overall, the method provides a faster, less expensive, and generally more reliable procedure as compared to other discussed in this deliverable. The system was able to accurately detail distresses on unpaved roads, but image processing in 3-D software was lengthy in time.

Indirect Data Acquisition: Survey – Ultralight Aircraft

Surveying unpaved road conditions using ultralight aircraft was developed to ease access to remote locations for corridor studies. Pilot studies have been conducted for corridor lasting over 90 miles in South Africa. In order to collect data, the investigator must be familiar with the topography, roadway plan, and other characteristics of the road. The ultralight aircraft is flown between 650 – 1640 feet. Important features are observed and verified with GPS coordinates. Descriptions of locations are recorded by an investigator who records notes on a tape recorder. This type of survey significantly reduces data collection time and survey costs.

3.3 Deliverable 3-A: Remote Sensing the Phenomena of Unpaved Road Conditions

Available for download at: http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del3A-Remote%20Sensing%20the%20Phenomena%20of%20Unpaved%20Road%20Conditions.pdf

Different kinds of phenomena pertaining to fundamental (e.g. color) and emergent (e.g. long, linear, pattern due to rutting) that are important for evaluating unpaved road conditions are outlined in this deliverable. The overall descriptions of both the fundamental and emergent characteristics of unpaved roads were used to aid in the selection of sensor(s) and image processing algorithms. The following characteristics were studied and analyzed to aid in the selection process of a sensor.

Color

Depending on the material content and conditions, the presence of a distress feature can have an effect on the color of an unpaved road. To aid in comparing colors quantitatively, gray-cards (of known color content) were placed along example road distresses. This highlighted how lighting and camera effects can change the measured color in a scene. Identical gray-cards in Figure 3-3 appear to be different colors, but after color correction they appear to be the same color (Figure 3-4). The correction also shows the road is actually more yellow than blue in color. Color correction is necessary in order to determine how much lighting affects color change and therefore must be considered in the selection of a sensor.

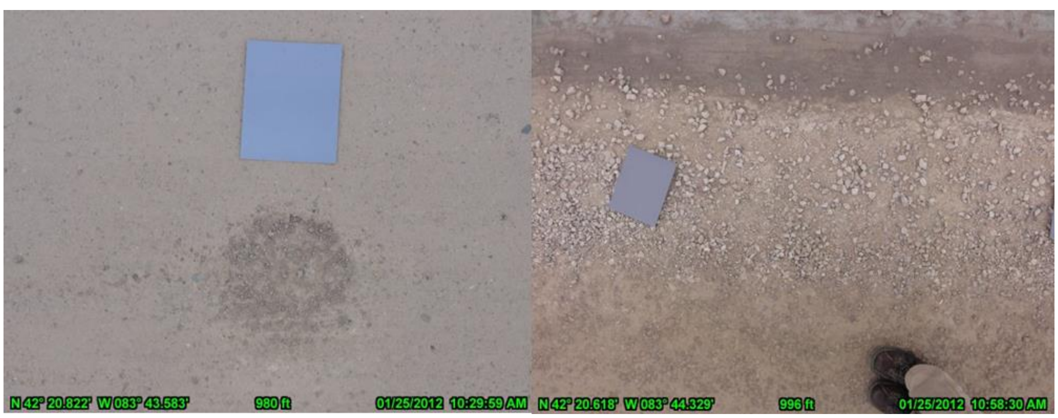


Figure 3-3: Example of how lighting and camera effects can distort measured color of a scene.

Figure 3-4: With the gray-card color equalized, the road surface on the left also changes color.

Texture

Textural changes are also necessary to be detected by the selected sensor and represent good and bad conditions of roads. For example, the presence of aggregate on the road segment will produce a characteristic texture that will change based on size and composition. Differential textures from different sections of road can be used to differentiate surface conditions and require measurements to determine if the texture changes reflect damage or impending damage. The selected sensor must be able to sense within an accuracy of 0.5-1 inches (1.2-2.5 cm) of distresses when measuring based on textural differences.

Pattern

Patterns tend to be repetitive combinations of textures that can be either long-range, or local, and are characteristic of road surface features. Long-range patterns, such as corrugations, are characterized by repetitive contract changes across a surface, while other distress features such as rutting are characterized by longitudinal edges. Other distress features have distinctive characteristics such as potholes, which are mainly oval in shape.

Profile

A road surface profile is a three-dimensional characteristic in that it can be described by the position on a road surface and the height at each position. 3-D information can determine long-range details (e.g. loss of crown) and local patterns that may exist. The selected sensor must be able to detect change in mean profile depth (a metric of surface condition) from a series of two-dimensional imagery. For this project, this was accomplished using "structure from motion" which recovers both the scene and camera motions from a series of stationary images. Road crown and local distresses can be extracted from this type of 3-D analysis.

Polarimetric Backscatter

Road surface distresses have characteristics of radar polarizations and polarimetric signatures in the infrared. The selected sensor must be able to produces images that when analyzed can be compared for a pixel-by-pixel basis for differences in polarization.

Overall, surface phenomena are the only characteristics that can be sensed optically. The selected sensor must be able to use these characteristics to define the location of distress features.

3.4 Deliverable 4-A: Sensor Selection for use in Remote Sensing the Phenomena of Unpaved Road Conditions

Available for download at:
http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del4A_SensorSelectionReport.pdf

The selected sensor that will aid in the detection of distress features and road characteristics along unpaved road segments was required to meet a certain set of defined criteria. This deliverable reviewed the set of define criteria and provided sensors that were capable of meeting the criteria.

Field-of-view

The field-of-view of the sensor depends on the range of the road and the focal length of the lens. Criteria state that the field-of-view must be twice the width of a typical road, about 72 feet (22 m).

Focal Length

Since the altitude of data collection platform will be approximately 100 – 400 feet (30 – 122 m), the focal length will correspondingly be 61 – 244 mm.

Resolution

Criteria state that the smallest resolution size needed was approximately 1 inch (2.5 cm). Based on the field-of-view and focal length, the sensor would have to produce an image with 1,728 pixels across the road. This equates to a 4 megapixel camera, which is widely available since most commercial sensors contain resolutions of 16 megapixels or more. Additionally, if a camera with a larger sensor is chosen, then the length of the lens can be reduced and still produce the desired results.

Frame-rate

At maximum, the necessary frame-rate for a sensor mounted on a manned, fixed-wing, aircraft flying at just above stall speed, which is 60 miles per hour, a field-of-view of 94 feet, and a 50% overlap in imagery, the frame-rate is 2.3 frames per second (fps). If the overlap percentage needs to be higher for 3-D reconstruction (approximately 75%) the frame-rate would rise to 3.5 fps.

Additionally, the sensor must meet two other requirements. First, it must have a remote trigger to allow software control of imagery collection. Secondly, all collection scenarios should be possible with a single lens.

Sensor Types

There are two types of optical sensors commonly available; charge-coupled devices (CCD) and complimentary metal-oxide semiconductor (CMOS). Through a detailed comparison analysis of these two types of sensors it was clear that neither had a clear advantage for this project and total cost is approximately equal. While the sensors are significantly different from one another, for the purposes of this program, these differences were not important. Therefore either the CCD or CMOS sensor would be acceptable.

Candidate Sensors with Recommendations

The project team conducted a review of a wide range of sensors that are commercially available. Table 3-4 is contains a subset of sensors that were considered appropriate. The first requirement was that the sensor must be remotely controllable. After eliminating those that did not have this feature, the remaining sensors were evaluated and it was determined that the Nikon D800 would be purchased for further consideration since it more than met all of the defined requirements.

Table 3-4: Comparison of candidate sensors

No single lens will fit our requirements
No Remote Trigger Option
Discontinued

Manufacturer	Model	Mp	Price (USD)	Max FPS (at fu	Max FPS (full r	Sensor Width	Sensor Heigh	Remote Trig
Nikon	D800	36.3	$2,999.95	4	4	7360	4912	Yes
Nikon	D3X	24.5	$7,999.95	5	5	6048	4032	Yes
Canon	EOS 5D Mark III	23.4	$3,499.00	6	6	5760	3840	Yes
Canon	EOS-1Ds Mark III	21.1	$6,999.00	5	5	5616	3744	Yes
Canon	EOS 60Da	19	$1,499.00	5.3	5.3	5200	3462	Yes
Canon	EOS-1DX	18.1	$6,800.00	12	12	5184	3456	Yes
Canon	EOS 7D	18	$1,699.99	8	8	5184	3456	Yes
Canon	EOS 60D	18	$999.99	5.3	5.3	5184	3456	Yes
Canon	EOS Rebel T2i EF-S	18	$699.99	3.7	3.7	5184	3456	Yes
Canon	Eos Rebel T3i EF-S	18	$849.99	3.7	3.7	5184	3456	Yes
RED	Epic	14.3	$34,500.00	120	120	5120	2700	Yes
RED	Scarlet-X	14.3	$9,700.00	30	30	5120	2700	Yes
Nikon	D4	16.2	$5,999.95	10	10	4928	4280	Yes
Nikon	D7000	16.2	$1,199.95	6	6	4928	3264	Yes
Nikon	D5100	16.3	$849.95	4	4	4928	3264	Yes
Canon	EOS-1D Mark IV	16.1	$4,999.00	10	10	4896	3264	Yes
Nikon	D300s	12.3	$1,699.95	7	7	4288	2848	Yes
Nikon	D90	12.3	$899.95	4.5	4.5	4288	2848	Yes
Nikon	D5000	12.3	$629.95	4	4	4288	2848	Yes
Canon	EOS Rebel T3	12.2	$549.99	3	3	4272	2848	Yes
Nikon	D700	12.1	$2,699.95	5	8	4256	2832	Yes
Nikon	D3S	12.1	$5,199.95	9	9	4256	2832	Yes
Pentax	645D	40	$9,995.95	1.1	1.1	7264	5440	No
Sony	NEX-7	24.3	$1,349.99	10	10	6000	4000	No
Sony	a77	24.7	$1,399.99	8	8	6000	4000	No
Sony	a65	24.3	$998.00	8	8	6000	4000	No
Canon	EOS 5D Mark II	21.1	$2,499.00	3.9	3.9	5616	3744	No
Pentax	K-5 Black	16.3	$1,099.00	7	7	4928	3264	No
Pentax	K-01	16.49	$899.00			4928	3264	No
Sony	NEX-5N	16.1	$699.99	10	10	4912	3164	No
Sony	TX66	18.2	$349.99			4896	3672	No
Sony	TX200V	18.2	$499.99			4896	3672	No
Nikon	D3100	14.2	$646.95	3	3	4608	3072	No
Sony	TX55	16.8	$289.99			4608	3456	No
Nikon	P510	16.1	$429.95			4608	3456	No
Nikon	P310	16.1	$319.00			4608	3456	No
Nikon	S9300	16	$346.95			4608	3456	No
Pentax	Optio WG-2 GPS	16	$399.00	1	1	4608	3456	No
Pentax	Optio VS20	16	$184.95	1	1	4608	3456	No
Sony	TX20	16.2	$329.99			4608	3456	No
Pentax	Q	12.4	$749.95	5	5	4000	3000	No
Nikon	1 V1	10.1	$896.95	5	5	3872	2592	No
Nikon	1 J1	10.1	$649.95	5	5	3872	2592	No
Nikon	D3000	10.2	$499.95					
Sigma	SD1	46	$2,299.00	6	6	14400	9600	Yes
Olympus	E-5	12.3	$1,699.99			4032	3042	Yes

Candidate Lenses with Recommendations

The choice of lens depended on exposure characteristics, focal length, and sensor resolutions. Table 3-5 is a list of lenses that would fit the necessary requirements.

Table 3-5: Lens comparison

Nikon	Nikkor	18-200mm	f/3.5-5.6G	$846.95
Nikon	Nikkor	28-300mm	f/3.5-5.6G	$949.95
Canon		28-300mm	f/3.5-5.6L	$2,689
Canon		18-200mm	f/3.5-5.6 IS	$629
Tamron		18-200mm	f/3.5-6.3 XR Di-II	$299.00
Tamron		18-270mm	f/3.5-6.3 Di II VC PZD AF	$649
Sigma		18-250mm	f/3.5-6.3 DC OS HSM	$479
Tamron		28-300mm	f/3.5-6.3 XR Di LD	$419
Sigma		18-200mm	f/3.5-6.3 II DC OS HSM	$499
Tamron		28-300mm		$629
Tamron		AF18-270mm	f/3.5-6.3 Ei-II VC LD Asph. AF (IF)	$449.95
Sony		18-200mm	f/3.5-6.3	$898
Tamron		18-200mm	f/3.5-6.3 Di III VC	$739
Sony		DT 18-250mm	f/3.5-6.3	$648.00
Sony		SAL-18200 18-200mm	f/3.5-6.3	$548.00

For testing purposes, the project team recommended the purchase of the Nikon AF-S 50mm f/1.4 lens.

3.5 Deliverable 5-A: Candidate and Recommended Remote Sensing Platforms for Unpaved Road Condition Assessment

Available for download at:
http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del5A_PlatformSelectionReport_UnpavedRoads.pdf

The selected platform(s) that will aid in the detection of distress features and road characteristics along unpaved road segments was required to be economical, easy to use with minimal training, and able to make the required measurements as conveniently as possible. This deliverable reviewed the set of define criteria and provided platforms that were capable of meeting the criteria.

Altitude

As required by the Federal Aviation Administration (FAA), all unmanned aerial vehicles (UAV) must remain outside of the national airspace and below 400 feet (122 m). As for manned systems, the FAA requires that aircraft not travel below 500 feet (152 m).

Speed

The maximum speed considered is 60 miles per hour or 97 km per hour (for the manned aircraft). This is above the stall speed, but slow enough for effective data collections.

Payload

The chosen platform(s) must be able to carry 5kg of payload, which consist of the camera, lens, battery, and control-system.

Range

Under FAA guidelines, the UAV must remain within line-of-sight. A manned system has unlimited range for the purposes of this project.

Additionally, the platform must meet three other requirements. First, it should be reliable. Secondly, the platform should have an autopilot. Lastly, it should remain cost-effective.

Candidate Unmanned Aerial Systems

The speed and altitude combination restrictions only allow the project to use rotary-wing or aerostat systems. Due to payload requirements, the aerostat (or blimp) is extremely large (greater than 10 meters) and would present issues in storage and deployment. Therefore, only rotary-wing unmanned aerial systems will be considered. As for manned platforms, any ultra-light to single-engine aircraft will work. The only limiting factor is cost.

For the UAS platform, the project team determined potential candidates, which are located within Table 3-6. Based on previous experiences and high costs, the Rotomotion SR2 and Visking Aerospace Wolverine III platforms were eliminated from the list. Ultimately, the Bergen R/C Tazer 800 platform was chosen since a pointable camera mount was not necessary. Two of these platforms were purchased, one with autopilot and the other without.

Table 3-6: Comparison of rotary-wing UASs

Manufacturer	Cost	Service Location	Comments
Rotomotion SR2	>$30k	France	Parent company located in North Carolina. Michigan Tech has purchased from them before, and had unpleasant problems with them.
Viking Aerospace Wolverine III	>$50k	Oregon	Good interactions with company, and good customer reviews.
Bergen R/C Tazer 800	<$15k	Michigan	Excellent service and customer reviews.
Bergen eObserver	<$20k	Michigan	Has gimbaled camera mount.

As for the manned aircraft, the overall choice was determined based solely on availability and the aircraft's ability to mount the camera system in a way to look down. A typical Cessna 206 rental was initially estimated to cost between $600 – $2,000 per hour. Typical data collections are estimated to last between 1 – 2 hours.

3.6 Deliverable 6-A: A Demonstration Mission Planning for use in Remote Sensing the Phenomena of Unpaved Road Conditions

Available for download at:
http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del6A_MissionPlanningSystemReport.pdf

In order to truly be able to collect aerial road condition data, the project team needs to know what is being collected , if they are any potential interferences with the collection, and how best to collect data. This deliverable provides tools to assist in planning a data collection and in making the plan as quickly, and efficiently, as possible.

First, the assets must be defined. For the purposes of this project, the team is only interested in measuring the condition of unpaved roads. Having a visual method of locating possible target roads is useful especially when a planner has access to map overlays such as unpaved roads and their classifications, conditions, date of last inspections, date and type of last remediation, and public comments. Secondly, flight safety and effectiveness must be considered. Unpaved roads with trees, high-voltage power towers and distribution lines, or locations that are near restricted airspaces cannot be listed as potential study sites. Lastly, flight trajectory planning is created by commercially available tool called the Ground Station Control program. Trajectories will not only be based on the location(s) of roads, but also on previous flight-safety site assessments. This program also has the ability to use a pre-programmed flight-plan to automatically take-off, fly, and auto-land the missions.

To aid in determining potential flight locations, the project team developed an unpaved roads network data layer using high-resolution aerial imagery that spanned seven counties that are part of the Southeastern Michigan Council of Governments (SEMCOG). Using a combination of Trimble's eCognition software and ESRI's ArcGIS software, a methodology was created to extract unpaved roads from the Michigan Framework Roads Network and other unpaved roads that were not included in the framework. After mapping the unpaved road networks, potential field sites were determined. A more detailed explanation into the mapping of unpaved road networks can be found in Appendix A, Deliverable 6-A.

3.7 Deliverable 6-B: A Demonstration Decision Support System for Managing Unpaved Roads in Roadsoft

Available for download at:
http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del6B_DecisionSupportSystem_for_UnsurfacedRoadManagement.pdf

This deliverable details how data collected using remote sensing systems can be integrated into a commercially available decision support system (DSS) package for use by transportation management. It also provides a framework for integration between various data collection and analysis routines present in the remote sensing systems and the DSS demonstration using RoadSoft. Since management of unpaved roads has historically been challenged by the lack of a method or system that provides decision support and allows for cost-effective data collection, the development of a cost-effective DSS that uses a standard road assessment and inventory technique would prove beneficial.

For the purposes of this project, the Army Corps of Engineer Unsurfaced Road Condition Index (URCI) distress classification method was selected for assessing road quality. URCI provides many advantages over other classification methods. For example, it provides a clear set of measurement criteria for each distress type (loss of crown, improper drainage, potholes, ruts, corrugation, loose aggregate berms, and dust), is applicable to a wide variety of unpaved roads in the United States, and the majority of road distresses are able to be detected using remote sensing techniques. Dust was the only distress feature that could not be measured using remote sensing techniques.

Upon data collection completion, the DSS provides a location for storing, organizing, and analyzing large amount of data and assists users in determining a course of actions concerning unpaved road management. For the purposes of this project, the DSS receives data from the eCognition processes, which produces the unpaved road inventory information, and from the remote sensing platform system, which produces road distress data and inventory. Additionally, it also receives data collected by traditional manual processes such as ground-based inspection (Figure 3-5).

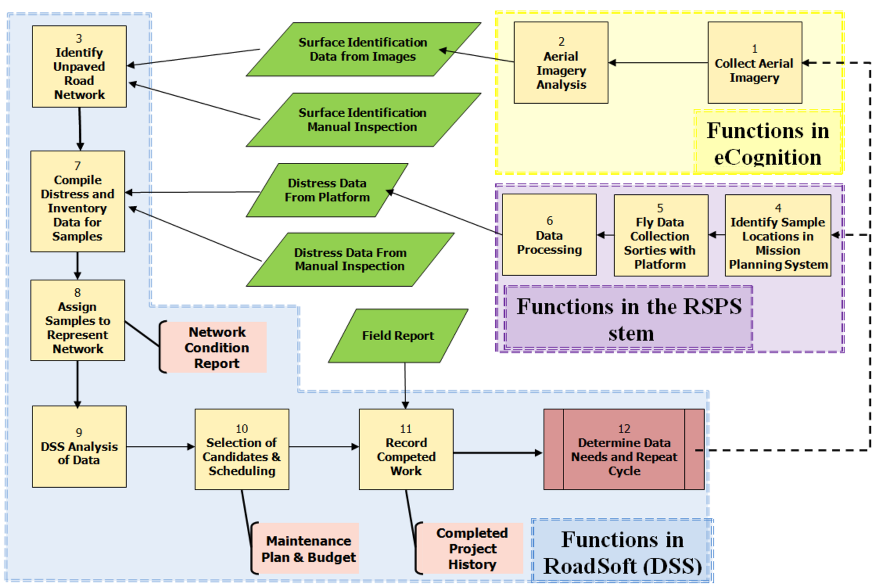


Figure 3-5: Road analysis process flow.

The process flow of the interactions between eCognition and the DSS, as well as the remote sensing platform system and DSS is briefly outlined below. The numbers correspond to the unit processes in Figure 3-5.

1. Collect aerial imagery: Imagery is collected by the user for an area of interest where the inventory of unpaved roads has not been collected or needs to be updated.
2. Aerial imagery analysis: Using eCognition, road segments within the Michigan Geographic Framework that are unpaved are identified. Locational and road information specific to each segment is exported is recorded.

3. Identify unpaved road network: The DSS will update existing pavement surface inventories. Road segments in the DSS identified as unpaved in aerial imagery, but do not have a pavement type assigned will be labeled as gravel. Road segments in the DSS that have an existing pavement surface type will be labeled as gravel if the most current surface type information is older than the aerial image date used for analysis.
4. Identify sample locations in mission planning system: Selections of sampling locations requires forethought and planning because samples need to be representative of the larger road segments that the sample represents, as well as being visible from the air without any obstructions.
5. Fly data collection sorties with platform: Field collection will take place during warm weather months, which is when distress features are likely to occur. Collect events can be as infrequent as annually or as frequent as monthly depending on the agency's business practice and budget specifications.
6. Data processing: Raw data processing will require a degree of post processing prior to export to the DSS. Final processed data will be in the form of URCI ratings.
7. Compile distress and inventory data for samples: Distress and inventory data from the remote sensing platform and manual field inspections will be placed into the DSS to create an all-inclusive database of unpaved road information.
8. Assign samples to represent network: The URCI method samples distress and inventory information to represent a larger network of roads. Users will be able to assign sampling locations to represent larger road networks.
9. DSS analysis of data: The URCI method provides a set of decision support criteria that acts as a guide to a road manager. This guide will assist the road manager in a specific course of action based on observed road distresses. The developed DSS will allow road segments to be ranked for rehabilitation or maintenance.
10. Selection of candidates and scheduling: Users of the DSS will also be able to set schedules for planned rehabilitation or maintenance.
11. Record completed work: Upon completing of unpaved road rehabilitation or maintenance, field reports can be used to update the DSS by changing statuses of projects.
12. Determine data needs and repeat cycle: At the end of the unpaved road analysis, users will need to determined data needs before repeating this cycle. Cycle repeats can be completed multiple times per year, or annually depending on DSS use and budgets.

3.8 Deliverable 6-C: Software and Algorithms to Support Unpaved Road Assessment by Remote Sensing

Available for download at:
http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del6C_SoftwareAlgorithms_DSS_RoadsMapping_fin.pdf

Summaries into the software acquired and developed including the DSS, image analysis components, and the road surface type data are the basis for this deliverable. Additionally, updates on the integration of distress data into the commercially available RoadSoft GIS tool as a demonstration of the developed DSS is also overviewed. Lastly, an update on the development of an unpaved roads mapping algorithm using readily available color-infrared aerial photography is overviewed.

Demonstration of DSS Software and Functions

The DSS is being used for storage, organization, and analysis of large quantities of data that assists road management in determining the proper course of action for road rehabilitation. The DSS, Roadsoft, uses a geographic information system interface to spatially locate and display data related to transportation assets. As discussed in the previous deliverable, the DSS receives data from both the Trimble eCognition-based process and the remote sensing platform system. Trimble eCognition analyses provide the DSS with location and attribute information of unpaved roads, which are based on aerial imagery. The remote sensing platform system collects raw data concerning road distresses and converts the raw data to URCI categories prior to being exported to the DSS. URCI densities of each distress are calculated and distresses are assigned deduction values based on their densities and level of severity (low, medium, or high). These deduction points are assigned based off URCI distress specific deduction value curves. Lastly, the URCI creates a combined index (URCI Rating) that is an overall measure of a road segment's condition. Overall, the DSS aids road managers in determined the best course of action for unpaved roads based on historical ratings and inventory information, and allows users to schedule projects for road rehabilitation.

Software and Algorithms Developed and Applied for Analysis of Unpaved Road Condition Imagery

The choice of software architecture has an important influence on the development efforts of a decision support system. Due to budgetary restrictions, this project could not realistically afford to develop exclusively new software, nor was it needed. Therefore, certain restrictions and goals had to be applied. For example, the software had to make use of already existing code, algorithms, and packages. It was also preferred that the software be usable in both Linux and Windows environments. The software exists as a multi-tool package, meaning that it is based on a variety of environments and tools (Figure 3-6). Additional goals, restrictions, and details about each tool in Figure 3-6 can be found in the Appendix A – Deliverable 6-C. Overall, as of this time in the project, all components of the signal processing chain, from data collection to reporting to the DSS have been identified. Work is still being completed to integrate individual components into an automated framework, so that data can be processed in an entirely automated fashion.

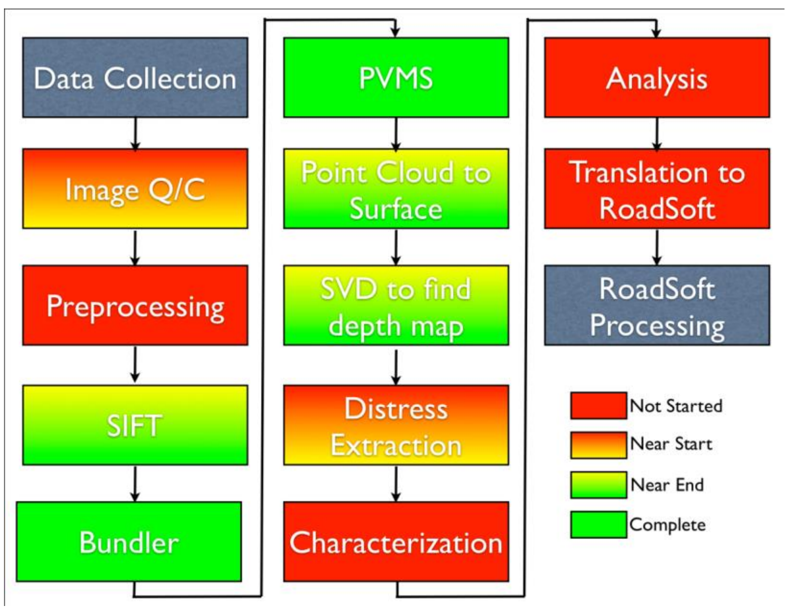


Figure 3-6: Processing functional flow; completion status represents the date of the 6-C report submittal (October 2012).

Example Case

Sampling was conducted in Milan, Michigan on Petersburg Road. Data was collected at an altitude of 20 meters, with a forward velocity of 2 m/s and a frame-rate of 2 fps. Through image processing, a 3-D point cloud and densified point cloud were created (Figure 3-7). After additional processing a depth map is created and filtered to remove single-voxel noise. While the filter will create a measurement somewhat less spatially accurate, it reduces the reported variance of the measurements to more realistic values (Figure 3-8).

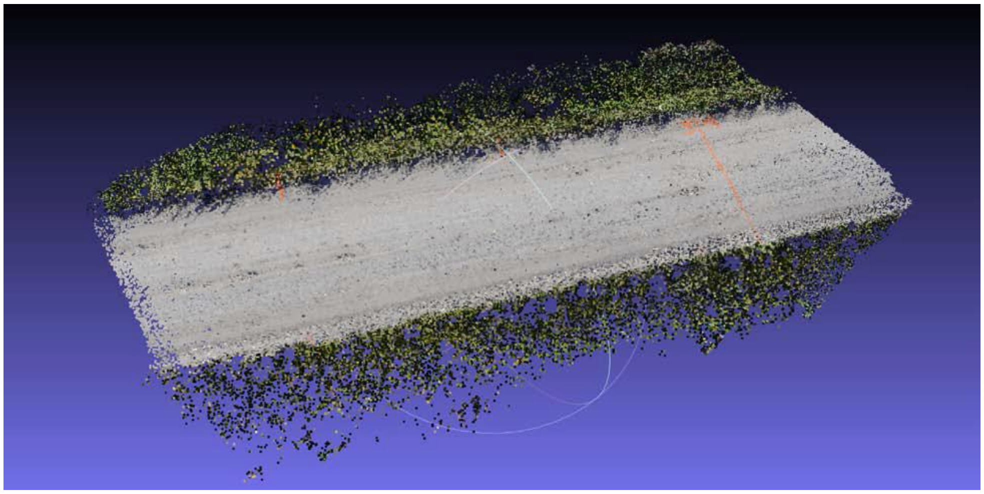


Figure 3-7: Densified point cloud created from 28 images.

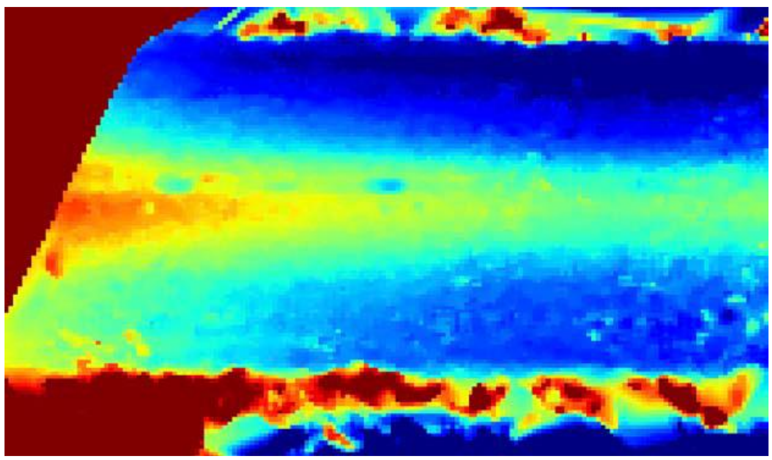


Figure 3-8: Depth map after median filtering. Blue colors represent lower elevations, red colors represent higher elevations.

Unpaved Road Identification and Classification

As discussed in Deliverable 6-A, the project team has developed a methodology to automatically detect unpaved roads in aerial imagery using Trimble's eCognition. This process was used to analyze roads in counties that are part of SEMCOG (Livingston, Macomb, Monroe, Oakland, St. Clair, Washtenaw, and Wayne Counties). Monroe County was analyzed and currently Oakland County is being evaluated.

3.9 Deliverable 7-A: Plans for Field Deployment of Recommended System for Remote Sensing of Unpaved Road Conditions

Available for download at: http://geodjango.mtri.org/unpaved/media/doc/deliverable_Deliverable_7-A_FieldDeploymentPlans.pdf

Field deployment plans for unpaved roads data collection platforms and sensors are described in this deliverable. This review also highlights a new platform, the Bergen Hexacopter, which provides a wider view of remote sensing platform capabilities. The additional platform and field collects will provide more data that will help refine the distress detection algorithms and demonstrations within Roadsoft GIS Decision Support System.

Data collections during the anticipated spring 2013 field deployment will aid in obtaining a larger set of example imagery for airborne platforms. Imagery will highlight unpaved road distresses and will go through the project team's analysis process and be scored based accordingly based on the URCI rating system. The same distress features will be measured on the ground, manually, and rated. Remote sensing platforms will consist of the Bergen Hexacopter and a manned fixed-wing Cessna 152 with a camera mounted to a modified flight-approved door. Roads segments will be selected based on a number of criteria, which can be found in Appendix A – Deliverable 7-A. Before data collection flights, each segment and distress will be manually assessed and rated. Different types of distresses will be marked using temporary road marking paint. This will help identify features during post-data collection analysis.

The Nikon D800 digital camera sensor with a fixed rate controller will be used to collect imagery on both the unmanned and manned aerial vehicles. Different lenses will be used, with a 50mm prime lens for the hexacopter and 200mm zoom lens for the manned fixed winged aircraft. Prior to any data collection, the area is inspected for any potential hazards or obstructions and weather conditions are also considered. A mission plan will also be prepared for each road segment. For unmanned flights, GPS and safety pilot modes will assist in keeping the UAV in the air and at designated way points. Additionally, these flights will only occur in uninhabited or sparsely inhabited areas. Manned aerial flights will only be operated along segments where a 500ft altitude can be maintained without danger to persons or property in case of an emergency landing, meeting standard FAA requirements. It is also important that manual ground truth surveys and aerial flights occur as closely to one another as possible. This will ensure that road conditions are similar between both collects. Ideally, both collects would happen on the same day.

3.10 Deliverable 7-B: Performance Evaluation of Recommended Remote Sensing Systems in Unpaved Road Type Condition Characterization

Available for download at:
http://geodjango.mtri.org/unpaved/media/doc/deliverable_Deliverable_7_B_PerformanceEvaluation_Final_2013-11-27_updated_1.pdf

The ultimate goals of this program were to design, build, and test a prototype remote sensing based unpaved road condition assessment system that is competitive with manual methods, and to incorporate these measurements into a decision support system (RoadSoft GIS) to aid in unpaved road network management. This goal was met and the integrated system has been named the Unsurfaced Road Condition Assessment System (URCAS). This deliverable begins by evaluating URCAS against the requirements set forth at the beginning of the project. For example, URCAS must be able to detect a 1 inch (2.5 cm) elevation change in a 9 ft (2.7m) distance for cross section measurements to be able to detect the presence of a sufficient crown. Next, the deliverable conducts a performance review of the URCAS system at each of the eight main unpaved road sites. Continuing, the performance review section describes the sensor system performance and software suite used to extract road distresses from aerial imagery. Lastly, the deliverable conducts a cost comparative analysis.

Requirements Review

Requirements for a successful unpaved road data collection were thoroughly specified in Deliverable 1-A and can be viewed in Table 3.1 (found in Deliverable 1-A review section). Additionally, Deliverable 2-A highlights the Unsurfaced Road Condition Index (URCI), which was the index used for the project's classification of distress systems due to its ability to integrate information on unpaved road distresses into management and cost information needed by road managers.

Performance Review

Sample data were collected at five sites (Monroe and Lenawee Counties) in 2012 and four sites (Livingston and Lenawee Counties) in 2013 (Figure 3-9). During these assessments, field crews conducted manual measurements of distresses, although not one location contained every type of distress of interest. Once a site was chosen, analysis had to occur within the next day or two in order to make sure the road conditions were relatively the same. In some instances, between site and data collection, road graders had passed over the road and eliminated any evidence of distress. Upon manual and UAV aerial data collection, the imagery was processed and reconstructed into a 3-D model (Figures 3-10, 3-11, and 3-12). It was determined that the analysis software was able to locate and categorize more road distresses than the ground crew, and therefore the ground truth data is better described as a spot-checking reference system.

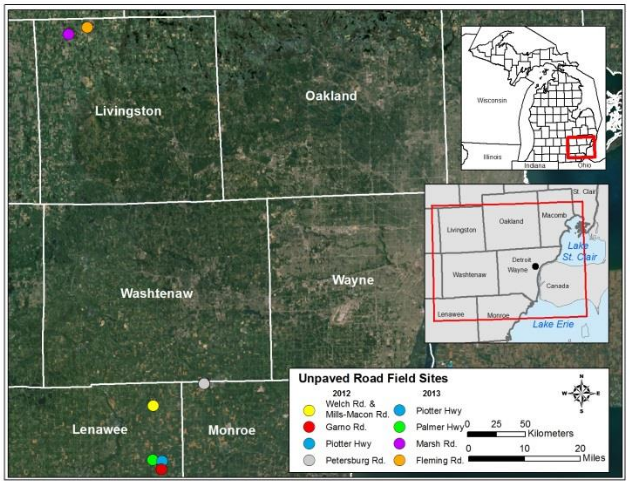


Figure 3-9: Locations of the eight sites where unpaved road imagery were collected in 2012-2013 for calculating road distresses and the Unsurfaced Road Condition Index.

Figure 3-10: Welch Road segments were marked, measured, and mapped prior to overflight.

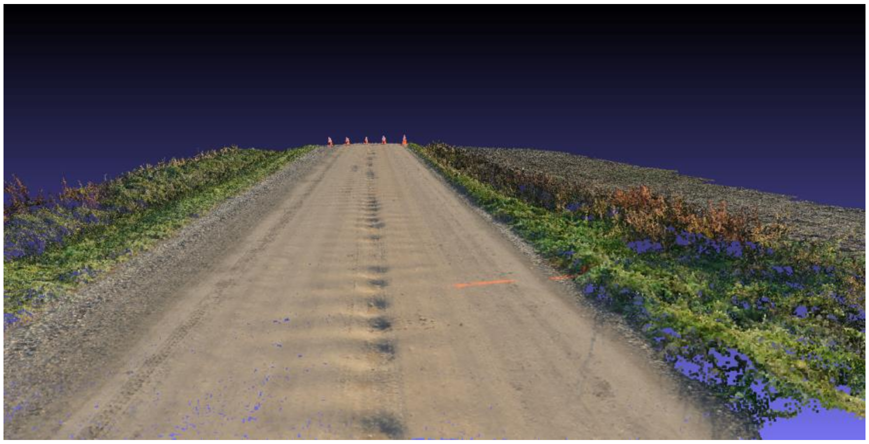


Figure 3-11: A 3-D point cloud generated through the project's structure-from-motion based remote sensing processing system software using overlapping UAV-collected imagery of Welch Road.

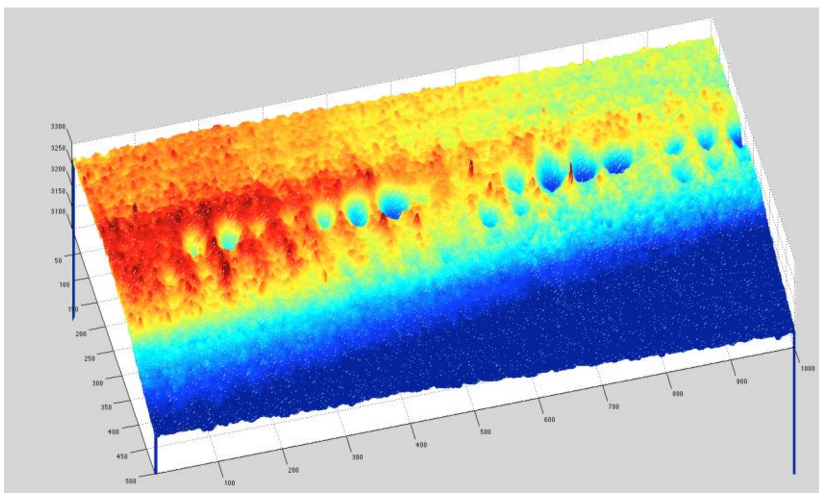


Figure 3-12: Part of the Welch Road segment displaying a height map where potholes and their depths can be seen.

Manned fixed aircraft data collections have the potential to collect overlapping aerial imagery of sufficient quality for extract distress information on unpaved roads (Figure 3-13). However, there were challenges acquiring imagery easily without a metric camera. Since the FAA requires the aircraft to stay 500 feet above ground level, in order to have the require amount of pixels needed to reconstruct a 3-D image of the road, the road would need to fill at least a quarter of a frame, but should theoretically best results would occur if it filled a third of the frame. Therefore, the photographer would have to keep as much as the road in the frame as possible. Additionally, the imagery should have sufficient angular diversity to enable complete imaging of distresses such as potholes at a variety of angles. This is difficult to achieve due to the relatively high speed and altitude of the aircraft. In the second year of testing, the camera was mounted to a modified aircraft door, with the idea of the camera remaining stationary and collecting imagery at nadir perspective. However, since the camera was not on a stabilizing device (gimbal), any change in the aircrafts pitch (nose up/down) or roll (wing up or down) would offset the camera. Lastly, the cost and aircraft / pilot availability is another factor, with costs of approximately $160 to $175 per hour based on discussions with local (Ann Arbor, MI) Cessna flight service companies.

Figure 3-13: A first pass at determining whether sufficiently high resolution data could be collected from a manned fixed wing aircraft.

For an optimal sensor system performance, imagery overlap must be carefully managed. One "rule-of-thumb" is that the same distress feature must appear in no less than five different images. Each image may be at different distances and orientations, but they must span several degrees of angular diversity. Data sampling using a manned aircraft allowed the project team to conclude that sensors above altitudes of 400 feet are not practical at this time and while using this type of reconstruction methods. A functional system that meets (or exceeds) all these requirements is a 36 megapixel sensor with a 50mm lens, firing at 2 frames-per-second, flying at an altitude of 25m at 2m/s forward speed. All of these parameters are achieved easily using readily available, inexpensive, commercial equipment. Such a system collects about 20GB of data per kilometer of road inspected.

Algorithm performance outputs were much different than what manual assessments were reporting. Though the output were not producing wrong values, it was determined that manual inspectors were missing distress features due to either oversight or they though that the distress was not sufficiently bad enough to report. Even though the algorithm is reporting every evident distress, which does not necessarily mean it is a good thing. Since the human raters tended to only report large damages, our automated outputs (which report everything), were routinely finding the roads less damaged than reported. This might lead one to believe the software was somehow defective. However, when a human, aided by the (very accurate) depth map, counts all the damages, we report more similar score to the algorithm outputs. Therefore, it was determined that our ground truth data is nothing of the sort. It is useful due to the fact that we can verify if a pothole is really as deep as the algorithm states, but when scoring an unpaved road, the ground measurements cannot be used to create a valid URCI score.

Each individual distress type was evaluated for its algorithm performance. The results for each category can be seen below.

Potholes

When measuring and classifying potholes, it is important to note that determining the extent of a pothole is highly subjective. This is due to the fact that potholes do not have uniform shape or slope and the beginning / end of a pothole is dependent on the human interpreter. In manual evaluations, a single point in the pothole is used for depth measurements. However in the algorithm, the entire pothole can be assessed. Table 3-7 compares manual detection of potholes to the potholes detected by the algorithm.

Table 3-7: Pothole detection comparison

Potholes	Detected Potholes	Potholes misidentified	Probability of Detection	Probability of False Alarm	Probability of Correct Classification
101	96	4	95%	4%	96%

Loss of Crown

Manual measurements of the crown were taken in 10 foot increments and heights at the edges and middle of the road to determine the difference. The width of the road was measured to determine the slope. 10 foot measurements were taken regardless of if the crown was visually better or worse and therefore variability went unmeasured. Table 3-8 compared the crown values.

Table 3-8: Comparison of crown values.

Damage Class	Manual Score (meters)	Algorithm Score (meters)
L	0	13.67
M	2.7	12
H	24.3	0

Ruts

Evaluation of algorithm performance for ruts was done by identifying ruts from the height map visually and then area and severity measured. The algorithm's detection of ruts was then compared against the manual score. Missed detections were often due to very short ruts. Similar to pothole, ruts have irregular shapes and size estimates must be visually classified. Additionally, depths were manually measured at one to two locations, whereas the algorithm is able to make measurements along the total rut. Table 3-9 is the probability of detection and false alarms for rut detection.

Table 3-9: Rut detection

Probability of Detection	Probability of False Alarm
67%	19%

Corrugations

Corrugations were measured similarly to rut distress. Since corrugations often occur along most of the road's length, manual measurements concerning severity and width were made at six arbitrarily selected points. The algorithm correctly identified all areas of corrugations. Since the algorithm measures corrugations at a fine detail, the manual measurement will be scored based on the worst damage present. Further corrugation classification needs further development. Table 3-10 shows the probability of detection and false alarms for corrugation detection.

Table 3-10: Corrugation detection

Probability of Detection	Probability of False Alarm
100%	38.5%

Loose Aggregate

There were no roads found with excessive loose aggregate. But the "loose aggregate finder" is just the rut algorithm, locating "inverted ruts". The performance should be comparable to the rut performance. This process is unable to differentiate a road surface completely covered in loose gravel from one without loose gravel.

Cost Performance Notes about Performance Evaluation

Caution must be made in comparing remote sensing and manual assessments of unpaved roads due to the scale of the output. For example, the remote sensing output is a centimeter-by-centimeter characterization of the entire unpaved road segment. However, manual assessments are more of an overview of road condition. Using a UAS to evaluate unpaved road conditions will cost $0.74 per mile, in addition to the cost to use a vehicle ($0.55 per mile). Using a manned fixed-wing aircraft would cost, under reasonably generous assumption, $10.26 per mile. However, the advantage to using a manned fixed-wing aircraft is a great reduction in time spent per mile, at an increase in cost.

The project team also developed a detailed description of the process of collecting and processing data, known as “Concept of Operations” (ConOps). ConOps includes instructions for selecting sites, developing flight plans, pre-flight checks, sensor setup, flight operations, data quality checks, and data selection. A more detailed description of each of these operation categories can be found in Appendix A – Deliverable 7-B.

Comparative Cost Analysis

Since data analysis is usually the single largest cost in an asset management program, effective management systems need a source of reliable, low cost data. This cost analysis is based on available information from several methods of unpaved road assessment and remote sensing data collection. Only methods that collect the URCI data are a direct comparison with the level of data that is produced by the remote sensing system.

For a manual URCI ground truth collection, the follow analysis was produced:

- Assessment moderate distress– 2 staff x $40/hr x 1.0hr + 1 staff x $40/hr x 0.5 hr = $100 per segment.
- Assessment high distress 2 staff x $40/hr x 1.5hr + 1 staff x $40/hr x 0.5 hr = $140 per segment.
- **Assuming a 2 sample segments per mile of road represented = $100 X 2 = $200 per mile of road represented for moderate distress**
- **Assuming a 2 sample segments per mile of road represented = $140 X 2 = $280 per mile of road represented for high distress**

For an unmanned aerial vehicle assessment of unpaved road conditions, the following analysis was produced:

- Cost per mile rated $30,590/yr/1575 mi/yr = $19.42/mi rated.
- However, two 100-foot measured segments represent one mile of road, so 5,280 ft/200ft is 26.4. Therefore each mile of measured road represents a road network 26 times larger.
- **Therefore cost is $0.74 per mile, in addition to the cost of vehicle use ($0.55/mi)**
- 8 hours/day, 3 days/week, 21 week season to collect 300 road-miles of data segments

For manned fixed-wing aerial vehicle assessment of unpaved road conditions, the following analysis was produced:

- Cost per mile rated $54.47 per mile assessed for up to five sites per mile.
- **$10.26 per mile (generous assumption of continuous data collection)**.
- $16,340 for same type of analysis as listed above.

4. Unpaved Road Inventory Algorithm

According to the Federal Highway Administration (FHWA), in 2008 there were 1,324,245 miles of unpaved road in the United States, accounting for almost 33% of the over 4 million miles of road in our national transportation infrastructure (FHWA and USDOT 2010). Local governments and transportation 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 allocation. 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; consequently they 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. The system described in this chapter provides the location of unpaved roads within a road network as a significant mission planning input.

Paved roads are characterized by either a bituminous, mixed bituminous, brick, block, composite, or cement concrete cover with a surface base with a thickness of at least 1 inch but typically 7 inches or more (FHWA 2004). In contrast, an unpaved road has no “hard” surfacing. Unpaved roads consist of a compacted aggregate or have no added surfacing. In this paper and in general use, the former are referred to as *gravel roads* and the latter as *unimproved roads*. It can be difficult to distinguish between a gravel road in poor condition and an unimproved road in the field. In general, at least 1.5 to 2 inches of gravel are necessary to be considered a gravel road; 6 to 10 inches is most desirable for areas of high traffic (Walker, Entine et al. 2002).

Unpaved road condition can change rapidly relative to paved roads, which may change little over several years. Likewise, unpaved road maintenance cycles are significantly shorter than those for paved roads. Rapid condition change and shorter maintenance cycles necessitates more frequent condition inspection for unpaved roads than paved roads. Developing the ability to assess the mileage and condition of unpaved roads on a comprehensive, repeatable and cost-effective manner is important to our project partners, the Road Commission for Oakland County (RCOC), the Southeast Michigan Council of Governments (SEMCOG), and the State of Michigan’s Transportation Asset Management Council (TAMC).

For the larger project, “Characterization of Unpaved Road Condition Through the Use of Remote Sensing”, it is necessary to reliably know the location of the unpaved roads to be evaluated. The location of unpaved roads within the larger transportation network is an important part of the project mission planning system. Before a flight, the roads to be evaluated must be identified and a flight plan that avoids obstacles (such as cell towers and power lines) must be established.

This project builds from methods developed to calculate the location and mileage length of unpaved roads as part of the TARUT study (Brooks et al. 2007, www.tarut.org). That study used visible-to-infrared ratios derived from 3-foot (1-m) multispectral aerial imagery and 2-foot (60-cm) Digital Globe Quickbird multispectral imagery to map road surface type, including unpaved roads. The TARUT project team was able to map road surface types with 86% accuracy; it was anticipated that using 4 band 1-foot per pixel imagery, it would be possible to increase classification accuracy to at least 90% with the goal of reaching 95%.

Figure 4.1 below is an example of 1-foot resolution imagery provided by our project partner SEMCOG where the differences between natural aggregate road (A), crushed limestone road (B), and a paved macadam road (C) are all visible. Four band (R, G, B, IR) aerial imagery should make these differences even more clear. The output from this road surface type analysis is a GIS layer that identifies unpaved road locations within the local road network.

Figure 4-1: 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.

It is important to know where unpaved roads are and how many miles there are in a road network, both for transportation asset management and mission planning requirements. Not all counties in the study area have an accurate inventory of their unpaved road location and length. Oakland County in southeastern Michigan estimates it has approximately 750 miles of unpaved roads, more than some counties in the Upper Peninsula of Michigan have in total road mileage (http://www.rcocweb.org/Commuters/Gravel_Roads.aspx). Figure 4-2 shows the project study area in southeastern Michigan. All counties in SEMCOG except Wayne County (which contains Detroit and few unpaved roads) were processed for this project.

Figure 4-2: Study area in southeastern Michigan for unpaved roads mapping for inventory and mission planning inputs.

4.1 Data Preprocessing

The classification effort followed the lead of Nobrega (2008) where a subset of an IKONOS scene was classified to find the road network in an area where no maps of the roads existed. Where Nobrega's work was limited to a relatively small area with the goal of mapping roads in the favelas of Sao Paolo, Brazil our study area included the unincorporated areas of six counties in southeastern Michigan, where the extent of the road network is already well known.

SEMCOG supplied the project team with four band (R, G, B, IR) 12-inch (30cm) per pixel resolution aerial imagery flown in spring (leaf-off) 2010. Each image had a 5000 by 5000 foot (1524m x 1524m) footprint. The 5000 x 5000 foot scenes were mosaicked into 10,000 x 10,000 foot (3048m x 3048m) tiles, which improved image processing speed significantly.

4.2 Road Centerlines

The better the road centerline in shapefiles align with roads visible in the imagery, the better the results of the classification. Correcting gross inaccuracies in the road centerline shapefile increases the accuracy of the results. Minor inaccuracies (less than 10 feet) do not have much of an effect on classification accuracy. For this study, the Michigan Framework Roads network (v11) for the counties in the study area was buffered by 30 feet (9.1 meters) to exclude features that were spectrally similar to roads but were not near road centerlines. The polygons that resulted from the buffering process were then dissolved into a single large county-wide road polygon feature. Buffering the road network not only significantly reduced image processing time it also allowed the team to exclude areas such as tilled farm fields, for instance, that were spectrally similar to roads but were away from any known road. The buffer around the road network allowed better tailoring of spectral signatures to the different road types found in the study area –

paved roads with concrete and asphalt surfaces and unpaved roads made of crushed limestone or natural aggregate - which improved the final classification.

4.3 Principal Component imagery

Three Principal Component images were created in ERDAS Imagine, a commercial image processing software tool. Principal component analysis (PCA) is based on an orthogonal transformation of the data to convert a set of data of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components (Joliffe 2002). The first principal component has the largest variance and accounts for as much of the variability as possible. Each succeeding component has the highest variance under the rule that it be orthogonal to (i.e., uncorrelated with) the preceding components. In this case, the principal component analysis was run on the 4-band aerial mosaic imagery and the first three principal components were chosen as the output.

4.4 Classification

The classification of a county road network into 'paved' and 'unpaved' classes is the goal of the image processing and classification. The heterogeneous nature of the landscape, the spectral similarity of unpaved roads to tilled fields (particularly in spring leaf-off imagery where there is not yet significant crop cover) and the frequent presence of tree canopy over the roads to be evaluated offer significant challenges to classification process accuracy.

The four band imagery and Principal Component layers are loaded into Trimble eCognition (version 8), along with the buffered roads layer. The area within the road buffer in each tile is then segmented into spectrally similar image objects. These objects were separated into five classes – Unpaved Roads, Paved Roads, Shadow, Bare Earth and Vegetation – using a rule set that takes the spectral characteristics of each image object into account.

4.5 Classification of Unpaved Roads

Image classification is a multi-step process that uses several eCognition routines. Chessboard segmentation was used to create an area that would contain a road (the Framework road centerline layer) (see Figure 4.3). Quadtree segmentation was run on the area of the potential roads which segments 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 is then run to combine spectrally similar areas into objects. Spectral difference segmentation is run that merges objects according to a user defined mean layer intensity value.

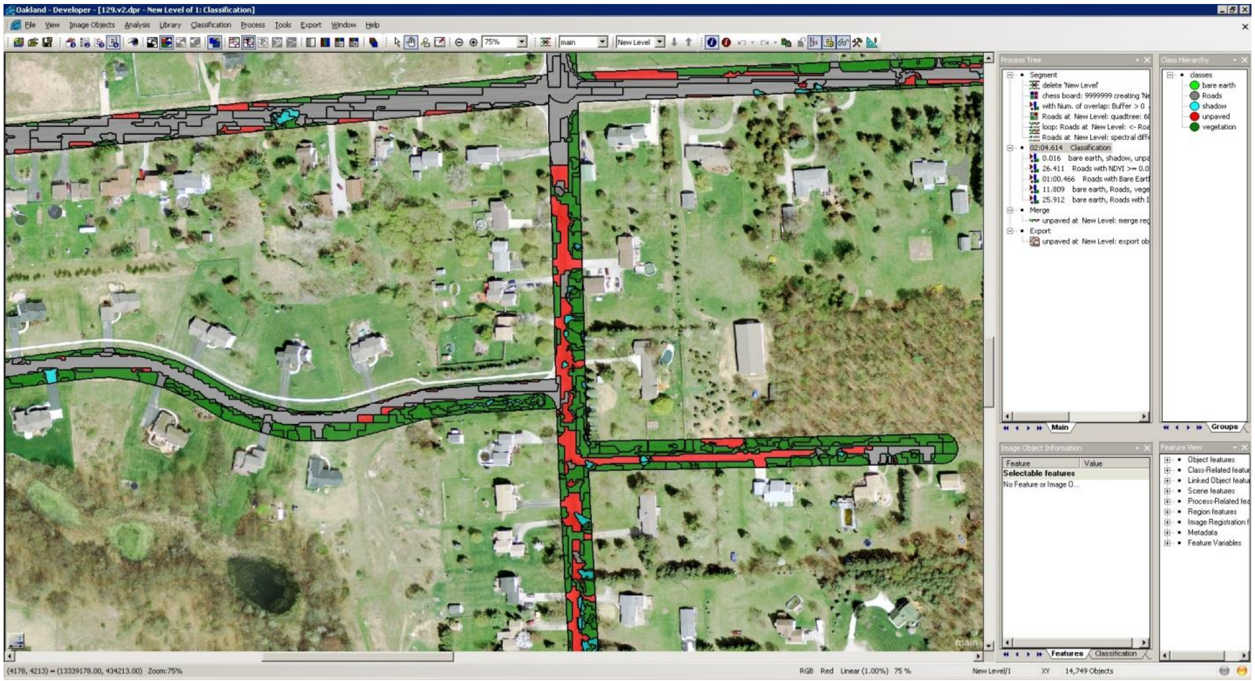


Figure 4-3: A small part of a four-band aerial image from Oakland County MI loaded into eCognition with rule sets for segmentation and classification at the right.
Segments that are gray have been classified as paved, green segments are classified as vegetation, cyan segments are classified as shadow and red segments are classified as unpaved.

The objects that result are run through a classification routine which assigns one of the five classes (unpaved road, paved road, shadow, bare earth or vegetation) to each object. An eCognition rule set classifies the resulting objects from the segmentation portion of the algorithm. This classification process uses a decision tree classifier, where a binary decision is made based upon the data within each object. The first step in the classification algorithm is to determine whether the object is vegetation by calculating the normalized difference vegetation index (NDVI) for the object. If the calculated NDVI value is greater than 0.065, it is classified as vegetation. If the polygon is not classified as vegetation it is passed on to the next step in the algorithm. This process is repeated for bare earth (the value must be greater than 0.8) and shadow classes. The process finally ends with the unpaved class.

The classification procedures for determining object classification as bare earth and shadow builds from the work of Nobrega et al. (2008) and require the use of the principal component analysis to make their determinations, as described above. Initial analysis 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. This relationship 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. An ROC curve is commonly used in signal detection (Hand 2001); however, its methods can be applied here when selecting particular values for algorithm components, such as the IR-Green value.

The ROC curve was calculated on the IR-Green parameter to find the optimal threshold for unpaved road detection. The ROC curve displays the fraction of true positives (TP) out of all positive results (ρ_d) plotted against the fraction of false positives (FP) out of all negative results (ρ_{fa}) for any IR-Green value. Plotting an ROC curve enables users to find the best value for the IR-Green parameter by selecting a value that maximizes the number of true positives (ρ_d) while minimizing false positives (ρ_{fa}). ROC curve analysis revealed that an IR-Green value of 6 (arrow) with a ρ_d of .88 and a ρ_{fa} of 0.13 returns the best results, although IR-Green values of between 0 and 6 will yield similar results (see Figure 4-4).

$$\rho_d = \frac{TP}{TP+FN}, \text{ Probability of True Postive}$$

$$\rho_{fa} = \frac{FP}{FP+TN}, \text{ Probability of False Positive, where;}$$

TP = Road pixel detected as road
FN= Road pixel detected as not road
FP = Not road pixel detected as road
TN= Not road pixel detected as not road

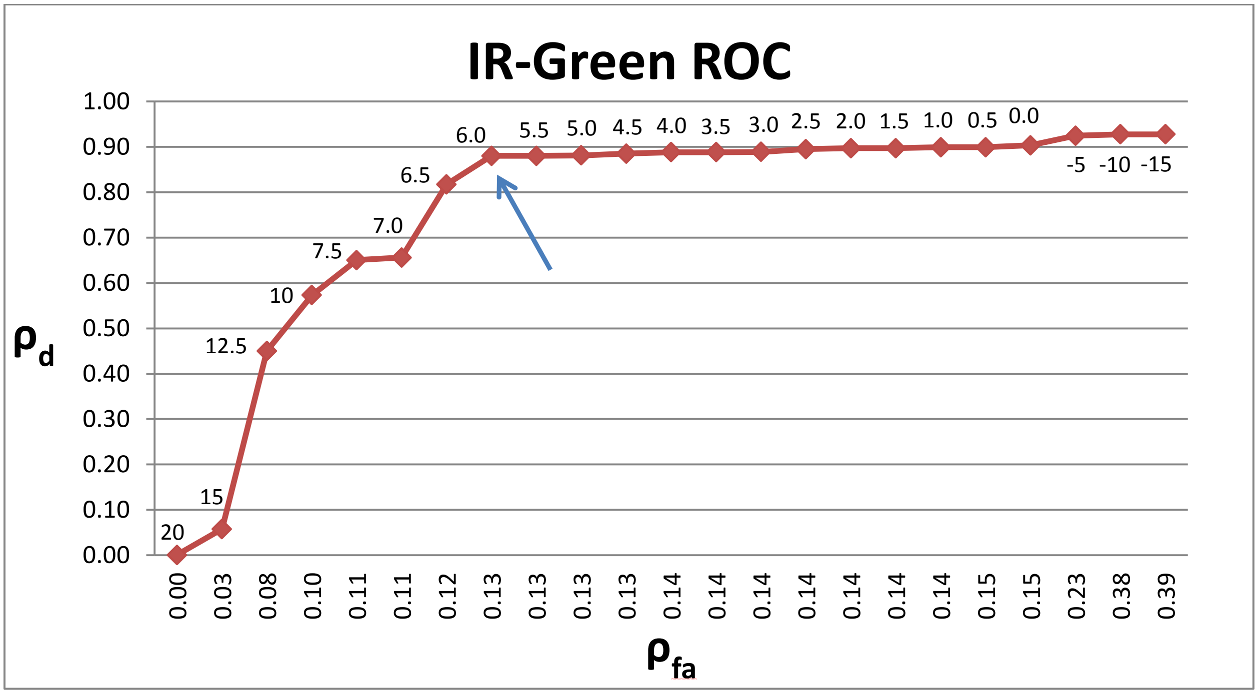


Figure 4-4: Receiver Operating Characteristic curve plot for the IR-Green parameter. Points on the curve are labeled with their corresponding IR-Green value.

4.6 Identifying unpaved roads in the Michigan Framework Roads Network using ArcGIS

Once unpaved roads are identified in eCognition, polygons classified as unpaved in eCognition are imported into ESRI ArcGIS as standard ESRI shapefiles. The shapefile output from the eCognition classification process form the basis of identifying unpaved roads in the road network. The shapefiles that represent unpaved road segments are imported into ArcGIS and intersected with the overall county road network, creating a shapefile that contains the linear segments of the road network that are considered to be unpaved. Each road segment in this shapefile was compared to the overall length of the original segment; if more than a particular percentage of the segment was classified as unpaved, then the entire segment is classified as unpaved.

4.7 Results and Discussion

This project evaluated imagery from six counties in Southeast Michigan – Monroe, Washtenaw, Livingston, Oakland Macomb and St Clair. Topography and land use ranges from flat, open, rural agricultural in southern Monroe County to a densely populated, forested glacial till plain with a significant number of kettle lakes in parts of Oakland and Macomb Counties. The varied landscape within the study area affected the accuracy of the image processing results. The number of road centerline miles each county road commission is responsible to maintain varies significantly – from 1742 miles in Monroe County to 3642 miles in Oakland County. The 'coverage' value used to determine whether a road is paved or unpaved varies from county to county as a result of the varied topography and land use. In Michigan, roads within incorporated areas are not the responsibility of the county road commissions and were excluded from the analysis.

The varying topography and land cover analysis of Monroe county data yielded an initial value of 25 percent coverage as returning an unpaved road value closest to SEMCOG's Pavement Surface Evaluation and Rating (PASER) data for the locations where status of paved vs. unpaved was recorded in their PASER surveys (see Figure 4-5 below). Additionally, a traditional error matrix based on field verification of part of Monroe County gave additional information, where the Producer's Accuracy for unpaved roads was 95%. Monroe County PASER data report 391 miles of unpaved roads out of a total road network length of 1974 miles. When road segments with at least 25% coverage as unpaved (based on the segmentation and classification analysis) were defined as unpaved, the MTRI algorithms found 397.4 miles of unpaved roads in Monroe County (Figure 4-6). This resulted in approximately 98% agreement between PASER data and using the 25% coverage rule for calling a Framework road segment as unpaved.

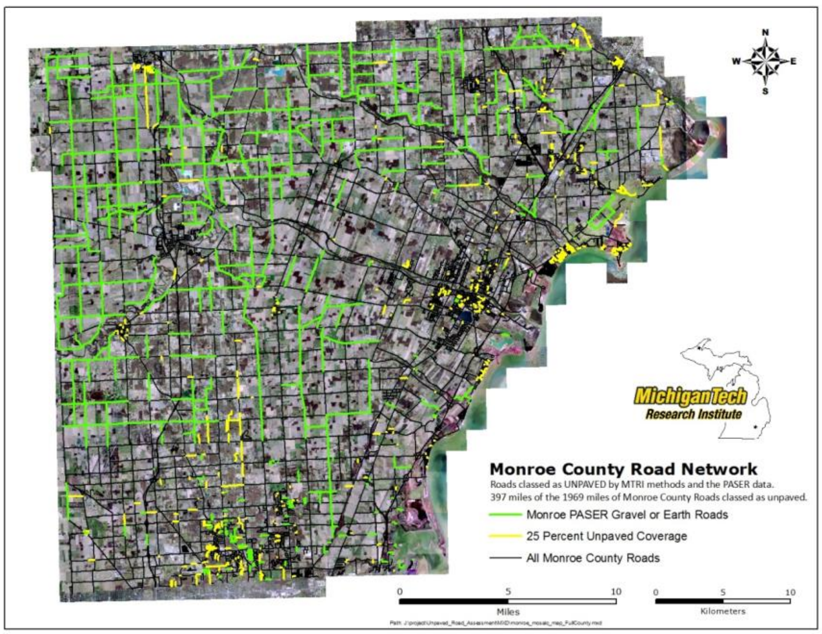


Figure 4-5: PASER data (green) over the MTRI 25 percent unpaved coverage (yellow) data.
The PASER dataset for Monroe County contains 1656.2 miles of the 1969 miles of roads in the Monroe County Framework Roads data layer. Of the 1656 miles in the PASER dataset, 391 are classified as unpaved. The 25 Percent Unpaved Coverage layer classified 397 miles of the road network as unpaved.

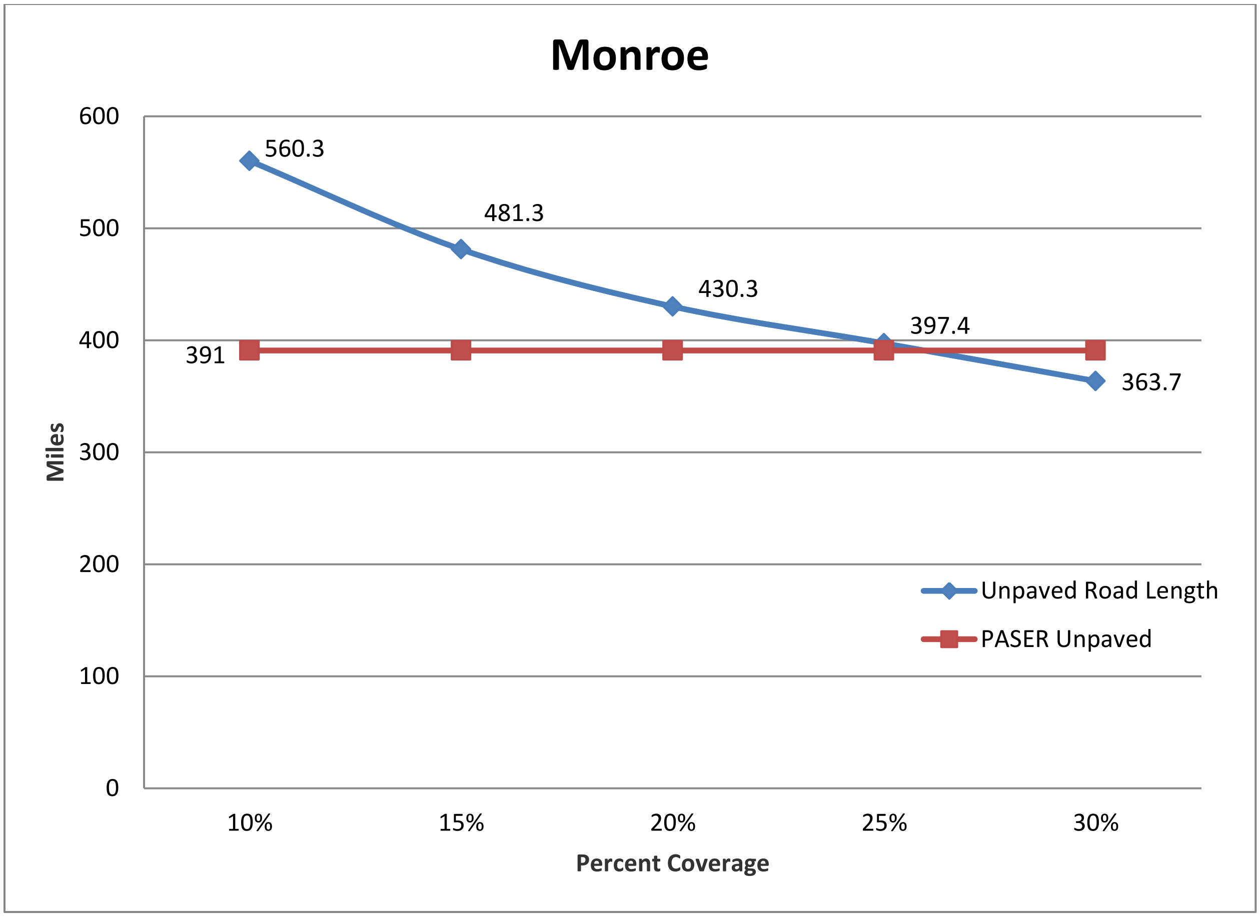


Figure 4-6: Agreement between PASER data and the "percent coverage" needed to label a Framework road segment as unpaved for Monroe County.

When the PASER data were superimposed over unpaved road classification results, it appeared that most errors of commission (the algorithm classified roads as unpaved when the PASER data did not) occurred most frequently where the road segments were relatively short and in residential areas. A review of classification results for roads that were classified as unpaved but are actually paved show that the IR-Green values are just above the cutoff of 6 that is used to classify a road as unpaved. Typically, paved roads have mean IR-Green values that are negative or slightly positive. Occasionally, paved roads in developed areas will be classified as unpaved as a result of IR-Green values in excess of the threshold of 6. Errors of omission (the algorithm classified roads as paved and the PASER data did not) occurred most frequently as a result of road centerline misalignment or unpaved roads where the IR-Green value was negative, which is more typical of a paved road. The phenomenon of an unpaved road having a strong spectral resemblance to a paved road may be a result of local road commissions using crushed limestone, a major component of both concrete and macadam pavement, for the road.

The shared Oakland County PASER data was not as complete as Monroe County data and could not be used directly as a complete ground reference data set. The Michigan Framework Roads layer for Oakland County shows a total of 7662 miles of roads, although not all are the responsibility of the RCOC. The Road Commission for Oakland County states “More than 750 of the 2,700-plus miles of the Road Commission for Oakland County's (RCOC) county roads are not paved…” (RCOC, 2013).

MTRI processing found 832 miles of unpaved roads in the Oakland County road network using the 25% criteria, the same methodology as applied to the Monroe County road network (Figure 4-7). When compared to the ~750 miles of unpaved roads that have been quoted by Oakland County, MTRI found approximately 82 miles more unpaved roads than the RCOC estimate. Like the numbers for Monroe County, these numbers are preliminary and subject to further revision, but the comparability is promising at this stage.

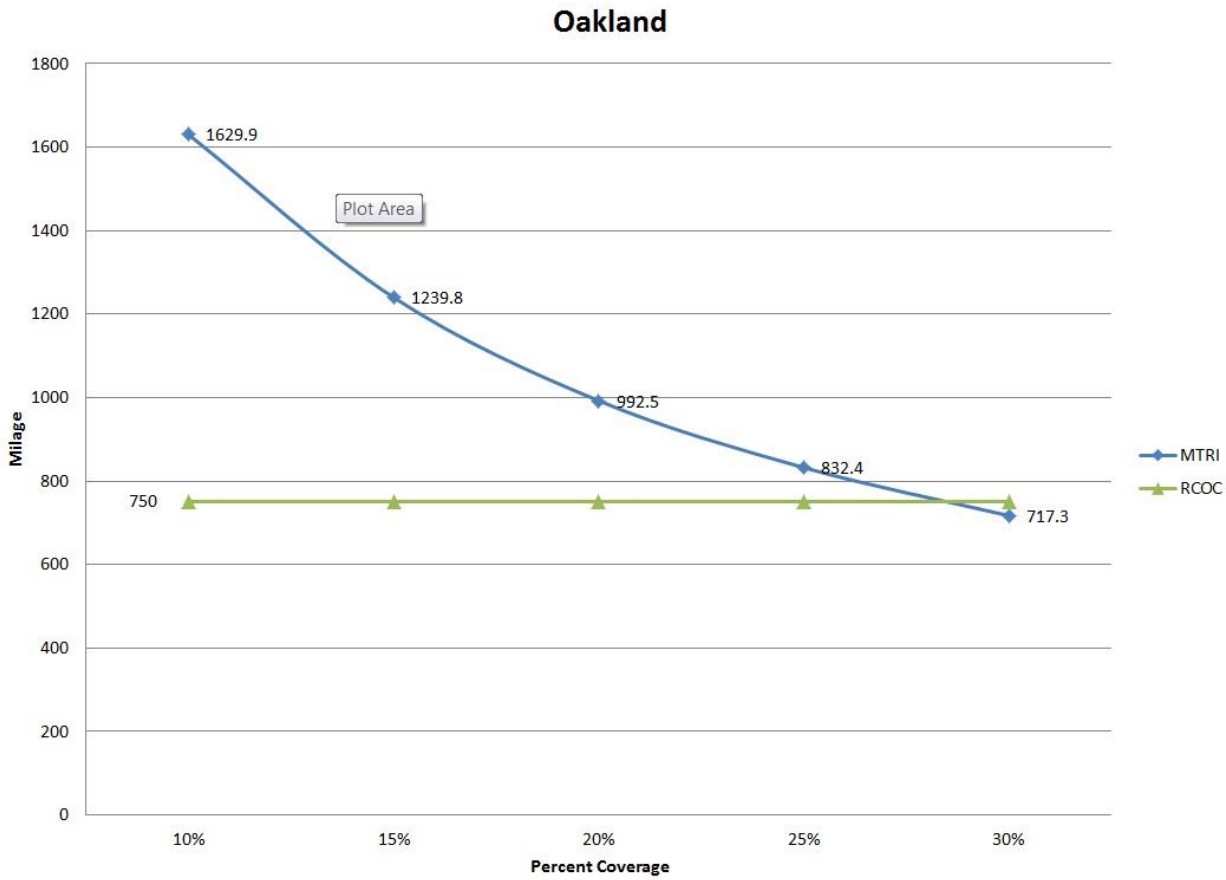
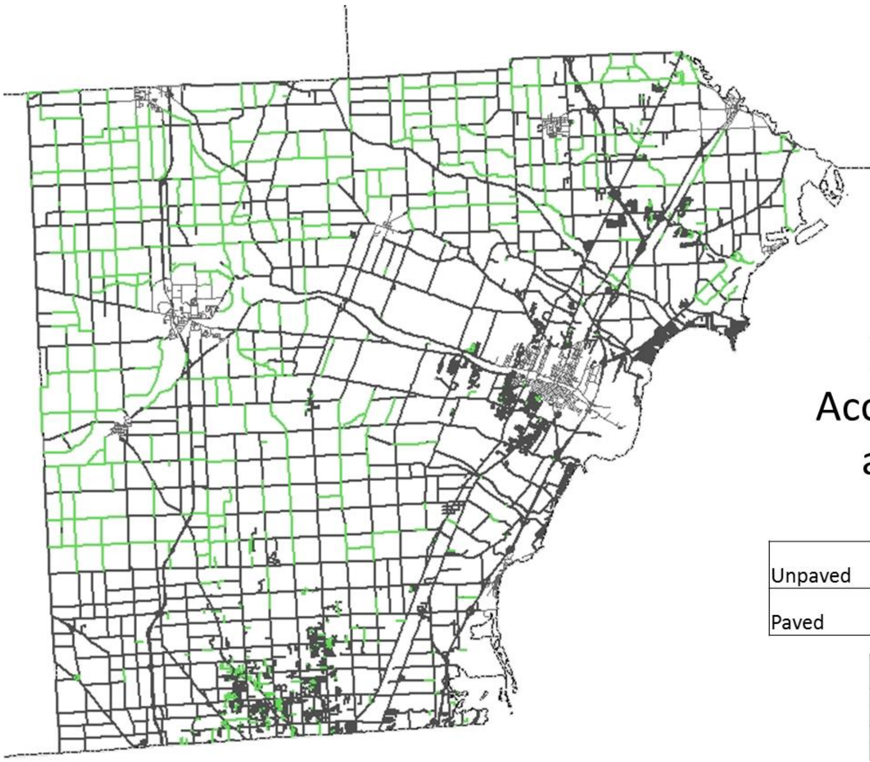


Figure 4-7: Agreement between PASER data and the "percent coverage" needed to label a Framework road segment as unpaved for Oakland County.

The PASER data sets for Macomb, St. Clair, Livingston and Washtenaw were not as complete as the data from Monroe County and Oakland County making it difficult to use PASER data to assess classification accuracy. Traditional error matrices for each county were calculated as part of the accuracy assessment process. Maps of the location of the unpaved roads were also generated. Error matrices were calculated for different coverage values (every 5 % from 10% to 30%) and generally, the coverage value that had the best overall accuracy was chosen to represent the roads in that particular county (Figures 4-8 to 4-13 below). Coverage values varied from one county to the next as a result of 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. Counties such as Oakland (Figure 4-9) and Macomb (Figure 4-10) have significant developed areas with a dense road network outside of incorporated areas, which were excluded from processing. The high density of the road network in large parts of these counties along with tree cover and rolling topography make accurately identifying unpaved roads more challenging. Washtenaw County (Figure 4-13) has a dense urban area (Ann Arbor) in the eastern part of the county with more wooded rural areas surrounding the city. A significant proportion of the roads outside the Ann Arbor area are unpaved. Monroe County (Figure 4-10) is predominantly open agricultural land with some development near Toledo, Ohio in the south and along the Lake Erie shoreline to the east. St. Clair County (Figure 4-12) is a predominantly rural county at the southern end of Lake Huron. Unlike Washtenaw County, the proportion of unpaved roads outside of incorporated areas is relatively low. Livingston County (Figure 4-11) is a predominantly rural agricultural county that is more rolling wooded topography in the southern and eastern parts of the county and more open agricultural in the northwest. Each of the counties has unique geographic characteristics that can confuse classifiers and affect the accuracy of road classifications.

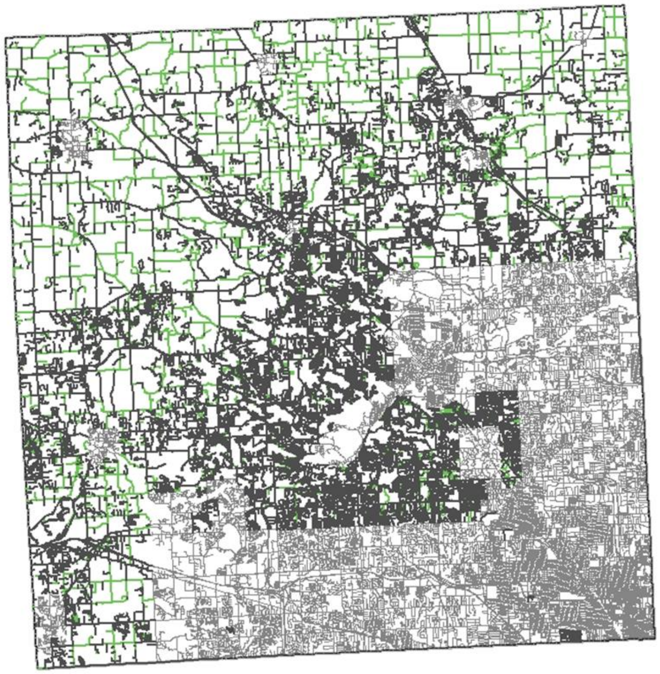


Monroe County
Accuracy Assessment
at 30% coverage

	Users	Producers	Overall
Unpaved	93.9%	77.5%	94.3%
Paved	94.3%	98.7%	

	Mileage
Paved	1390.0
Unpaved	351.9
Total Mileage	1741.9

Figure 4-8: Map of unpaved roads (represented in green) found in the Monroe County MI road network and its accuracy assessment.

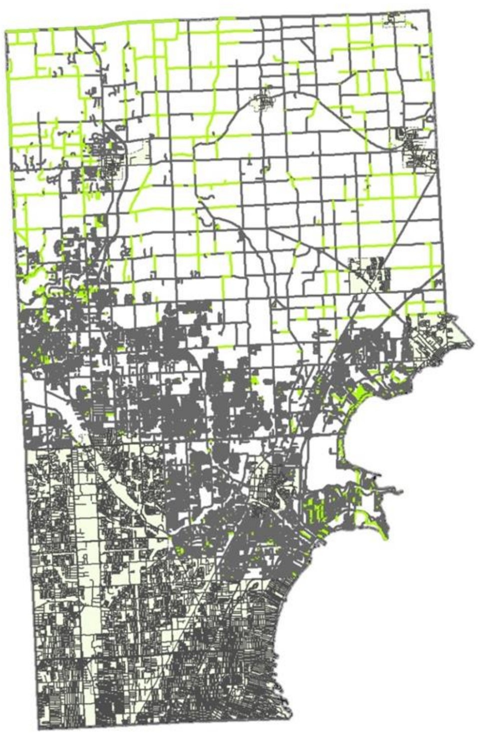


Oakland County
Accuracy Assessment
at 25% coverage

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

	Mileage
Paved	2948.2
Unpaved	693.9
Total Mileage	3642.1

Figure 4-9: Map of unpaved roads (represented in green) found in the Oakland County MI road network and its accuracy assessment.

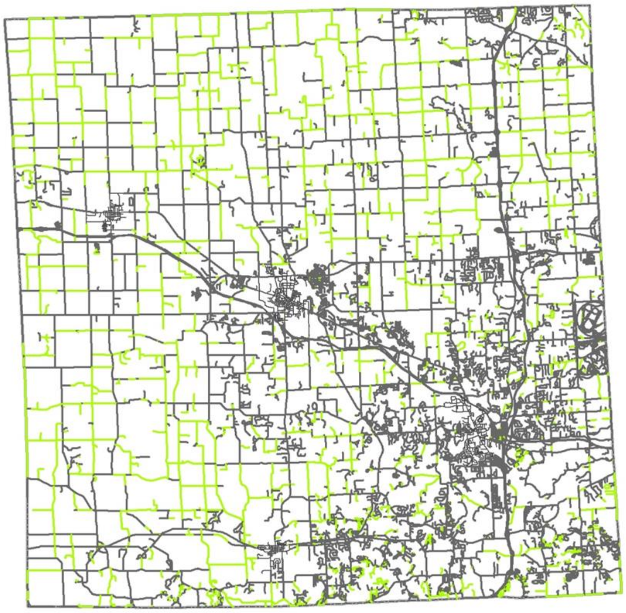


Macomb County
Accuracy Assessment
20% coverage

	Users	Producers	Overall
Unpaved	71.8%	60.9%	94.3%
Paved	96.2%	97.6%	

	Mileage
Paved	1847.0
Unpaved	319.4
Total Mileage	2166.4

Figure 4-10: Map of unpaved roads (represented in green) found in the Macomb County MI road network and its accuracy assessment.

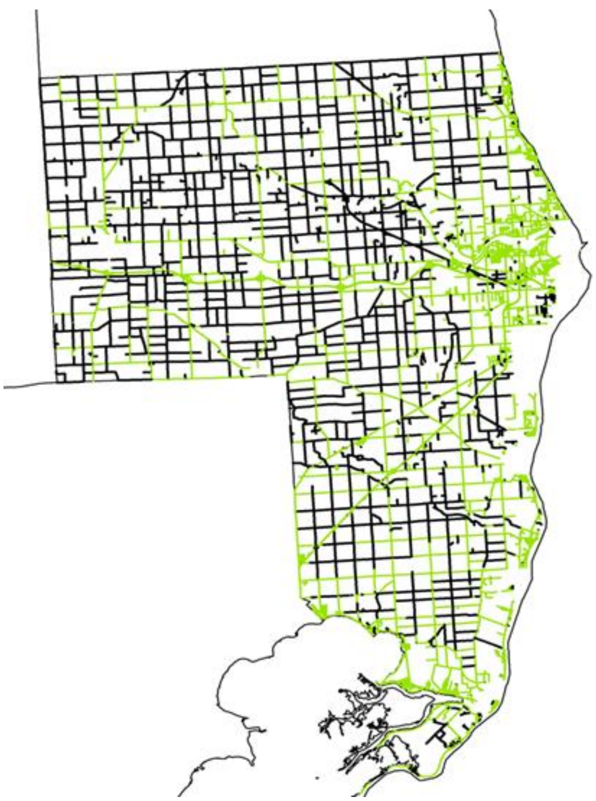


Livingston County
Accuracy Assessment
25% coverage

	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 4-11: Map of unpaved roads (represented in green) in the Livingston County MI road network and its accuracy assessment.

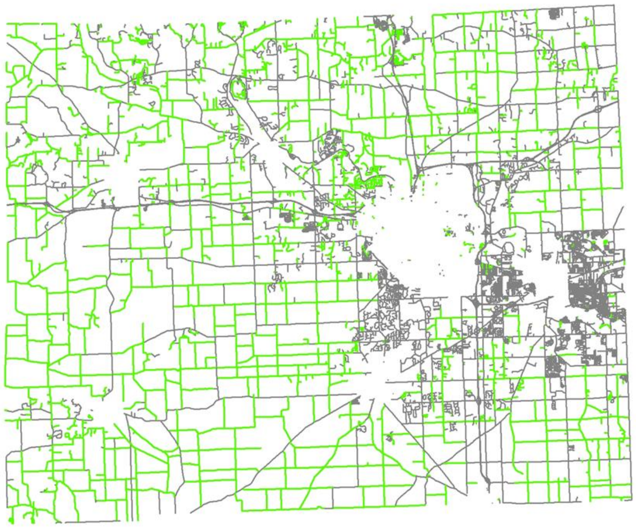


St Clair County
Accuracy Assessment
15% coverage

	Users	Producers	Overall
Unpaved	0.853	0.696	0.825974
Paved	0.813	0.916	

	Mileage
Paved	1222.41
Unpaved	737.42
	1959.83

Figure 4-12: Map of unpaved roads (represented in green) in the St. Clair County MI road network and its accuracy assessment.



Washtenaw County
Accuracy Assessment
20% coverage

	Users	Producers	Overall
Unpaved	0.793	0.773	87.1%
Paved	0.903	0.913	

	Mileage
Paved	1434.91
Unpaved	904.89
	2339.80

Figure 4-13 Map of unpaved roads (represented in green) in the St. Clair County MI road network and its accuracy assessment.

Processing challenges have generally been the variable road network centerline accuracy when displayed over the high resolution aerial imagery. Some road centerlines align very closely to their associated feature in the four band high resolution aerial imagery while other road segments within the same roads dataset do not align well. This may be a function of scale of which the roads are digitized. Centerline accuracy issues were found in all of the counties in the study area.

Another challenge encountered has been 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 misclassification in both directions. The spectral similarity between bare soil and natural aggregate (such as locally sourced river sand and gravel) is another potential source of misclassification. 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.

A significant challenge has been the presence of shadows from trees which obscure the road making it difficult classify a road that passes under the canopy. This is a known issue for remote sensing processes where forest cover limits surface visibility. The project team used the "percent coverage" rule to address this problem, whereby only a certain percentage of a road segment needed to be called unpaved for the entire segment to be labeled as such.

The results of the classifications have been used as mission planning input for the project field data collection campaigns of assessing unpaved road condition from an Unmanned Aerial Vehicle and manned fixed-wing aircraft campaign (Roussi and Brooks 2012). This fits into the larger "Characterization of Unpaved Road Conditions through the Use of Remote Sensing" project that needs to know where the unpaved roads are located before data collection missions will be flown. The unpaved vs. paved mapping results have been shared with SEMCOG and the Transportation Asset Management Council of Michigan as part of project outreach efforts. Note that these methods became the basis of the Brooks et al. 2013 ASPRS Conference paper.

5. Software, Algorithms, Platforms, and Sensors Developed and Applied for Analysis of Unpaved Road Condition Imagery

The requirement that 3-dimensional (3D) information be derived from an inexpensive platform limits the possible number of algorithms. Among the most effective, given the parameters of this project, is so-called “structure from motion”. This refers to the process of estimating a 3D structure from a series of 2-D images of the scene. This is done by locating points in an image that have characteristics invariant between images (for example, contrast edges). One detects these features in a series of images, then finds a correspondence between images, locating the same features. Given that the scene is stationary, one can find the time-trajectory of a set of features, and derive both the camera geometry and the scene’s 3D structure.

5.1 Bundler

Rather than write such a system “from scratch”, a number of commercial off-the-shelf (COTS) tools were evaluated.

Bundler is one such structure-from-motion (SFM) system. It takes unordered image sets, image features, and image matches as input, and produces a 3D reconstruction of the camera and (sparse) scene geometry as output. The system, described in [1] and [2], reconstructs the scene incrementally (several images at a time), using a modified version of the Sparse Bundle Adjustment package of Lourakis and Argyros [3] as the optimization method.

The images come from the airborne collection system. The image features come from running an algorithm (Scale-invariant Feature Transform, or SIFT) on each image.

The SIFT algorithm used is a variant of one published in 1999. The method transforms an image into a collection of feature vectors, each vector representing a local image feature. Each vector is invariant to image translation, rotation, and scaling. They are partially invariant to illumination changes, and insensitive to local geometric distortion. Features (called “keys”) with low contrast are rejected, keeping only the ones that are likely to be preserved across images. Indexing consists of storing SIFT keys and identifying matching keys from other images. Each of the SIFT key points specifies a 2D location in the image, the scale, and orientation. When matched in the database of keypoints, it will have a record of its parameters relative to the image in which it was found. These are then used to find the camera positions and initial 3-D scene estimate.

The resulting (sparse) 3-D reconstruction is not sufficiently detailed to meet the spatial resolution requirements of the project. A refinement step is needed to “fill in” the point cloud.

5.2 Patch-Based Multi-view Stereo (PMVS)

PMVS is a multi-view stereo software that takes a set of images and camera parameters, then reconstructs 3D structure of an object or a scene visible in the images [5]. Only rigid structure is reconstructed. In other words, the software automatically ignores non-rigid objects such as pedestrians or moving vehicles. The software outputs a set of oriented points instead of a polygonal (or mesh) model, where both the 3D coordinates and the surface normals are estimated at each oriented point.

This software takes the output of a structure-from-motion (SfM) software as input, then decomposes the input images into a set of image clusters of manageable size. It is possible to process each cluster independently and in parallel, with the union of reconstructions from all the clusters containing the information (as if it were computed all together).

This yields a dense 3D point cloud, from which all further data extraction proceeds.

5.3 Algorithm Flow

Once a set of images has been collected, they are processed to extract a fully 3-dimensional representation of the scene. The end-to-end processing is depicted below.

The objects in the scene form a point-cloud from which a surface is formed. This surface is manipulated into a standard orientation, distresses are measured, and the results are formatted in XML for output (and later use by the decision support system). The process by which the point-cloud itself is formed is depicted Figure 5-1.

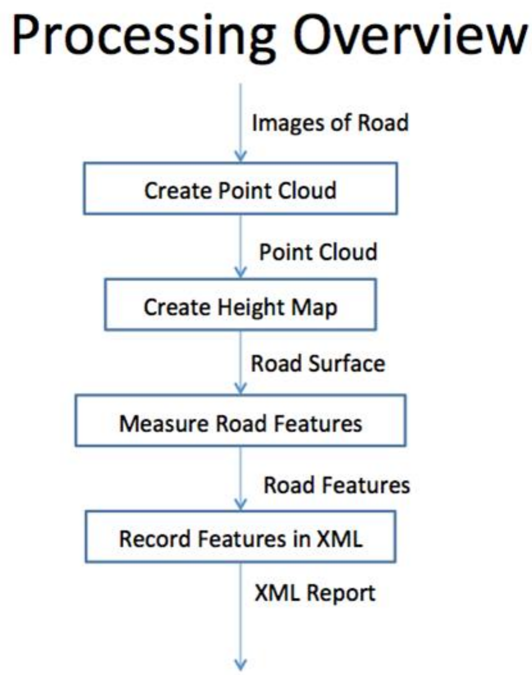


Figure 5-1: The methodology used to create a point-cloud.

First, locations containing image features, called "key points", are found in all images. These are usually places where contrast edges intersect. They are characterized by a scale-invariant feature vector. By matching key points between two images, features that are the same in both images can be found, even in the presence of scale and orientation changes. Finding the same feature in more than two images increases the confidence that the same point in space has been located. These matches are then used, assuming that the scene is rigid, to find the camera location in 3 dimensions, and the projection that was needed to take those 3D points into the 2D recorded image. This allows the key points to be placed in their true 3D locations. Once the point cloud has been filled in ("densified"), a height-map is created (Figure 5-2).

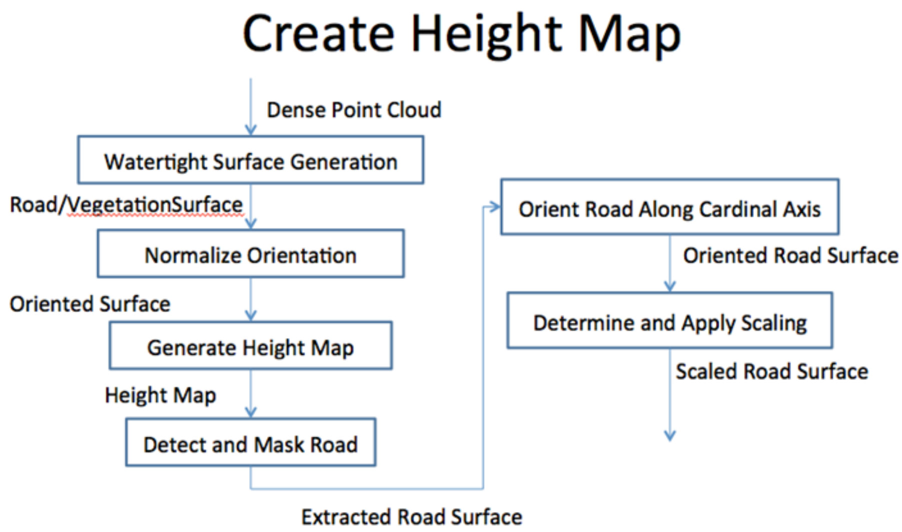


Figure 5-2: The methodology used to create a height map.

First, a Poisson surface-fit is made, creating a so-called "watertight" surface (containing no holes). This surface is presumed to be largely flat (it is a road, after all), and is manipulated into a standard orientation where the height variations are in the z-direction. The road surface itself is segmented from the rest of the scene based upon the image entropy (the road is, for the most part, much smoother than the rest of the natural scene). This segmented road is oriented with the along-track direction aligned along the y-axis.

The data are now in a form from which a variety of distress measurements can be made, as depicted in Figure 5-3.

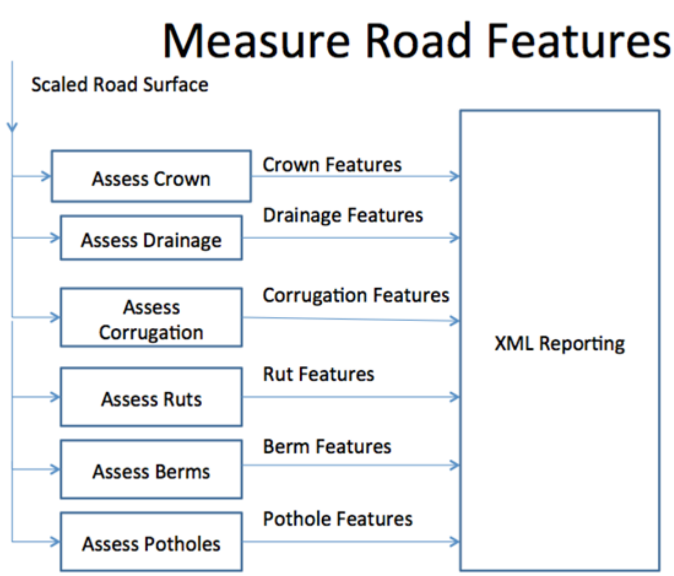


Figure 5-3: The methodology used to measure road features or distresses.

The scaled road surface is fed, in parallel, to a number of distress measurement routines. Each distress has unique characteristics, and algorithms were chosen to extract those characteristics. For example, potholes are circular (or elliptical) in nature, and the Hough Circle Transform algorithm is well-suited to find and measure circle-like features in an image. Other distresses, such as ruts and corrugations, manifest themselves as periodic lines at known orientations. For these, Gabor Filtering is an appropriate way to characterize them.

5.4 Camera Configuration

Although a Nikon D800 was used during development and testing, any camera with the following characteristics will work:

1. 16 megapixels+
2. 50mm prime lens
3. able to be triggered at 2fps+
4. adjustable ISO, aperture, and shutter speeds

The primary requirement on the images (in order to achieve good 3D extraction) is that they be clear. The most likely reason for poor image quality is motion-blur, so the camera needs to be set in such a way to limit this. We recommend this process for camera adjustment:

1. set the aperture at least 2-stops below full-open. this limits vignetting, and increases depth-of-field
2. set the shutter speed to 1/250s or faster. Faster settings are needed if the wind is gusting, or you plan on flying faster than 2m/s.
3. adjust the ISO to achieve a good exposure of the road from ground level. It is better to be slightly underexposed than overexposed.

5.5 Mission Setup

This process assumes the use of a DJI Wookong-M autopilot with a 2.4GHz wireless data link module, as used on the project’s hexacopter platform.

1. Choose a measurement site, making sure that there are no obstructions, and that the flight-path does not take the aircraft over people or property.
2. Ensure that there is a clear path to the launch-point from every point along the flight-path, in case the aircraft enters “failsafe mode”, and returns to the launch-point.
3. Make sure that there is clear line-of-sight to the aircraft at all times, in case the pilot-in-command needs to resume manual flight.
4. Configure the camera as in the section above
5. Prepare the aircraft through pre-flight
6. Bring up the Ground Station app on the iPad, to monitor speed, battery condition, etc.
7. Pre-flight check the aircraft
8. Start the camera controller, verifying the lens-cap is removed, and GPS is turned on.
9. Collect the data.

6. Integration of Analyzed Results with RoadSoft GIS

6.1 Decision Support System Background

A roadway decision support system (DSS) uses a wide variety of data sources (asset inventory data, condition data, and project history data) to produce intelligence that is used to produce management guidance that promotes a desired outcome. The intelligence produced by a DSS allows users to make informed asset management decisions quickly and see the impacts of these decisions on the long-term health of their road network and can reliably store the large quantities of data.

The DSS used for this project is a commercially available product called Roadsoft®. Roadsoft® uses a geographic information system (GIS) interface to spatially locate and display data related to transportation assets (Colling et al. 2012). For more information on Roadsoft® go to www.roadsoft.org

6.2 Remote Sensing Data for Unpaved Road Management

The remote sensing system developed for this project provides several pieces of critical data necessary for effective management of an unpaved road system. These data include:

- Spatial location information for all data
- Identification of unpaved road surfaces in the road network (surface inventory)
- Unpaved road width
- Unpaved road condition data using the Unsurfaced Road Condition Index (URCI) distress measurements.

The unpaved road condition data for the DSS can be collected as frequently as four or five successive flights per year, or as infrequent as once every year, depending on specific user needs and budgets. Data collection that is more frequent allows for more active management of routine maintenance issues, while infrequent collection on a yearly basis provides data for an overall network level measure of road quality.

Data from remote sensing collection sorties are delivered to the DSS using a XML data transfer protocol. This protocol allows the remote sensing system to be compatible with other decision support systems. Appendix E provides sample XML field descriptions that is sent to the DSS from the remote sensing processing system (RSPS). Appendix F provides actual XML data output from a field collection in Livingston County, Michigan.

6.3 Surface Type Inventory Data

Unpaved road surfaces that are identified by the remote sensing system are spatially related to road map segments in the Roadsoft® database. This updated inventory information is recorded in the Roadsoft® database. Once stored in the database inventory information can be graphically displayed to show the extent of the unpaved road system on a map, or can be used to generate an inventory report of unpaved roads. Understanding the extent and location on the unpaved roads in a road network is the first step toward data driven management. Inventory data is also the first step in developing a collection plan for distress data. Figure 6-1 below illustrates an unpaved road network collected by the remote sensing system.

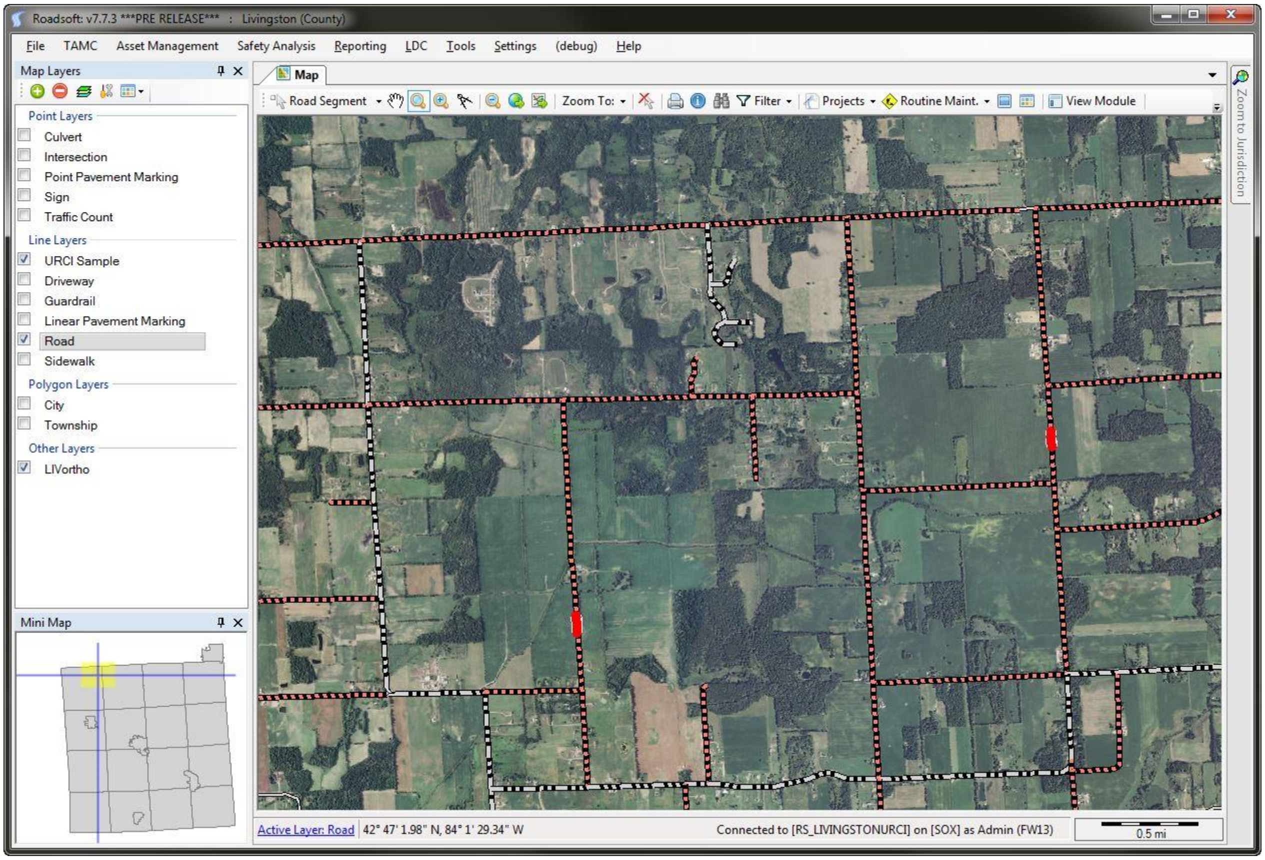


Figure 6-1: Unpaved road network for Livingston County.
Unpaved roads are denoted with a red highlight.

6.4 Distress Data

Unpaved road distress data from field collection sorties are spatially related to a specific road segment in the Roadsoft® database correlating to the location where the data was collected. The URCI uses a sampling method to related data collection locations to represent a larger network of roads. According to the URCI method, each 100 to 200 foot sampling location can represent up to 0.5 miles of road with similar characteristics. *Technical Manual No. 5-626: Unsurfaced Road Maintenance Management* (Department of the Army 1995) describes the process of representing a road network by samples.

Roadsoft® allows the user to assign specific sampling locations to represent a larger road segment. Figure 6-2 illustrates how a sampling location (shown with the red highlighted segment) from Fleming Road located in Livingston County Road Commission can be assigned to represent a larger road network (shown by the yellow highlighted road segments).

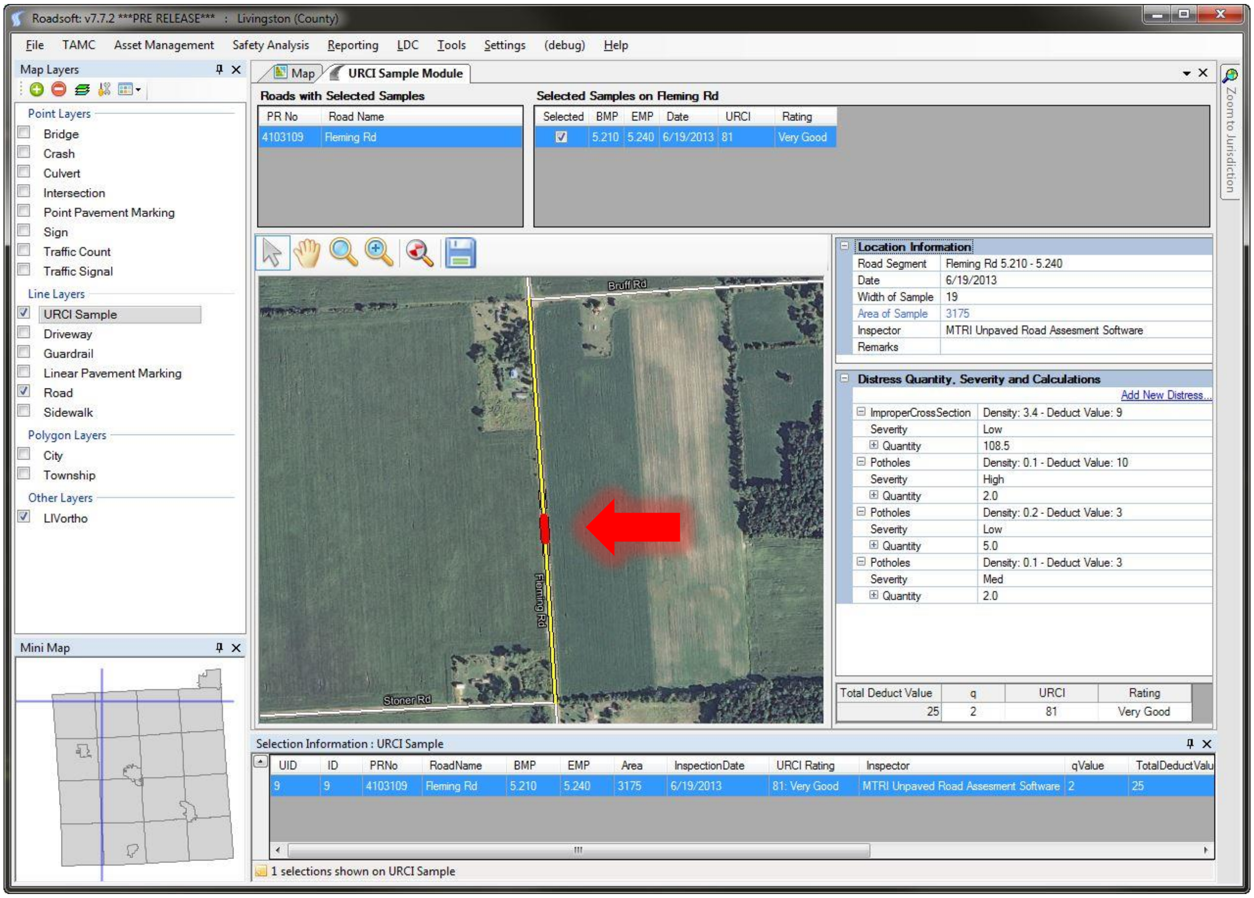


Figure 6-2: Assigning road sampling locations to a network of representative roads in the DSS.
Note deduct values calculated from distress severity and density.

6.5 Characterization of Quantifiable URCI Distress Data

The data collected from field sorties provides measurements on the density and severity the following URCI distresses:

- Loss of road cross section
- Improper drainage
- Corrugations
- Potholes
- Ruts
- Loose aggregate berms

Dust was the only URCI distress type that was determined to unfeasible to collect with remote sensing techniques because to collect this distress a pilot vehicle must loft dust particles. Additionally, the guidelines in the URCI method for dust are subjective.

Improper drainage was technically feasible to collect in areas where vegetation or tree cover was not excessively thick and the ground surface was visible. Both dust and improper drainage can be collected manually to supplement remote sensing data collection if desired.

6.6 URCI Distress Deduct Value Calculation

The URCI method uses unique plots of density and severity or 'deduct value curves' for each individual distress to calculate URCI deduct point values for each of the distress. Distresses higher in severity and density accumulate more deduct points. The Total Deduct Value (sum of all deduct points) is used together with a 'q value' or number of distresses greater than 5 on the Total Deduct Value curve to find the UCRI rating. Individual distress deduct point values as well as total deduct values are useful in planning maintenance activities for unpaved roads (Department of the Army 1995).

The complete set of deduct value curves for each distress can be found in *Technical Manual No. 5-626: Unsurfaced Road Maintenance Management* (Department of the Army, 1995) and are also included in *Deliverable 6-C: Software and Algorithms to Support Unpaved Road Assessment by Remote Sensing* (Roussi et al. 2012a).

Roadsoft® saves the user time by automatically calculating deduct values from distress density and severity data collected from field sorties. An example of individual deduct values calculated by Roadsoft® for the distresses present in on Fleming Road in Livingston County are shown in the *Distress Quanitity, Severity, and Calculations* box (middle right hand side of the screen) in Figure 6.2.

6.7 Selection of Candidates and Scheduling

The DSS functionality created for this project allows ranking road segments based on their condition, and determining which roads are candidates for rehabilitation or maintenance treatments based on their historical distress ratings and inventory information. The URCI method provides users guidance for the type of corrective action and relative cost category for repairs based on the road's current URCI rating (Department of the Army, 1995).

The user can also rank potential road projects by considering other factors such as geographic location, traffic volume or other factors stored in the database. The DSS allows users to use any number of features to be used as criteria for filtering and sorting candidates for ranking. For example, a user could filter unsurfaced roads of a specific functional class, in a specific region or political jurisdiction (township for example) that are in poor condition according to the URCI combined index. Road criteria are available in a number of reports and tables in the DSS. The DSS is capable of displaying candidate projects meeting specific criteria visually on a base map. Figure 6-3 provides roads in Livingston County ranked by UCRI rating.

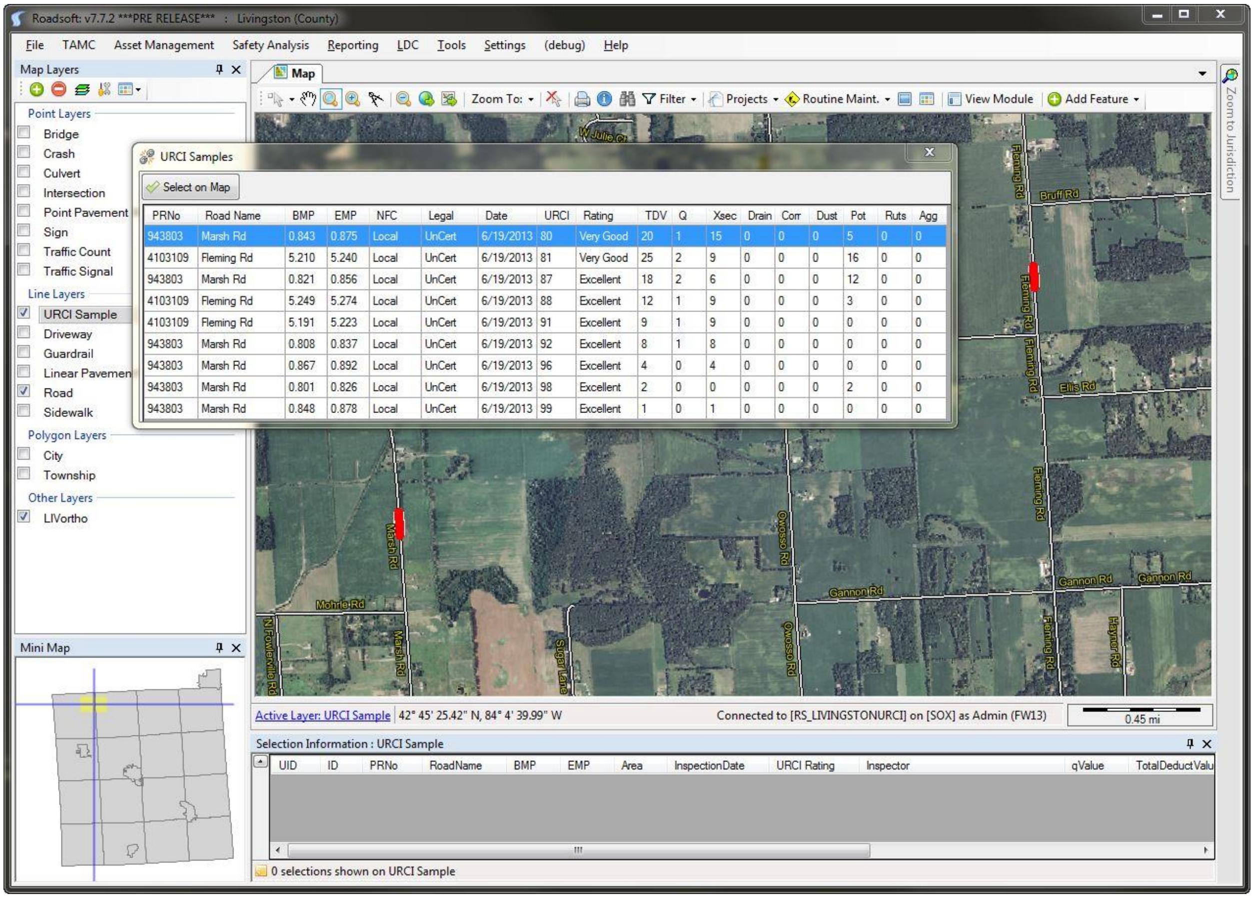


Figure 6-3: Example unpaved road project candidate ranking matrix based URCI rating.

The DSS allows users to set up and schedule projects for all or part of a road segment or group of road segments. The scheduling tool allows users to define specific information about each planned project including project cost, project type, project location, job number and notes. A scheduled projects module is available for display in the DSS base map, as well as in a planned project report.

6.8 Record Competed Work

As road maintenance projects are completed, field reports can be used to update the DSS database by changing the status of projects from "planned" to "completed." Completed construction and maintenance projects are reported by road segment history reports along with historical rating activities. Completed projects are also be available in historical construction activity reports (Colling et al. 2012).

6.9 Determine Data Needs and Repeat Cycle

At the end of the unpaved road analysis cycle, user agencies must determine their data needs prior to restarting the data cycle. Agencies may repeat the data cycle several times per year or as little as once per year depending on how they intend to use the DSS and the level of budget that they have available for data collection activity. Less frequent data cycles will limit the type of DSS analysis that is possible with the distress and inventory information. For example, a single annual data collection event may not provide enough distress data to determine monthly schedules for routine grading, but it may provide sufficient information for determining where reconstruction or heavy rehabilitation activities need to take place, as well as provide an overall network metric for the analysis of a maintenance program on an annual basis.

7. Outreach and Implementation

7.1 System Demo: Sioux Falls, South Dakota

The project team, as part of our outreach efforts, demonstrated the use of URCAS in Sioux Falls, South Dakota in June 2014. This demo was attended by over 30 (36) members of 15 different state and local road maintenance and operations agencies and groups. Of these, 15 were from the South Dakota Department of Transportation (DOT) and the rest were from various local DOTs and LTAPs, such as the Clay County (SD) highway office, the Grant County (SD) highway office, and the Lake County (SD) highway office. Others were from the Nebraska LTAP, Bureau of Indian Affairs, and North Dakota LTAP.

The demo included a live flight of the UAV system, collection of unpaved road imagery, review of data and results, discussion of cost and implementation and a round-table discussion. During the demonstration, participants were taken to an unpaved road where the hexacopter collected imagery of a representative segment of road. This imagery was processed through Agisoft Photoscan to quickly generate a 3D model of the surface for display during the afternoon session. Prior to the demo, imagery of other sites were collected to show multiple types of unpaved road distresses. These included washboarding, road washouts, and potholes.

During the round-table discussion, collected imagery and results were displayed and participants suggested several new applications for the system. These included natural disaster documentation, road/intersection geometry, and haul road monitoring. Additional applications were clearly possible to the audience through high resolution imagery that is collected from the hexacopter, and the types of analyzed products that can be created from this imagery.

The real advantage and interest to transportation agencies was the UAV’s ability to rapidly evaluate the roadway from above with very high resolution imagery. Current evaluation methods called "windshield surveys" are performed by driving down unpaved roads while looking for distresses. The advantage of collecting imagery with the hexacopter is that inspectors are able to clearly see the road surface and the adjacent land. This helps with identifying drainage and culvert issues. Ditches and culverts are usually concealed by vegetation next to the roads and therefore difficult to see while driving past.

A discussion on implementation revealed that this system would most likely be used as a service either on a regularly planned evaluation or on an as needed bases. One participant from the South Dakota DOT thought that they would most likely purchase a system rather than outsource, but most attendees expressed concern in owning equipment in-house due to cost of purchasing the whole system and maintaining it, in addition to training staff to fly the system. Some participants felt that they would not use the system often enough to justify purchasing it and it would be better to hire a third-party service company to collect data with the system.

At the end of the demo, everyone was handed a questionnaire (Figure 7-1). This helped the demonstration organizers to understand and quantify the needs of transportation agencies and how they think the system would be incorporated into operations. Some questions that were answered most often included how transportation agencies would use the system (purchase in house or other), how often they would use it and how would using the equipment save them time and money.

MichiganTech Research Institute

Unpaved Roads Assessment Technology Feasibility Questionnaire

Name: ____________________ Title: ________________________

Agency: ____

Desired Purchase Model

Rank 1 – 3 with 1 indicating the most likely method you would be interested in, or indicate if you are not interested in using this based upon your information today.

- Purchase Hardware & *In-House* Software Data Analysis: __________
- Purchase Hardware & *Outsource* Software Data Analysis: __________
- Purchase Service – "Pay as you Go": __________
- Not Interested: __________

Price-Point

Estimate the range or price point which you would reasonably feel you (or your representative agencies) could dedicate to this service or product.

- Purchase Hardware $__________
- Purchase Software License $__________
- Price per Mile $__________
- Annual Budget *Possible* to Invest in Asset Management $__________

How often would you use this equipment and software system?

When would you use this equipment and software?

Unpaved Roads Assessment Technology Feasibility Questionnaire

Continued...

How would using this equipment save you money?

How would using this equipment save you time?

How would this equipment be an improvement over current road assessment?

What concerns do you have about this equipment being practical or useful for your agency?

What questions or concerns do you have about training for use of the equipment?

What questions or concerns do you have about maintenance of the equipment or software?

Do you have any other comments regarding the system you would like to add?

If you would like us to follow-up with you after today, please list your phone number below and a team member will contact you. Thank you!!

Phone #: ______________________________

Figure 7-1: Example questionnaire which was handed to the demo participants.

7.2 Summary of Comments from the questionnaires:

How often would you use this equipment and software system?

- Monthly
- Whenever Necessary
- At least monthly
- Very interested in the technology and data processing
- Not enough to justify the cost – would need to have outsourced the project
- I could foresee using this in a training scenario and/or in a service provided scenario as an LTAP trainer. Use would be dependent on demand.
- As the technology evolves, I can see tremendous use.

When would you use this equipment and software?

- Summer Season
- Disasters
- Road Condition Evaluations
- Inventory
- Site Monitoring
- Picking location for RWIS Stations

- Picking location for Permanent DMS Signs
- Agriculture Uses, Wildlife Monitoring, Disaster, Fire & Rescue
- In spring of year to inventory roadway features
- Build condition inventory for comparison prior to natural disaster events, change in road status, etc.
- To evaluate “trouble” spots that get complaints.
- To prioritize capital improvements.
- Haul roads before and after inspections
- Pre maintenance assessment inspections
- Bridge inspections

How would using this equipment save you money?

- Inventory
- Making less site visits

How would this equipment save you time?

- Inventory
- Making less site visits

How would this equipment be an improvement over current road assessment?

- Accuracy/Detail
- Amount of time and detail obtained in a short time period

What concerns do you have about this equipment being practical or useful for your agency?

- It appears to be practical
- Very good

What questions or concerns do you have about training for the use of the equipment?

- Outsource to avoid any training needed

What questions or concerns do you have about the maintenance of the equipment or software?

- Outsource – include in the price
- How often it would need to be updated

Do you have any other comments regarding the system you would like to add?

- It was a very interesting presentation & demo
- Thank you! (many thanks were received for coming to Sioux Falls and doing an in-person technical outreach demonstration to the South Dakota, Nebraska, and North Dakota attending agencies)

7.3 Webinar and Project Website

Integrated Global Dimensions (IGD) has worked closely with MTRI to develop other outreach materials. These include a webinar which introduces the technology and a project website which provides project updates, both of which are instrumental in providing information to our stakeholders and potential collaborators.

The webinar includes several interviews with stakeholders and the project team, which introduce the technology and explain the importance of its use. Several stakeholders including Dave Huft (SDDOT) and Ken Skorseth (SDLTAP) were interviewed after the demo in South Dakota and verbally expressed their support of the use of URCAS. To date (9/30/2014), 93 individuals have watched the webinar. They include academic, state DOTs and private sector companies (Table 7-1).

Table 7-1: Online Webinar attendees.

State DOT	Academic	Private Sector
Florida State Department of Transportation	University of Florida	HDR
Minnesota State Department of Transportation	Auburn University	Mandli
Nebraska Department of Roads	Marquette	Alta Planning
Kansas Department of Transportation	Kansas State University	Praxiar
Tennessee Department of Transportation	University of Texas	
Louisiana Department of Transportation	Texas A&M University	
Wisconsin Department of Transportation		
Missouri Department of Transportation		
Idaho Department of Transportation		
Pennsylvania Department of Transportation		

The project outreach-focused website has also attracted some attention since going public (www.unpavedroadsremotesensing.com). To date there have been 307 page views with an average time on site of 2 minutes. The website describes the process as well as shows results and also provides the project deliverables. A testimonials section is included which includes expert insight from Caesar Singh, Dave Huft and Ken Skorseth. There is also access to the webinar for interested stakeholders.

7.4 Publications and Presentations

The project team submitted manuscripts to trade publication, a refereed journal, and the Transportation Research Board. The titles and abstracts are as follows:

Advances in Gravel Road Management Start with Condition Assessment was submitted to American Society of Civil Engineers Magazine on April 23, 2014 for review for publication.

Abstract

The *Characterization of Unpaved Road Conditions through the Use of Remote Sensing* research project completed by Michigan Technological University through a cooperative agreement with USDOT Office of the Assistant Secretary for Research and Technology (OST-R, previously known as the Research and Innovative Technology Administration, RITA) provided a complete system offering data collection and network condition assessment for asset management of unpaved roads. An unmanned aerial vehicle (UAV) equipped with a remote sensing system collected unpaved road condition data. The data were exported and processed in decision support software (DSS) to provide an Unsurfaced Road Condition Index (URCI) for each sample collected. When combined with a road agency budget, the UAV remote sensing and DSS system is a complete package that can be used as a decision making aid for management of unpaved roads.

A Review of the State of the Practice of Data Collection Techniques for Unpaved Roads was submitted to American Society of Civil Engineers Journal of Transportation Engineering on April 23, 2014 for peer review for publication.

Abstract

Condition assessment systems for unpaved roads range in purpose from use in daily management to systems that are targeted at ongoing research. 32 publications were identified and reviewed to outline existing distress assessment systems and their unique characteristics presented here. Types of condition assessment methods and technologies available to acquire data for unpaved roads can be sub-divided into the following methodologies: visual, combination; visual and direct measurement, and indirect data acquisition with specialized equipment. Times to collect data, record keeping processes, and data applications are also included where available. Benefits and limitations of each method are also discussed.

The project team presented project results to transportation and other technical conferences. The titles and abstracts are as follows:

Transportation infrastructure assessment using high-resolution remote sensing was presented at the Mid-Continent Transportation Research Forum in August 2014

Abstract

State and county transportation agencies have become increasingly interested in using remote sensing technology to inspect transportation infrastructure. Traditionally, condition assessments for pavement, bridges and other transportation infrastructure have been performed by inspectors who visually classify and record the extent and severity of distresses. These traditional methods of inspection take significant time and can expose inspectors to safety hazards when completing their duties on roads and bridges. Two systems have recently been developed to collect high resolution imagery of transportation infrastructure to help automate and reduce the cost of the inspection process. A vehicle based system, 3DOBS (3D Optical Bridge-evaluation System), and a remote controlled unmanned aerial system (UAS) based data collection system known as the Unsurfaced Road Condition Assessment System (URCAS) show promise for collecting, low cost, high accuracy data. 3DOBS has been developed to assess the condition of bridge decks, while the remote controlled UAS system is designed to assess unpaved road condition. Both systems use overlapping imagery to generate 3D models of the road surface that can be analyzed with specialized algorithms to detect distresses such as spalls, potholes or ruts. These systems allow for the rapid collection of objective and repeatable data that can be used to assess road surface condition and provide data to help transportation agencies plan their maintenance efforts.

Transportation Infrastructure Assessment with High-Resolution Remote Sensing was presented at ASPRS 2014 spring conference in March 2014

Abstract

Transportation agencies are increasingly interested in using remote sensing to perform inspections of transportation infrastructure. Traditionally, assessments are performed by inspectors visually evaluating and estimating condition ratings. Two systems have been developed to collect high resolution imagery of transportation infrastructure. A vehicle based system, 3DOBS (3D Optical Bridge-evaluation System), and a remote controlled helicopter based system. 3DOBS was designed to assess the condition of bridge decks, while the remote controlled helicopter system was developed to assess unpaved road condition. Additional systems are in development to asses confined spaces and traffic conditions. Both systems use collected imagery to generate a 3D model of the road surface that can be analyzed with specialized algorithms to detect distresses such as potholes. These systems allow for the rapid collection of objective and repeatable data that can be used to perform condition assessments and plan maintenance efforts.

Implementation Assessment of Unpaved Road Condition with High-Resolution Aerial Remote Sensing was presented at the Southeastern Michigan GIS Users Group meeting in February 2014

Developing an Unpaved Road Assessment System for Practical Deployment with High-Resolution Optical Data Collection using a UAV-capable Helicopter was presented at ASPRS 2013 fall conference in October 2013

Applying remote sensing technologies for transportation infrastructure assessment in Michigan was presented at the Michigan UAS conference in October 2013

Integrating remote sensing, GIS, and existing infrastructure data for decision support was presented at the FHWA Road Noise Workshop in August 2013

Collecting Decision Support System Data via Remote Sensing of Unpaved Roads was submitted to Transportation Research Board in August 2013 was accepted, presented as a poster (January 2014), and accepted for publication in the Transportation Research Record. Online at: http://trid.trb.org/view.aspx?id=1289748

Abstract

Unpaved roads make up roughly 33 percent road system within the United States and are vitally important to rural communities to transport people and goods. Effective asset management of unpaved roads requires frequent inspections to determine the asset's condition and the appropriate preventive maintenance or rehabilitation. The major challenge with managing unpaved roads is collecting low-cost, condition data that is compatible with a decision support system (DSS). The advent of cheap, reliable remote sensing platforms such as unmanned aerial vehicles (UAVs) along with the development of commercial off-the-shelf image analysis algorithms provides a revolutionary opportunity to overcome these data volume and efficiency issues.

This paper outlines the development of a market-ready system to detect unpaved road distresses that are compatible with a DSS by taking advantage of these technological leaps. The system uses aerial imagery that can be collected from a remote controlled (RC) helicopter or manned fixed-wing aircraft to create a three dimensional model of sensed road segments. Condition information on potholes, ruts, washboarding, loss of crown and float aggregate berms are then detected and characterized to determine the extent and severity of the distresses. Once detection and analysis is complete, the data are imported into a GIS-based DSS (Roadsoft®) for use by road managers to prioritize preventive maintenance and rehabilitation efforts.

Developing an Unpaved Road Assessment System for Practical Deployment with High-Resolution Optical Data Collection using a Helicopter UAV was presented at the International Conference on Unmanned Aerial Systems (ICUAS) conference in May 2013

Abstract

The need of local governments and transportation agencies to periodically asses the condition of unpaved roads in a cost-effective manner with rapid response times has lead to interest in the use of UAVs (Unmanned Aerial Vehicles) and remote sensing technologies. Currently these assessments are done through visual inspections with agency staff making occasional spot measurements. An unpaved road assessment system was developed to address these issues while at the same time providing a more accurate means of characterizing distresses and determining the roads condition for inspectors. This system uses a single-rotor UAV-capable helicopter with a Digital Single-lens Reflex (DSLR) camera to capture overlapping imagery of unpaved roads. The helicopter is equipped with a full combination GPS plus IMU (Inertial Measurement Unit) that allows it to fly predetermined waypoints with great stability while at the same time allowing the pilot the ability to take over at any time. Collected imagery is analyzed to locate road distresses. The imagery is run through a Structure from Motion (SfM) algorithm that generates a 3D model of the road surface from which additional condition information can be characterized.

Identification of Unpaved Roads in a Regional Road Network Using Remote Sensing was presented at the ASPRS 2013 annual conference in March 2013.

Abstract

An accurate inventory of the road network length class and condition within a county, state or region is important for efficient use of maintenance resources. Part of the maintenance equation is knowing where unpaved roads are and how many miles are unpaved. Local governments and transportation agencies are responsible for a large part of this unpaved infrastructure. These agencies need a cost-effective way to identify the unpaved infrastructure in order to effectively maintain these roads and optimize resource

allocation. Unpaved roads typically have low traffic volumes, and consequently may receive less attention from local agencies with limited resources. Remote sensing techniques provide a way to identify unpaved roads within a county's road network. Four band optical imagery (R,G,B,IR) was acquired and an algorithm developed to separate paved and unpaved roads in two counties in Southeast Michigan as part of a larger USDOT Research and Innovative Technology Administration grant investigating remote sensing of unpaved road condition. The county road network is buffered and segmented using eCognition. An eCognition ruleset that evaluates relationships between NDVI, Principal Component (PC) 3 and the blue band, PC1-blue, IR-blue and IR-green is applied to the buffered, segmented data to separate the signature of unpaved roads from other classes. The unpaved road segments are merged with the road centerline network and then identified. Location and length of unpaved roads within a county road network can be calculated from the data, providing additional information from which road maintenance decisions can be made.

Identification of Unpaved Roads in a Regional Road Network using Remote Sensing was presented at the Ohio Geographically Referenced Information Program in January 2013

Characterization of Unpaved Road Conditions through the Use of Remote Sensing was presented at TRB 2013 conference at the Sensing Technologies Workshop in January 2013

Remote sensing of transportation infrastructure: bridges and unpaved roads was presented at ASPRS 2012 spring conference in March 2012.

Abstract

Innovative methods of assessing transportation infrastructure are needed in a budget-limited environment. Remote sensing provides ways of aiding Departments of Transportation with transportation condition evaluation while complementing traditional methods. This paper summarizes two USDOT Research and Innovative Technology Administration projects, one for assessing bridge condition and the other for unpaved road assessment. For bridge condition assessment, synthetic aperture radar (SAR), 3D optics, thermal infrared, LiDAR, digital image correlation, and optical satellite imagery analysis have been used for Michigan bridges. Data have been integrated into a decision support system for use by state DOTs. For unpaved roads, a Michigan Tech team is working with USDOT-RITA to prototype a polarized optical system to create practical, rapid methods of assessing an important transportation network component that does not often receive sufficient attention. Readily deployable systems, including a manned fixed wing or an unmanned aerial vehicle are under evaluation.

Initial Direction of a Project to Implement a System for Assessing Unpaved Road Condition with Remote Sensing was presented at TRB 2012 conference at the Sensing Technologies Workshop in January 2012

7.5 Implementation:

Through the course of this project a working prototype has been developed to collect data and assess the condition of unpaved roads. This included determining the appropriate UAV platform (Deliverable 5-A), sensor configuration (Deliverable 4-A) and developing a software package that generates 3D models and detects distresses (Deliverable 6-C). Despite the progress made during the project, the algorithm still needs to be developed further in order to be commercially ready, particularly for ruts and washboarding calculations. While the algorithm is capable of processing imagery to generate xml output of the road condition, it is currently not a user friendly package that can be easily distributed. Some technical work is needed to make the code more portable for commercial installation at a third-party service company (for example). These improvements will have to be made before implementation.

Overall the highest priority modifications needed are: correcting for inaccuracies in point cloud densification due to camera parameter estimation from very disparate geometries, providing a tool to remove blurred imagery, adding switches for all script parameters, adding the ability to input road segment length and width, and developing a graphical user interface for the software. New distress and road feature detections would be added, based on local partner and TAC input, such as measurement of intersection geometry, evaluation of drainage or flooding issues, changes in haul road condition, and input data for road safety audits. These additions would make URCAS more flexible and able to suit the needs of local road managers.

Before URCAS can be used commercially, the FAA has to issue rules that allow for the use of commercial UAS. Currently these rules are expected to be released in late 2015 or early 2016 after the FAA's official rule making process is complete. With continued outreach efforts and development by the project team which include partnering with private sector companies, URCAS will be ready for commercial use when the new rules are released.

Implementation of URCAS will be done with the involvement of “third party” private sector companies (those that provide services to government agencies). Discussions with multiple companies interested in the commercialization of the system have taken place during the project. It was anticipated and confirmed by the input provided by the South Dakota demo attendees that this system would be a commercial service that should be offered to local road managers.

Companies can offer URCAS as a third-party, commercially-available service to transportation agencies for assessing unpaved roads (and other transportation assets and issues), after new regulations are issued by the FAA for more practical day-to-day UAV usage. For this reason, the Michigan Tech PIs have had discussions with aerial remote sensing firms to take URCAS to full commercialization. Working with multiple third-party commercial providers helps ensure that URCAS is available nationwide.

8. Conclusion

It is important to note that this project evaluated both manned and unmanned options for sensor deployment, finding that using a typical manned, fixed-wing aircraft did not result in data with sufficient angular diversity to create 3D data of high enough resolution to meet system requirements when flying at a minimum safe height of 500' (see Deliverable 7-B) with the same sensor system (a 36-mp Nikon D800 digital SLR camera), such as potholes in classes at 2" (5cm) or better and a corrugation class with less than 1" (2.5 cm) depth (see Deliverable 1-A for requirements that drove this project). A sensor that can be flown below 100m (about 330'), however, with lower costs, was demonstrated through this project that took advantage of the capabilities of the selected hexacopter UAV platform. Tests of the hexacopter-based system were concluded in Michigan, South Dakota, Iowa, and Nebraska, with 45 road segments evaluated in 2012 and 2013. These tests, plus a technical demonstration in South Dakota that included implementation discussions, formed the basis of the needed data for this project.

Deliverable 7-B, the "Performance Evaluation of Recommended Remote Sensing System in Unpaved Road Type and Condition Characterization" report (see http://geodjango.mtri.org/unpaved/media/doc/deliverable_Deliverable_7_B_PerformanceEvaluation_Final_2013-11-27_updated_1.pdf) described the data collected in 2012 and 2013 for the project, how well the distress algorithms performed, a concept of operations for the system, and a detailed comparative cost analysis. Assuming that users are taking advantage of the Unsurfaced Road Condition Index concept of evaluating two 100' (30m) segments per mile of road needing assessment, then costs can be as low as $0.74 per mile vs. similar costs of $7.58 per mile for manual URCI methods (Wyoming URCI moderate distress estimate) and $10.26 per mile assessed for fixed wing aircraft. These costs demonstrate that UAV-based sensing of unpaved road conditions can be done at reasonable financial rates that are promising for commercial adoption.

This project included significant outreach efforts, which were expanded in the last year through integration of an experienced Outreach Specialist. At the technical system demonstration on June 26, 2014, 50 members of state and local transportation agencies were able to see URCAS fly and collect unpaved roads imagery, they reviewed data and results, and participated in a round-table discussion where implementation ideas were discussed. Conference presentations to ASPRS (in 2012, spring and fall 2013 meetings, and 2014), the Transportation Engineering Road Research Association (TERRA) in 2012, TRB Annual Conferences (in 2012, 2013, and 2014), the Federal Highway Administration (2013), the Michigan UAS Conference (2013), the International Conference on Unmanned Aerial Systems (2013), the Mid-Continent Transportation Research Symposium (2014), and the Michigan Transportation Asset Management Conference (2014) all provided opportunities to reach out to interested end users and the professional community interested in the advanced being funded by USDOT. Two Technical Advisory Committee meetings enabled sharing of valuable input from subject matter experts. Informal meetings with cost-share partners TAMC, SEMCOG, and RCOC provided additional opportunities for feedback, particularly on the value of improved unpaved road inventories. Seven popular press articles, three conference proceedings articles, and one accepted peer-reviewed article provide a long-term printed resource and readily available reference for end users, researchers, government agencies, and other stakeholders to access.

We have developed a practical, cost-effective system capable of both mapping the locations of unpaved roads through existing aerial imagery and assessing their condition with high-resolution imagery collected by a UAV platform with readily available digital camera sensor. When the FAA issues new rules allowing use of UAVs on a commercial basis for most of the U.S. (due by late 2015, with a 2016 date possible instead), then the Unsurfaced Road Condition Assessment System can be ready for commercial usage. In the meantime, a follow-on phase focused on technical improvements and implementation-focused outreach would be a logical continuation of this project.

8.1 Acknowledgments

As Project lead Principal Investigator, I (Colin Brooks) would like to thank USDOT Program Manager Caesar Singh, P.E., for providing guidance, oversight, and insight during the entirety of this project. My associate Co-Principal Investigators, Chris Roussi (of MTRI) and Dr. Tim Colling, P.E., (of the Michigan Tech Center for Technology and Training) were critical for the detailed results and technical success of this project, providing their in-depth knowledge, software development, engineering capabilities, and outreach help. Team member and Outreach Specialist Valerie Lefler, MPA, provided a late-stage push on outreach that provided critical, more widespread exposure of the project to potential end users, including a well-organized technical demonstrate in June, 2014 in Sioux Falls, SD. I would be remiss in any thanks without recognizing my project team – Rick Dobson, Ben Hart, David Banach, Joe Garbarino, Brian White, David Dean, Dr. Melanie Kueber Watkins P.E., K. Arthur Endsley, Michelle Wienert, Dr. Robert Shuchman, Dr. Andrea Vander Woude, and Gary Schlaff are part of that list, along with the project interns who helped with data collection and demonstrations, many of whom should become part of the advanced, technologically-savvy transportation workforce of the future thanks to this project. The project's Technical Advisory Committee provided crucial input as well, including Bill McEntee (Road Commission for Oakland County, retired), Carmine Palombo (Southeast Michigan Council of Governments), Dave Huft (South Dakota Department of Transportation), Ken Skorseth (South Dakota Local Technical Assistant Program), Lou Lambert (Michigan Department of Transportation, retired, and Cambridge Systematics, retired), Mark Craft (Gratiot County Road Commission and National Association of County Engineers), and Roger Surdahl (USDOT Federal Highway Administration – Central Federal Lands). Their TAC input is greatly appreciated.

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Appendix A. Reports

Deliverable 1-A: Requirements for Remote Sensing Assessments of Unpaved Road Conditions

Deliverable 2-A: State of the Practice of Unpaved Road Condition Assessments

Deliverable 3-A: Remote Sensing the Phenomena of Unpaved Road Conditions

Deliverable 4-A: Sensor Selection for use in Remote Sensing the Phenomena of Unpaved Road Conditions

Deliverable 5-A: Candidate and Recommended Remote Sensing Platforms for Unpaved Road Condition Assessment

Deliverable 6-A: A Demonstration Mission Planning System for use in Remote Sensing the Phenomena of Unpaved Road Conditions

Deliverable 6-B: A Demonstration Decision Support System for Managing Unpaved Roads in RoadSoft

Deliverable 6-C: Software and Algorithms to Support Unpaved Road Assessment by Remote Sensing

Deliverable 7-A: Plans for Field Deployment of Recommended System for Remote Sensing of Unpaved Road Conditions

Deliverable 7-B: Performance Evaluation of Recommended Remote Sensing Systems in Unpaved Road Type Condition Characterization

Michigan Technological University

Characterization of Unpaved Road Conditions Through the Use of Remote Sensing

Deliverable 1-A: Requirements for Remote Sensing Assessments of Unpaved Road Conditions

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Introduction

Best engineering practices for system design and development demand that requirements be established. These requirements, for this program, fall into several categories, including the measurement requirements for features characterizing unpaved road distress (e.g. their types, sizes, range of values), the system requirements on the sensor and software (e.g. sensor resolutions, size, weight, power, etc.), and the operational requirements (e.g. costs, time-constraints, user requirements, etc.).

This requirements document details these requirements for a remote sensing data collection system capable of collecting inventory and distress data for unpaved roads that can be utilized to develop a commercially viable unpaved road data collection and asset management system. This document will be modified as needed based, among other considerations, on the input from the TAC following their requirements session meeting. The contents will serve as the guidance during system development and testing.

The process to develop system requirements demands an overall picture of what the gravel roads asset management system will do and what types of decisions the system will support users making. In outlining the requirements for this system, research staff have been outlining the state of practice for unpaved road distress identification and management systems. This information will be presented separately in project deliverable 2-A, the " State-of-the-Practice of Unpaved Road Condition Assessment" report. . It is anticipated that the proposed unpaved roads decision support system will be similar in scope to the United States Department of the Army (USDA) Unsurfaced Road Maintenance Management System as defined by USDA Technical Manual # 5-626 of 1995. The project team has found this manual to be a detailed and well-described system for integrating unpaved road condition data into easily understandable and actionable information.

General Operational Requirements

Data Collection Rate

The remote sensing system is intended to be a commercially viable system, meaning that it can collect economically unsurfaced road distress and inventory data at a rate and cost that is competitive with traditional land-based assessment methods in terms of cost-per-mile of data collected for similar quality data. The efficiency of data collection is a function of the sensor platform’s capital cost, operating costs, estimated useful operating life divided by data collection operating speed. A system is needed that is at least the same or is more cost competitive than current methods and provides better functionality. Whether the unpaved road condition data are collected via remote sensing or via more traditional manual collection methods, the cost to collect the data is still the primary driver.

Data Processing and Output Time

It is known that raw data collected from a remote sensing system will require some degree of post-processing or analysis before the data can be used in a decision support system. This post-processing delay can be as long as three to five days per collect day without introducing a hardship to end users. A relatively fast processing time is needed so the data is still actionable after being collected, because unpaved road conditions can change rapidly. However, users must have some method of determining the quality of collected data in the field before concluding daily data collection activities. An in-field data quality check insures that the necessary information was collected before moving to another site or concluding collection activities.

Operation of the Sensor System vs. Operation of the Platform

The sensor system needs to simple to operate. The precise definition of “easy” will be determined through discussions with potential users including the project's Technical Advisory Committee, but generally implies that little (to no) training will be needed, and no special skills will be needed to operate the sensor itself.

The sensor platform needs to be fast and easy to deploy. Again, the precise meaning of “fast and easy” will be determined through potential customer input. The platform itself may require significant operator training depending on the choice made in Task 5, Platform Selection. For example, a manned fixed-wing platform will require a trained pilot.

The sensor and its carrying platform will be integrated into an overall system deployed by a transportation agency and/or made available as a service from a vendor or vendors to transportation agencies.

Reporting Segments Size, Sample Spacing, and Geo-location

The remote sensing data collection system is required to report the data outlined in this document on reporting segments at a minimum of 100 feet in length (30.48 meters) as measured down the centerline of the road, with a maximum width perpendicular to the direction of the road of 70 feet (21.34 m). Reporting segments are required to be geo-located with a precision of ten feet (3.05 m) horizontally. The system will need to sample at minimum ground sample spacing of approximately three feet (one meter), allowing us to detect serious but localized distress, and will report a summary statistic every 100 feet. Position information for the sampling unit location must be of similar accuracy to the accuracy of the Michigan Geographic Framework linear referencing system which is being utilized for this project. The Michigan Geographic Framework linear referencing system is generally considered to be the state's 1:24,000 scale base map (Blastic 2010), and National Map Accuracy Standards for 1:24,000 scale data are +/- 40.0 feet (12.2 meters) (Congalton and Green, 2009).

The remote sensing system must be capable of being programmed to measure pre-selected locations semi-autonomously. These locations may be directly adjacent to each other or may be several miles distant, depending on the parts of an unpaved road system that is being measured via remote sensing..

Phenomenon Sensing Requirements

Pavement Surface Type Inventory

The pavement surface type should be determined before unpaved road sensing as a required input into mission planning.. This analysis method must be capable of determining if a surface is paved (asphalt, sealcoat and concrete) or one of two types of unpaved (gravel and unimproved earth) surface. Ideally the system would be capable of determining the exact surface type (asphalt, concrete, sealcoat, gravel or unimproved earth), however this is a secondary consideration and is not mission-critical for the scope of this project. For the purposes of this project, pavement types are defined as follows:

Gravel Pavement: A pavement that is entirely constructed from aggregate (processed or unprocessed) layers that do not have a bituminous asphalt treatment cap or have structural layers of PCC, HMA, or WMA.

Unimproved Earth Pavement: A pavement that is constructed entirely of native subgrade material that is shaped into a road section. No processed materials are used in the construction of unimproved earth pavements and they typically develop a vegetative covering in all but the wheel path.

Paved Roads: These could be one of three types (Asphalt Pavement, Concrete Pavement, Sealcoat Pavements), but it is not necessary to differentiate between them; it is sufficient to determine paved vs. gravel or unimproved. This will allow the user to task the system to collect only roads of interest.

The acceptable error rate for identification in these three types (errors of commission / omission) is a requirement that must be defined. In remote sensing classification, 85% accuracy is a generally recognized goal for cover types. However, based on results obtained from road type classification in the TARUT Study (Brooks et al. 2007), it is our goal to obtain 95% accuracy in road surface type using these three classes.

Pavement Surface Width

The majority of unpaved roads have no more than two lanes. Typical driving lanes are at least nine feet (2.7 m) wide to a typical maximum of twelve feet (3.66 m) wide (24 feet / 7.32 m maximum width for both lanes combined). The total width of the driving surface is a required inventory feature. The pavement surface width is defined by the area of road that has been surfaced and graded with the intent to carry traffic and does not include ditch slopes, fore slopes or material windrows for pavements that are recessed or “cut in” to the surrounding terrain. Figure 1 below illustrates two examples of road width measurements for a recessed road (top photo) and a road constructed in a fill section (bottom). Road width will already be known based on the provided inventory. In addition, the road width can be calculated from the sensor data. Road width measurements are required be collected every ten feet (3.05 m) linearly down a sampling unit and are required to have precision of four inches (10.2 cm) (i.e., the precision of the width must be +/- 4 inches).

Figure 1: Examples of road width measurement based on graded driving surface.

Road Cross Section

High quality unpaved roads are constructed with a "crowned" section meaning that the center line of the pavement is higher in elevation than the edges of the pavement to facilitate surface water drainage. A typical high quality unpaved road cross section has a two to four percent vertical cross slope that falls away from the centerline of the pavement to its edge where the shoulder or ditch slope starts. Figure 2 below illustrates a typical well-constructed pavement cross slope. Traffic, snow plowing and improper grading operations can contribute to loss of this cross section "crown". Roads without a proper crown do not shed surface water which leads to accelerated deterioration of the pavement surface and can create significant structural issues.

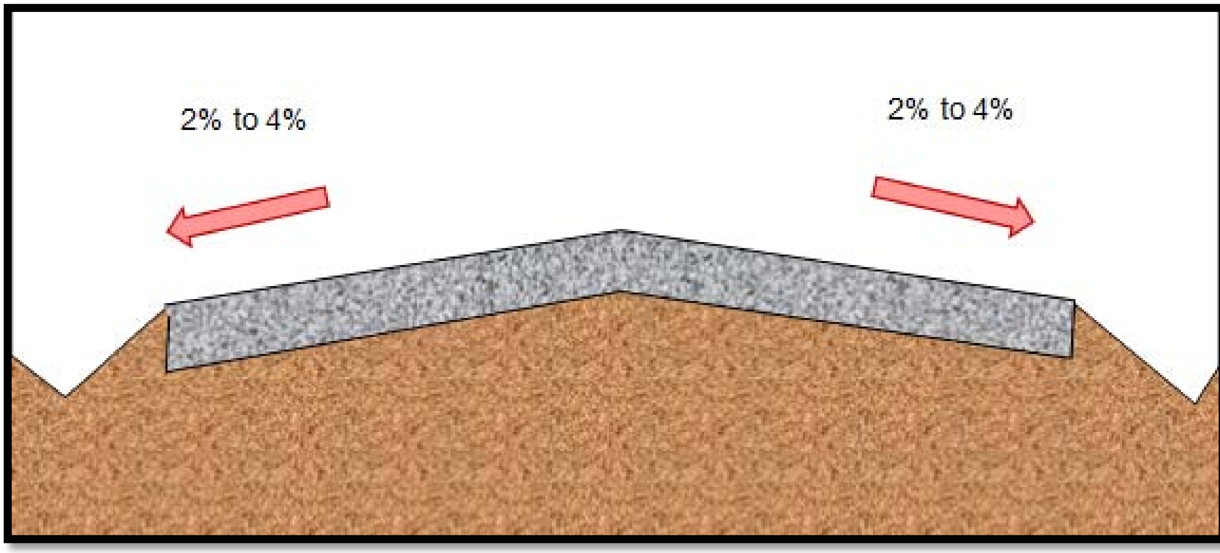

Figure 2: Road cross section illustrating an example of a typical cross slope.

The remote sensing system is required to measure the pavement cross slope between the center line of the road to the edge of pavement where the beginning of the ditch slope start on both lanes of the pavement. The requirement is to measure the profile of the cross section of the road. For example, for a nine-foot wide lane, a 1% slope would drop approximately one inch (2.5 cm). Pavements that have negative slopes would indicate that the centerline of the pavement is lower in elevation than the edges of the pavement. Elevation points measured at the centerline of the pavement and the edge line of the pavement must be identified as such. Cross section elevation data must be recorded at intervals of at least every ten lineal feet (3.05 m) per sampling unit as measured with the direction of the road.

Potholes

Potholes are roughly bowl shaped depressions in the surface of a pavement that are usually less than three feet (0.91 m) in diameter (Department of the Army, 1995) and are typically more than six inches (15.2 cm) in diameter. Potholes allow surface water to collect in their depressed areas during rainy periods which accelerates their growth by weakening the pavement surface making it susceptible to further deformation by traffic. Figure 3 below illustrates a typical pothole pattern during wet conditions.

Figure 3: Typical pothole pattern during wet conditions.

The remote sensing system must be capable of identifying each pothole in a test section. Potholes must be classified by their diameter and depth as measured from the adjacent road surface outside the limit of the pothole to the center point in the pothole. The number of potholes in a test section will be classified into the bins based on diameter and depth shown in Table 1 below to be able generate the severity level of the potholes. Potholes become a significant issue when they are visually detectable and exceed six inches (15.2 cm) in diameter. The remote sensing system needs to be able to detect pothole diameter with a precision of +/- four inches (10.2 cm) and depth with a precision of +/- two inches (5.1 cm). The total area of potholes cannot exceed the surface area of the pavement.

Table 1 Measurement bins for pothole classification (Department of the Army, 1995):

Max. Depth	**Average Pot Hole Diameter**			
	<1 ft (<0.30 m)	**1-2 ft (0.30 -0.61 m)**	**2-3 ft (0.61 - 0.91 m)**	**>3 ft (> 0.91 m)**
<2” (<5.1 cm)	Number of Occurrences	Number of Occurrences	Number of Occurrences	Number of Occurrences
2”-4” (5.1 cm - 10.2 cm)	Number of Occurrences	Number of Occurrences	Number of Occurrences	Number of Occurrences
>4” (>10.2 cm)	Number of Occurrences	Number of Occurrences	Number of Occurrences	Number of Occurrences

Ruts

Ruts are longitudinal depressions in the surface of an unpaved road caused by vehicle tire loads causing one or all of the pavement layers to deform permanently. Ruts have a minimum of width of a typical vehicle tire (six to seven inches wide / 15.2 cm to 17.8 cm) and can be as large as the wheel path travel area of the lane (approximately 24 inches wide / 0.61 m). Ruts tend to run linearly in excess of ten feet (3.05 m). Figure 4 below shows a typical rutting pattern caused by wet conditions and excessive load. The formation of ruts may be accelerated during wet conditions or during spring thaw when the pavement layers are saturated or during periods of repeated heavy loading.

Figure 4: Typical rutting pattern.

The remote sensing system must be capable of detecting the square foot area of a test section that exhibits rutting. Rutted areas of the road surface must be classified by the depth of ruts comprising it as measured from the bottom of the rut to the top of the adjacent pavement surface. Rutted surfaces will be classified into the following three bins: up to one inch deep (2.5 cm) ruts, one inch to three inch deep (2.5 to 7.6 cm) ruts and greater than three inch ruts (>7.6 cm). Each bin of rutted surface will have its total surface area calculated for the sample unit. the remote sensing system needs to be able to detect width with a precision of +/- four inches (10.2 cm) and depth with a precision of +/- one inch (2.5 cm). Ruts that are less than ten feet (3.05 m) in length or four inches (10 cm) in width will not be considered significant. The total rutted area cannot exceed the surface area of the pavement.

Corrugations

Heavy traffic use during dry conditions on an unpaved road can result in the formation of a repeating pattern of closely spaced ridges and troughs perpendicular to the direction of travel. These corrugations typically have spacing as little as eight inches (20.3 cm) crest to crest to as large as 40 inches (1.02 m) crest to crest. Corrugations tend to have similar crest to crest spacing (period) and depths (magnitude).

The crest to crest spacing of corrugations has been related to the modal speed of traffic using the pavement (Republic of South Africa Department of Transport, 1990). Corrugations typically first form in the heavily traveled wheel paths areas (approximately two feet / 0.61 m wide per wheel path) of a gravel pavement, however, as corrugations begin to cause poor ride drivers tend to shift their lane position causing the propagation of corrugations across the entire width of the pavement. These corrugations are commonly referred to as “washboarding” for their resemblance to the surface of the historic clothes washing tool of the same name. Corrugations can result in significant safety and road user operational issues if not corrected by maintenance grading. Figure 5 illustrates a typical surface condition as a result of corrugations.

Figure 5: Typical corrugation pattern in a gravel road.

The area (in square feet or meters) of sections of road exhibiting corrugation must be identified by the remote sensing system. The system will need to detect that corrugations are present (for example, from changes in tone in images) and when present corrugated areas of the road surface must be classified by the depth of corrugations comprising it as measured from the top of the corrugation ridge to the bottom of the adjacent trough with a precision of +/- one inch (2.5 cm). Corrugated surface areas will be classified into the following three bins: up to one inch (2.5 cm) deep corrugations, one inch to three inch deep (2.5 cm to 7.6 cm) corrugations, and greater than three inch (>7.6 cm) corrugations. Each bin of corrugated surface will have its total surface area calculated for the sample unit. The total area of corrugation cannot exceed the surface area of the pavement in the sampling unit.

Roadside Drainage

Roadside drainage facilities vary greatly among unpaved roads. The lack of a properly constructed and maintained drainage can significantly weaken the structure of an unpaved road and can lead to accelerated distresses. Some roads have well defined, deeply cut ditches that allow surface water to drain away, while others may have no ditches or worse have instances where the road bed is actually lower than the existing grade (cut in) forcing surface water onto the road, as such the presence of a ditch is considered an important inventory feature. Improperly maintained ditches that have excessive vegetative growth or have significant standing water are also a concern and can be considered an unpaved road distress. Roadside drainage is a desirable inventory feature to collect, but is not mandatory for the success of the remote sensing system as it is a potential factor that may influence pavement quality but is not a direct measurement of pavement quality.

The remote sensing system must be able to measure the elevations of the ditch fore slope and back slope (if present) for each ditch perpendicular to the direction of the road. Ideally for a well constructed road the ditch bottom should be six to twelve inches (15.2 cm to 30.5 cm) below the bottom of the pavement. The system needs to be able to measure this difference. Elevation measurements must be collected for each ditch starting at the edge of pavement to a minimum of fifteen feet (4.57 m) either side of the pavement and must be identified as being measured on the ditch surface. Ditch elevation measurements are required to measure elevation to a precision of +/- two inches (+/- 5.1 cm). Ditch section elevation data must be recorded at intervals of at least every ten lineal feet per sampling unit as measured with the direction of the road.

The remote sensing system must be capable of sensing the presence of standing or running water in the ditch area. Water present in ditches will be noted by the section width of water surface present for each ditch and at least one elevation data point for the water surface at each ditch. Water elevation measurements are required to measure elevation to a precision of +/- two inches (+/- 5.1 cm), and width measurements are required to be measured with a precision of +/- four inches (+/- 10.2 cm). Where significant vegetation was present, this would prevent the measurement of the ditch depth and the presence of water.

Loose Aggregate

Heavy traffic use or poor materials on an unpaved road can result in the formation of linear berms of segregated loose aggregate particles in the less traveled areas adjacent to wheel paths. This loose aggregate is commonly referred to as “float” aggregate and can result in significant safety and road user operational issues if not corrected by maintenance grading. Float aggregate berms typically span six to 24 inches in width (15.2 to 61.0 cm) (perpendicular to the road direction) and run longitudinally with the direction of the road for significant distances. Figure 6 illustrates the typical position that float aggregate berms form.

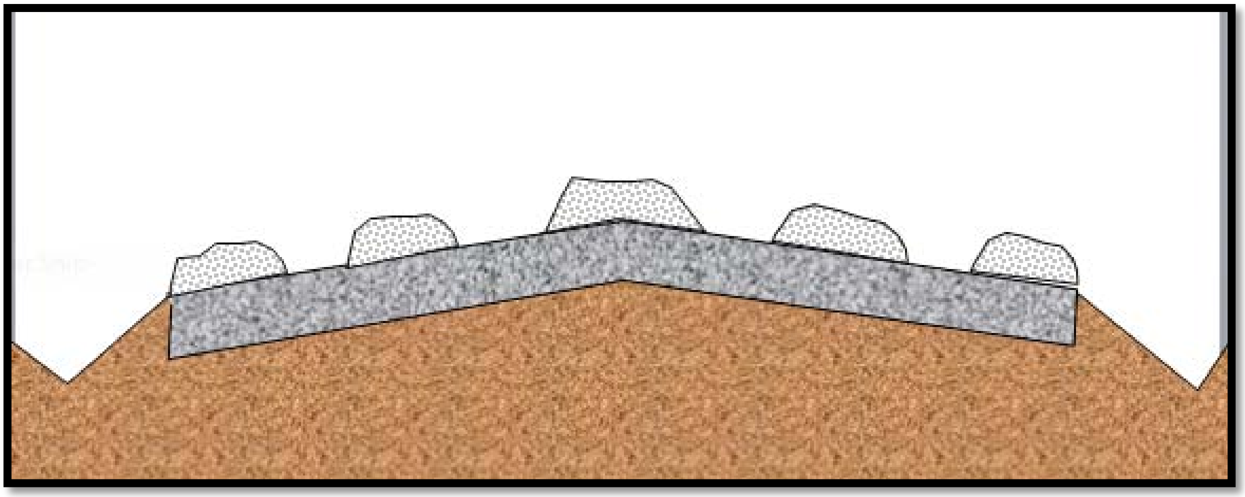

Figure 6: Typical location of float aggregate berms.

Discrete float aggregate berms must be identified by their width perpendicular to the road direction, their length parallel to the road direction and their average depth (thickness) of unconsolidated loose material. They also typically produce a distinct look that the remote sensing system should be able to detect. In other words, the remote sensing system needs to detect the features when present and quantify them within a precision of +/- two inches (5.1 cm). Width and length measurements must have a precision of +/- four inches (10.2 cm). Each discrete float aggregate berm must be measured and recorded separately. Float berm data must be recorded at intervals of at least every ten lineal feet per sampling unit as measured with the direction of the road. Aggregate berms that are less than ten feet (3.05 m) in length or four inches (10.2 cm) in width will not be considered significant. Float aggregate berms will be classified into three bins: less than two inches deep, two to four inches deep, and more than four inches deep.

Dust

The loss of fine material in the form of dust from unpaved roads a commonly cited nuisance from road users and can be the source of safety concerns because of reduced visibility. Dust can be a concern from a pavement management aspect due to the fact that the particles that are most susceptible for loss as dust are likewise responsible for giving a gravel pavement its plasticity which is a desirable physical quality. Dust is a desirable feature to collect, but is not mandatory for the success of the remote sensing system as it is a factor that may influence operational safety on a road, but is not a direct measurement of pavement quality.

If dust were assessed, the remote sensing system would need to be capable of measuring the opacity of a dust plume crated by a pilot vehicle at the center of the road at intervals of fifty, one hundred and two hundred feet behind the vehicle (15.24 m, 30.48 m, and 60.96 m).

Critical Indicators for Unpaved Road Condition Assessment Summary:
Critical leading indicator:

* Cross section (loss of crown)

Trailing indicators:

* Loose aggregate
* Corrugations
* Potholes
* Ruts

Desirable but optional:

* Road-side drainage
* Dust

Derived Requirements

The sizes of the required distress features, and their ranges, coupled with the assumed flight profiles of the remote sensing system will impose other (indirect) requirements on the sensing system. This section details these derived requirements.

Flight Geometry
From the requirement that the system be fast and easy to deploy, we infer that one will not have to file formal flight-plans with the FAA; this implies that the UAV will not be flying above the FAA-imposed limits of 400ft (121.92 m). For a manned platform, we assume that we will be flying at the lowest practical altitude.

Field-of-View/Focal Length
The road and adjacent drainage are specified as no larger than a total of 36 feet / 10.97 m (two 12 ft / 3.66 m lanes and two 6ft / 1.83 m ditches). Assume that the platform can reliably navigate down the road, never moving beyond its edges. This means that the sensor field-of-view (FOV) must be twice the width of the region of interest, or 72 feet (21.95 m). This FOV corresponds to an angle of about 11^{o}; this angle is achieved with a camera lens with a 75mm focal length.

Resolution
It is clear from the requirements on distress features that the smallest, and thus the most difficult to image, feature is on the order of 1 inch (2.5 cm). For a 75mm lens with a FOV of 72 feet, this would correspond to 864 1 inch (2.5 cm) samples across the road. Oversampling is needed by at least twice (the Nyquist sampling criteria) to be able to measure features of 1" / 2.5 cm, so this would be 1728 pixels across the road, and would correspond to the sensor size of a 4 million pixel (4MP) digital camera. Typical consumer-grade cameras are available currently with 16MP, which provides ample oversampling to find the feature of interest.

Speed of Image Capture
The worst-case data collection, in terms of speed of image capture, is for a manned, fixed-wing platform. These typically cannot fly slower than about 75mph (33m/s). Since the along-track FOV is 94ft (29m),

this implies that, for sufficient overlap (50%), the camera must collect images no slower than once each 0.4s, or 2.25 frames per second. Most consumer-grade digital cameras can collect at least this fast.

In summary, the sensor system should have at least the following properties:

1. Flight altitude ~400ft (~122 m)
2. 11º FOV at that altitude -> 75mm lens
3. >4MP sensor
4. >2.25 fps imaging rate

There are other requirements on the sensor that cannot be determined at this time, since they will depend on experimentally-collected data (e.g. the maximum aperture of the lens will need to be determined based on the illumination and reflectivity of typical scenes, not known at this time).

Summary of Requirements

The following table summarizes the requirements for a successful system. Metric units are available within the main document.

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’
17	Field-of- View	Sensor	11 degrees
18	Resolution	Sensor	0.5”, (4M pixels for this geometry)
19	Image Capture Speed	Sensor	2.25 frames per second

Use of the Requirements and Next Steps:

These requirements will be used to guide the next steps in the project, including the algorithms needed to analyze the phenomena affected by each useful feature characteristic of road condition (Task 3: Phenomenology) and the list of candidate commercial sensors likely to be able to meet the phenomenology needs (Task 4, Sensor Selection). As the project develops, these tasks will in turn affect the selected platform (Task 5), we have proposed to evaluate a typical, manned, fixed-wing aircraft, as well considering possible UAV airborne platforms including fixed-wing, helicopter, and aerostatic (e.g. blimp) unmanned vehicles, to see if and when these platforms best meet the needs of the needs of the transportation user community, as evaluated through this Requirements Definition Task and the input of the Technical Advisory Committee. Either one, or both platforms, could be selected through this process.

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Characterization of Unpaved Road Condition Through the Use of Remote Sensing

Deliverable 2-A: State of the Practice of Unpaved Road Condition Assessment

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Deliverable 2-A: State of the Practice of Unpaved Road Condition Assessment

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Introduction

The first step in solving any problem is to understand it fully; this ensures that any solution builds upon existing knowledge. This document details the current state of the practice in unpaved road condition assessment. It complements the Deliverable 1-A report, "Requirements for Remote Sensing Assessment of Unpaved Road Conditions", submitted to USDOT RITA on 10/31/2011 and available in its current form at www.mtri.org/unpaved (specifically, at http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del1-A_RequirementsDocument_MichiganTechUnpavedRoadsr1.pdf).

Determining how to manage unpaved roads has been an ongoing problem for road-owning agencies in the United States as well as in other parts of the world. Unlike condition assessment methods for paved roads, unpaved road assessment methods are not well understood by most transportation professionals (Skorseth, 2002). The following factors not present in paved roads complicate unpaved road condition assessment methods, contributing to their lack of use: design and construction variability, rapidly changing road conditions, and disproportionate maintenance to management costs.

Unpaved roads vary significantly in their design, construction, and use which impacts the maintenance practices performed on them. For example, a forest access road that is “cut in” to the surrounding terrain and has no structural layer of aggregate will perform significantly different than a full-width gravel county road that is designed and operated similarly to its paved counterparts.

Unpaved road conditions change rapidly in comparison to paved roads. The condition of an unpaved road may change significantly from month to month, whereas the condition of a paved road typically remains relatively static over long periods of time. This necessitates more frequent inspections than are typical on paved roads.

Unpaved roads are typically lower-cost assets than their higher-cost paved counterparts. Maintenance interventions for unpaved roads tend to cost significantly less per mile than those performed on asphalt or concrete pavements. However, management of unpaved roads requires routine collection of condition data which can become expensive, potentially outweighing any cost savings that could have been achieved through good management. For example, an assessment method that helps determine the optimum times to grade an unpaved road, but requires condition data that costs several thousand dollars a mile to collect, may prove more costly to implement than simply performing the grading activity more frequently than necessary. In addition, highly traveled unpaved roads may be more costly to manage over their life cycle than a paved road in the same setting.

Several methods for assessing unpaved road conditions and managing their maintenance have been established and are used by road-owning agencies, while other rating techniques are still considered current research. The assessment methods can be classified into the following categories: visual, combination (visual and direct measurement), and indirect data acquisition with specialized equipment. The techniques that use specialized equipment to indirectly acquire road data were initially developed for use on paved roads, but are now gradually making their way into use for unpaved road assessment. These include laser profilometer, ground penetrating radar (GPR), accelerometers, and digital video. Others, such as using a remote sensing system in an manned or unmanned aerial vehicle for data acquisition, are more on the cutting edge. Some of the rating methods have established processes that can incorporate the acquired data into asset management plans, while other techniques must still be detailed for use on unpaved roads.

Definition of Terms

The unpaved road assessment methods outlined in this report are described by their authors using an array of definitions and terms; many of which are synonymous with different terms used by other methods. Definitions for the most commonly used terms and their synonyms are provided below.

Characteristics, also referred to as **conditions** or **attributes**, are the aspects of a road that define its physical structure (individual condition types defined below) (Skorseth, 2000).

A road **cross-section**, also referred to as **cross slope** or **crown**, is the steepness of the slope of a road from its centerline to the edge of the shoulder (Skorseth, 2000; Jones, 2003).

Drainage, or road side drainage performance, is based on the suitability of drainage ditches and culverts (if any) present, and the amount of debris and overgrowth (Department of the Army, 1995; Jones, 2003).

The **gravel quality** of a road is based on gradation (which relies on the correct mixture of sand, aggregate, and fines) and plasticity. The presence of excessive silt or clay, unbound sand, and oversized aggregates help to identify gravel deficiency (Skorseth, 2003).

Gravel roads typically have a **gravel thickness**, or surface course thickness, of six inches (150mm) that wears away over use and time. A deficiency of gravel in this layer exposes the sub base to environmental conditions and traffic (Jones, 2003).

Distresses, also referred to as **defects** (van der Gryp, 2007), are a characterization of the types of damage (individual distress types defined below) that have developed on a roadway. Distresses are typically the outcomes of road condition problems or can be a result of traffic loading (Skorseth, 2003).

Corrugations, also referred to as **washboarding**, on an unpaved road are caused by traffic and are compounded by dry conditions and low quality gravel (Skorseth, 2003). Washboarding typically results in ridges that have spacing as little as eight inches (20.3 cm) crest to crest, to as large as 40 inches (1.02 m) crest to crest (Department of the Army, 1995). Washboarding tends to result in corrugations that have similar crest to crest spacing (period) and depths (magnitude) (Department of the Army, 1995).

Fine material loss or **dust** on a roadway is an indicator of the gravel layer quality. Particles that are most susceptible for loss as dust are responsible for the gravel layer plasticity which is a desirable quality (Skorseth, 2003).

Erosion on a roadway is a crack, crevice, or channel that can appear in the longitudinal and transverse directions. Erosion occurs because material washes away in areas such as those that experience heavy acceleration and deceleration such as the bottom and top sections of steep hills (WCPA, 2007).

Loose aggregate on a roadway is typically caused by heavy traffic or poor materials and forms linear berms of segregated loose aggregate particles. Typically, loose aggregate berms are six to 24 inches (15.2 cm - 61.0 cm) in width (perpendicular to the road direction) and run longitudinally with the direction of the road for significant distances (Department of the Army, 1995).

Potholes are roughly bowl shaped depressions in the surface of a pavement and are typically less than three feet (0.91 m) in diameter. Water can accelerate pothole growth by collecting in these depressions and weakening the surrounding surface making it susceptible to further damage by traffic (Department of the Army, 1995; Skorseth, 2003; WCPA, 2007).

Ruts, also referred to as **rutting**, are longitudinal depressions in the wheel path of a roadway that are caused by excessive vehicle tire loads. Ruts can fill with water causing it to drain along the road instead of away from the road (Department of the Army, 1995; Skorseth, 2003). Minimum width of a typical vehicle tire is six to seven inches wide (15.2 cm - 17.8 cm) and can be as large as the wheel path travel area of the lane, approximately 24 inches wide (0.61 m) (Department of the Army, 1995).

Methods

Several methods for assessing unpaved road conditions have been developed. These methods range from very simple, low-cost inspection methods to very complex and involved methods, some of which are still being researched. Each assessment method outlined in this report can be broadly classified as one of the following methods: visual, combination (visual and direct measurement), and indirect data acquisition.

Visual

In visual methods, trained personnel observe the type and severity of road conditions and distresses. No physical measurement equipment (rulers, hand level, measuring tape) is used.

Visual methods include:

- Unimproved PASER & Gravel PASER
- Road Surface Management System
- Standard Visual Assessment Manual for Unsealed Roads, TMH12
- Central Federal Lands, Highway Division - Subjective Rating System

Combination (Visual and Direct Measurement)

Combination methods rely on trained personnel to use direct measurement, performed through the use of basic measuring equipment (rulers, hand level, measuring tape), in addition to their visual observations, to determine the type and severity of road conditions and distresses.

Combination methods include:

- Central Federal Lands, Highway Division - Objective Rating System
- Unsurfaced Road Condition Index (URCI)

Indirect Data Acquisition

Indirect data acquisition methods use specialized equipment to indirectly acquire road condition data. These include laser profilometers, ground penetrating radar (GPR) units, accelerometers, and digital video recorders. These methods were initially developed for paved road assessment and are now making their way into use for unpaved road assessment.

Indirect data acquisition methods include:

- Ground Penetrating Radar
- Remote Sensing – Unmanned Aerial Vehicle (UAV)
- Survey – Ultralight Aircraft
- Road Roughness Using Accelerometer Technology by Opti-Grade®

The following sections provide a more detailed overview of all of the methods. Where available, the costs and speed of data collection, record keeping approaches, and data application are also included. Additionally, limitations of each technique or method are discussed.

Visual Methods

VISUAL: Unimproved PASER & Gravel PASER

Overview

The PASER system was developed to allow road managers to quickly and cost-effectively assess conditions that can guide road maintenance decisions, and at the same time be easily communicated to elected officials and the public. The Pavement Surface Evaluation and Rating (PASER) system was developed by the Wisconsin Transportation Information Center, University of Wisconsin-Madison (PASER manuals are available online at http://tic.engr.wisc.edu/Publications.lasso). This system has separate evaluation methods and rating criteria for each discrete pavement type that include unimproved earth pavements and gravel pavements. The PASER system is used extensively throughout Michigan and Wisconsin for state-wide data collection efforts because its use is mandated. The system is also used by other agencies throughout the United States on an agency by agency basis, mostly at the local agency level rather than by state departments of transportation (Walker, 2002b; Walker, 2001).

The PASER system is a visual assessment method that allows users to classify 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. Because PASER is a visual assessment method, there is an emphasis on the rater's ability to estimate the severity and extent of road characteristics and distresse, rather than focusing on physical measurements. Road segments are broken by project segments with aid of historical records or where distress patterns change in the field. The PASER rating method is intended to be applied to all of the road segments in a road network, rather than relying on samples of the road network to be representative of larger areas. Assessment of road segments is typically completed in a slow-moving vehicle that stops periodically to allow raters to more closely inspect questionable road characteristics and distresses (Walker, 2002b; Walker, 2001).

The Unimproved Earth PASER System

The Unimproved Earth (PASER) system was developed by the Wisconsin Transportation Information Center in 2001. The system classifies roads into one of four rating categories (rating of 1 to 4) with a rating of 1 being very poor and a rating of 4 being very good. Rating categories are defined based on the presence or absence of five characteristics, and the extent and severity of four distress types. Road characteristics and distresses considered during a PASER condition assessment are defined in Table 1 and rating category descriptions are shown in Table 2 (Walker, 2001).

Table 1. Unimproved Earth PASER System – Road characteristics and distresses assessed (Walker, 2001).

Road Characteristics and Distresses	Assessment Criteria
Surface Material Makeup	Assessed based on the quality of the surface material, with more granular material being considered favorable and material with a high silt or clay content being consider less favorable.
Crown	Segments possessing a cross slope that allows positive drainage from the centerline of the road to its edge are considered favorable, and segments with no cross slope considered unfavorably for rating.
Drainage	Road segments that have been constructed to include provisions for drainage ditches and culverts where necessary are considered favorably, while segments that do not have provisions for drainage are considered negative.
Profile and Ride	This factor is assessed based on the longitudinal profile of the road and the comfortable speed that users can operate on the road. Road segments that have been graded to include cut and fill sections and have higher comfortable operating speeds (>25 mph) are considered favorably while road segments that follow the natural terrain and require low speeds are considered negatively.
Access	This factor is assessed based on the span of time the road can be used for vehicle traffic during the year, with road segments that have year round access being considered favorably, and road segments that are untraversable during parts of the year considered negatively (Walker, 2002b; Walker, 2001).
Ruts	Ruts have a minimum of width of a typical vehicle tire (six to seven inches wide / 15.2 cm to 17.8 cm) and can be as large as the wheel path travel area of the lane (approximately 24 inches wide / 0.61 m). Ruts are classified based on their depth.
Potholes	Potholes are classified based on the frequency of their occurrence.
Rocks and Roots	The presence of large stones, boulders and tree roots are considered a distress in the PASER unimproved earth assessment system. This factor is assessed based on its presence. However, no guidance or metrics for rating this distress are given with the method.
Washboarding	Washboarding is assessed based on its extent (Walker, 2002b; Walker, 2001).

Table 2. Surface ratings adapted from the Unimproved Pavement Surface Evaluation and Rating (PASER) Manual visual method (Walker, 2001).

Surface Rating	General Description	General condition, distress, and improvement	
4	Very Good	Graded, cut & fills. Crown present. Drainage: ditches & culverts. Ride: > 25 mph comfortable.	Ruts & potholes: not significant. Surface material: sandy, stable. Access: available year around. Improvement: not needed.
3	Good	Grading: limited. Crown: limited. Drainage: limited. Ride: 15 – 20 mph comfortable.	Ruts: < 3" deep. Potholes: few. Washboarding: scarce. Access: available year around except in severe weather. Improvement: routine maintenance, spot grading.
2	Fair	Grading: ungraded, cut & fills. Crown: little to none. Drainage: little to none. Ride: < 15 mph comfortable.	Ruts & potholes: occasional. Access: limited during & after rain. Improvement: required to improve drainage, repair distresses, and improve condition to good.
1	Poor	Recreational trail. Ride: < 10 mph comfortable.	Ruts & potholes: severe. Access: may be restricted extensively. Improvement: reconstruction needed to improve access, repair distresses, improve road to good.

The Gravel PASER System

The Gravel PASER system was developed by the Wisconsin Transportation Information Center in 1989 (Walker, 2001). The system classified roads in to one of five categories (ratings of 1 to 5) with a rating of 1 being very poor and a rating of 5 being very good. Rating categories are defined based on the presence or absence of three road characteristics, and the extent and severity of five distress types. Characteristics and distresses considered during a Gravel PASER condition assessment are shown below in Table 3 and rating category descriptions are shown in Table 4 (Walker, 2002b).

Table 3. Gravel PASER System - Road characteristics and distresses assessed (Walker, 2002b).

Road Characteristics and Distresses	Assessment Criteria
Crown	Estimation of the elevation difference between the centerline of the road and the edge of the pavement crown measurements are used to classify this attribute into three bins: six to three inch (15.2 cm to 7.6 cm), less than three inch (<7.6 cm) crown, and zero to negative crown.
Gravel Layer	Aggregate thickness measurement guidelines to determine suitability are not provided beyond indicating that a high quality pavement will have ten to six inches (25 cm to 17.6 cm) of aggregate. Surface area coverage guidelines are provided for lower rating classifications.
Drainage	Road segments that have been constructed to include provisions for drainage ditches and culverts where necessary are considered favorably while segments that do not have provisions for drainage are considered negatively (Walker, 2001).
Ruts	Ruts are classified based on their depth in ranges of: less than one inch (2.5 cm), one inch to three inches (2.5 cm to 7.6 cm), and over three inches (>76 cm).
Potholes	Potholes are classified based on the frequency of their occurrence and depth with ranges of: less than two inches (<5.1 cm), two to four inches (5.1 cm to 10.5 cm), and over four inches (>10.5 cm).
Dust	Dust is assessed on its presence or absence and is only a determinant factor for the highest two ratings in this system.
Loose Aggregate	Loose aggregate is assessed based on the depth of loose material present with ranges of: less than two inches (< 5.2 cm), and over four inches (>10.6 cm) deep (Walker, 2001).
Washboarding	Washboarding is assessed based on the depth of its corrugations in ranges of: one to two inches (2.5 cm to 5.1 cm), and over three inches (> 7.6 cm) deep. (Walker, 2001)

The Gravel PASER Manual and the Unimproved PASER Manual provide full details of the criteria for each condition category with descriptions and pictures of the distresses as well as examples of typical conditions that exist in each rating category (Walker, 2002b).

Record Keeping

There are minimal data fields necessary to record PASER data, because the system emphasizes the use of judgment in estimating distress extent and severity, rather than physical measurements. Typical PASER records consist of location information for the segment of road being rated, the pavement type for the segment**,** and the PASER number. In some instances, raters may also provide notes on the types of distresses that are present as a basis for their rating category decision (Walker, 2002b; Walker, 2001).

Table 4. Surface ratings adapted from the Gravel Pavement Surface Evaluation and Rating (PASER) Manual visual method (Walker, 2002b).

Surface Rating	General Description	Visible Distress	General condition/ treatment measures
5	Excellent	No visible distresses or dust. Excellent: surface and ride.	New construction/total reconstruction. Excellent drainage. Little/no maintenance required.
4	Good	Dry conditions: dust. Loose aggregate: moderate. Minor washboarding.	Recently regraded. Good crown and drainage throughout. Adequate gravel for traffic. Maintenance: routine grading, dust control may be needed.
3	Fair	Crown: 3”- 6”. Adequate ditches: > 50% of roadway. Some additional aggregate may be necessary in some areas to correct washboarding/isolated potholes/ruts. Some culvert cleaning needed. Washboarding: 1”-2” deep, 10%-25% of roadway. Dust: partial obstruction of vision. Rutting: None or less than 1” deep. Potholes: occasional, less than 2” deep. Loose aggregate: some, 2” deep.	Visible traffic effects. Maintenance: regarding, ditch improvement, culvert maintenance. Areas may require additional gravel.
2	Poor	Crown: < 3”. Adequate ditches: < 50% of roadway. Ditches may be filled, overgrown, show erosion in areas. 25% or area: little or no aggregate. Culverts partially full of debris. Washboarding: > 3” deep, > 25% of area, moderate to severe. Rutting: 1”-3”, > 10%-25% of area. Potholes: 2”-4”, > 10%-25% of area. Severe loose aggregate (over 4”).	Less than 25 mph travel speed required. Additional new aggregate needed. Maintenance: major ditch and culvert construction required.
1	Failed	Roadway crown: nonexistent or road is bowl shaped. Extensive ponding. Ditching: little, or none. Filled or damaged culverts. Rutting: > over 3” deep, > 25% of the area, severe. Potholes (over 4” deep), over 25% of area. No aggregate: > 25% of areas.	Travel: difficult Frequent road closures. Needs complete rebuilding and/or new culverts.

Data Collection Rate and Equipment

PASER data collection requires minimal collection equipment. At a minimum, PASER data collection requires: a data entry sheet to record the location of ratings and pavement type, a data collection survey vehicle that can be any type of automobile, and a trained rating technician. Many agencies choose to use some form of GPS-enabled data collection equipment to simplify data record keeping, reduce collection time, and reduce road segment location error. This data collection equipment can include commercially available handheld survey units and/or specialized software designed to run on a GPS enabled laptop. RoadSoft asset management software (see Figure 1) from Michigan Tech's Center for Technology & Training (http://www.roadsoft.org/) is one example of a software package that includes a laptop data collection utility that reduces the time necessary to collect PASER data.

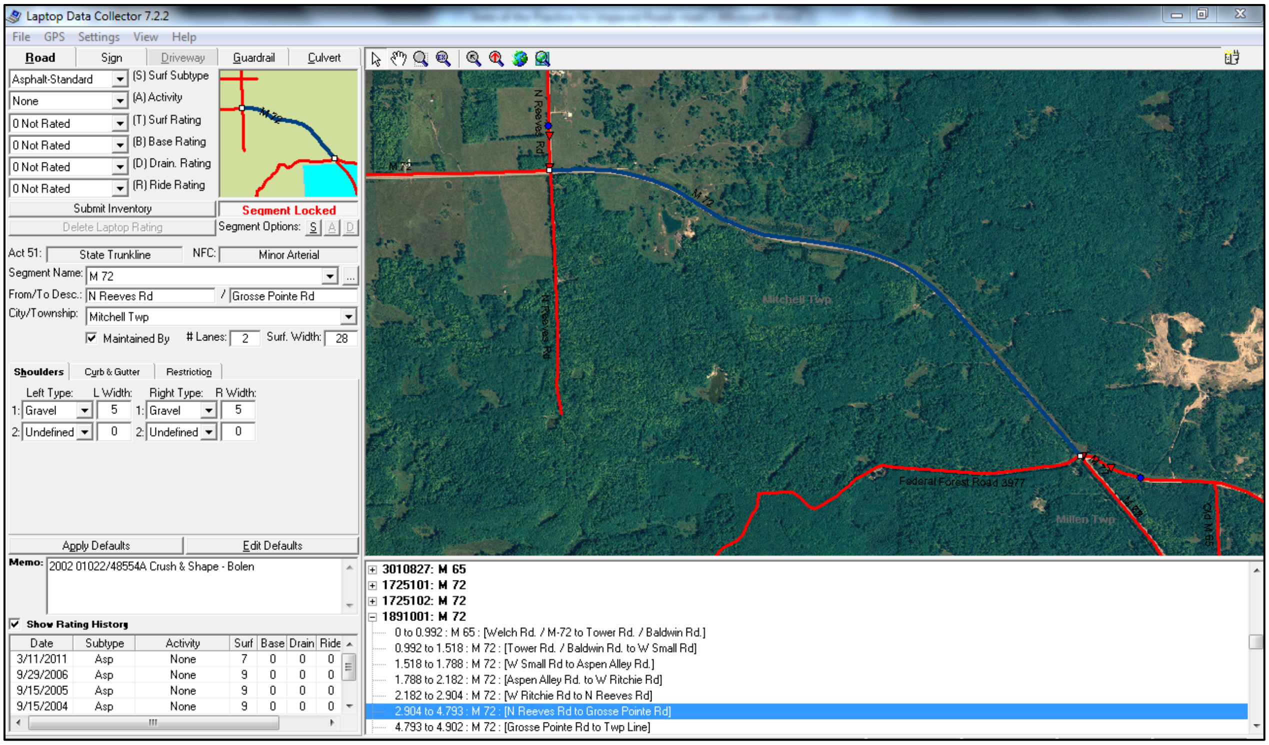


Figure 1: RoadSoft v7.2 Laptop Data Collector utility for collection of PASER data.

The number of data collection personnel used to collect PASER data varies by agency. Some agencies use a single data collection technician that drives the road system alone, while other agencies use data collection teams of two to three people. When multiple data collection personnel are used, a division of labor allows for more streamlined collection. For example, one person on the collection team is assigned to driving the collection vehicle, the second person is assigned to rating, and the third person is assigned to record keeping. Using multiple data collection staff is believed to be safer than using a lone data collector because the driver can focus exclusively on driving, rather than on detecting and rating pavement distresses or recording rating information (Michigan TAMC, 2009).

Data collection productivity with the PASER rating system is relatively high, given the limited resources necessary for data collection. Data collection rates using a three-person team can range from 12.4 centerline miles (19.96 km) of road rated per hour to 20.6 centerline miles (33.15 km) of road rated per hour (CRAM / MDOT). Rating teams using fewer than three staff will collect data at lower productivity rates, however they also can collect data at a lower overall costs since the main cost component is staff labor. For example, the Michigan TAMC reimburses agencies at the rate of $11.65 per centerline mile of PASER data collected on the paved non-federal aid road network. This reimbursement rate was based on an unpublished cost study using productivity and labor estimates for data collection teams.

Michigan Modifications of the PASER System

The Michigan Transportation Asset Management Council (TAMC) was established under Public Acts 499 (HB 5396) to implement asset management practices on all public roads in the State of Michigan. As part of that mission TAMC funds the annual collection of PASER data for public roads in the State and provides training for road raters and sets requirements for members of data collection teams (Michigan TAMC, 2009). TAMC requires the use of the PASER system for condition ratings on asphalt, concrete, and sealcoat pavements. Initially TAMC also required the use of the PASER system for gravel and unimproved earth roadways. However, after experimenting with the use of the PASER rating system on gravel and unimproved earth, TAMC determined the unimproved earth and gravel PASER rating systems were not adequate for their needs. Currently, TAMC does not collect pavement condition data on gravel or unimproved earth roads, because a suitable rating system that can be deployed cost-effectively is not available. The interest of TAMC in this project and their willingness to provide data as their main cost-share contribution is based in part on their experience with attempting to use the PASER rating systems for unpaved roads.

For a brief period, TAMC used a modification of the original PASER rating system that was developed by Mr. Ron Young, P.E., the Alcona County Road Commission Engineer. The Michigan Modified PASER Gravel system has five rating categories that are numerically labeled from 2 to 10 which allow rating of 2,4,6,8, and 10. This change was completed to make the Michigan Modified Gravel rating system similar to the PASER system for asphalt and concrete pavements, where a 10 point scale (10 discrete categories) is used. The Michigan Modified PASER Gravel rating system also includes other defining criteria in an attempt to make categories more discrete (Table 5) (Young, 2003).

Table 5. Michigan Modified PASER Gravel Rating System Guide (Young, 2003).

PASER Rating	Description	Condition/Defects	Remedy/Action
10	Excellent	New gravel surface. Well Crowned with excellent drainage. Surface tight and stable. Dust controlled. Roadside likely open.	None.
8	Very Good	Adequate gravel, well crowned, and well drained. Moderate loose aggregate but maintains shape for significant time after grading. Dust may be controlled or dusty when dry. Roadside likely open.	Routine grading.
6	Good	Adequate gravel (4” minimum), well crowned, at least 50% well drained. Surface loose but maintains shape for limited time after grading. Dusty when dry. Roadside at least 50% open.	Routine grading with spot applications of gravel and/or binder required over less than 50% of length. Some drainage improvement and culvert maintenance may be needed.
4	Fair	Limited gravel. Little to no crown. Less than 50% well drained. Roadside may be heavily vegetated and encroaching on roadway. Frequent low speed required.	Substantial grading with additional gravel and/or binder needed over more than 50% of length. Drainage improvement and/or ditch and culvert cleanout or replacement needed. May require roadside clearing.
2	Very Poor	Very limited gravel, little to no crown, little to no drainage. May be impassable for extended periods and/or over extended length. Very low speed and/or special vehicle frequently required.	Extensive grade improvements including: roadside clearing, base drainage, and gravel improvements needed over fully or nearly full length.
0	Not Rated		

Note: Performance and stability will vary considerably with traffic volume and type, drainage, and sub base.

Wyoming Modifications of the PASER System

Wyoming Technology Transfer Center at the University of Wyoming developed a gravel roads assessment system that has been proposed as a solution for management of rural gravel roads. The system was developed as part of a study that evaluated road characteristics and distresses, in an effort to predict the deterioration of gravel roads in rural Wyoming. Following the study, the assessment method was formalized and implemented on a county scale as a pilot project. The system has been used subsequently for studies to assess the damage on the Wyoming gravel road network caused by increased heavy truck traffic (WTTC, 2010).

The Wyoming gravel assessment system is a modification of the PASER gravel road assessment system that is similar in application, method, and record keeping. The Wyoming system uses similar evaluation criteria as the PASER system for rutting, dust, loose aggregate, potholes and washboarding, but does not consider crown, drainage, and gravel quality as criteria. The Wyoming system also includes additional criteria for rating that includes an assessment of comfortable riding speed (WTTC, 2010). The authors of this study were contacted to obtain information regarding data collection costs. Costs could not be obtained in time for submission of this document, but will included in later reporting when available.

The Wyoming system has 10 rating categories that are ordered from 1 to 10, with 10 being the best rating and 1 being the worst. The Wyoming rating scale is essentially a doubling of the five point gravel PASER rating scale. It includes five intermediate condition categories that have similar distress criteria to the traditional five PASER condition categories, but differentiates ratings by travel speed (Table 6). For example, a Gravel PASER rating of 4 is similar in distress to a Wyoming system rating of 7 or 8, with the determining factor between a rating of 7 or 8 being the travel speed (WTTC, 2010).

Table 6. Wyoming rating scale (WTTC, 2010).

Rating	Descriptor	Speed mph*	Distresses** Adapted from the Gravel - PASER manual
10	Excellent	60+	
9	Very Good	50-60	
8	Good	45-50	Dust under dry conditions; Moderate loose aggregate; Slight washboarding
7	Good	40-45	
6	Fair	32-40	Moderate washboarding (1”- 2” deep) over 10%-25% of area; Moderate dust, partial obstruction of vision; None or slight rutting (less than 1” deep); An occasional small pothole (less than 2” deep); Some loose aggregate (2” deep)
5	Fair	25-32	
4	Poor	20-25	Moderate to severe washboarding (over 3” deep) over 25% of area; Moderate rutting (1”-3”) over 10% - 25% of area; Moderate potholes (2”-4” deep) over 10%-25% of area; Severe loose aggregate (over 4”)
3	Poor	15-20	
2	Very Poor	8-15	Severe rutting (over 3” deep) over 25% of area; Severe potholes (2”-4” deep) over 25% of area; Many areas (over 25%) with little or no aggregate
1	Failed	0-8	

Deliverable 2-A: State of the Practice of Unpaved Road Condition Assessment

Summary

The PASER data collection system is a well-established condition rating system with a large user base in the Midwest, specifically in Michigan and Wisconsin. The system has been shown to work well with asphalt, concrete, and sealcoat pavements for both large area network level assessments, and more detailed project level assessments. The PASER system for these pavement types produces data at a low per mile cost because there is no specialized equipment and limited actual field measurement necessary. However, several concerns exist with the use of the Unimproved Earth and Gravel PASER system. Unimproved Earth and Gravel PASER system categories are not as well defined as the concrete and asphalt PASER systems. This can lead to ambiguity when rating these pavement types. For example, in the Gravel PASER rating system, a pavement exhibiting washboarding between one and two inches deep is indicative of a PASER rating 3. However, the next rating down in the scale (PASER 2) has an acceptable washboarding depth of greater than four inches (10.16 cm) deep. These criteria create an ambiguity for pavements that exhibit washboarding of three inches (7.62 cm) deep because the distress level does not fit into either of the two categories.

VISUAL: Road Surface Management System, University of New Hampshire & FHWA

Overview

The Road Surface Management System (RSMS) and its accompanying software, RSMS®, was developed for use by local agencies to create road network maintenance plans and to assist in the prioritization of road projects. The method was developed by the University of New Hampshire, in conjunction with the USDOT Federal Highway Administration (FHWA) in 1992 for small and medium sized municipalities for paved and unpaved roads (Goodspeed, 1994). According to the University of New Hampshire, the RSMS method currently has approximately 5,000 users in seven countries. The system is especially popular in the New England states near where it was originated. It is estimated that over 100 agencies within New Hampshire use the RSMS system (Goodspeed, 2011).

The RSMS system is used to rate homogenous road segments that are segregated by the rater's judgment based on having similar construction and maintenance histories, as well as similar distress patterns. Ratings are developed for the entire unpaved road network on a segment-by-segment basis. Each rating is representative of the predominant condition of the road segment. Assessment of road segments is typically completed from a slow moving vehicle that stops periodically, to allow raters to more closely inspect conditions (Goodspeed, 2011).

The RSMS rating system assesses seven road characteristics and distresses. Four distress criteria (corrugations, potholes, rutting, and loose aggregate) are classified by severity and extent. Severity is categorized as either low, medium, or high, based on distress depth. Extent is categorized as low, medium, or high, based on the percent of the surface area that is covered by the distress. Low extent indicates less than 10% of the surface area is covered with the distress, medium extent indicates 10% to 30% of the surface area is covered with the distress, and high extent indicates greater than 30% of the surface area is covered with the distress. The other three rating criteria (cross section, drainage, and dust) are classified only by qualitative condition, and are rated as good, fair, or poor. Criteria considered during an RSMS condition assessment for unpaved roads are shown in Tables 7 and 8 below (Goodspeed, 1994). Table 9 describes how the road characteristics and distresses are assessed.

Road Surface Management System (RSMS): Unpaved roads (Goodspeed, 1994).

Table 7. Severity and extent.

Distress	Severity	Extent
Corrugations	Low Medium High	Low: <10% Medium: 10% - 30% High: >30%
Potholes	Low Medium High	Low: <10% Medium: 10% - 30% High: >30%
Rutting	Low Medium High	Low: <10% Medium: 10% - 30% High: >30%
Loose Aggregate	Low Medium High	Low: <10% Medium: 10% - 30% High: >30%

Table 8. Condition.

Distress	Condition
Cross-section	Good Fair Poor
Drainage	Good Fair Poor
Dust	Light Medium Heavy

Table 9. Road Surface Management System (RSMS) - Road characteristics and distresses assessed (UNH TTC, 2011; UNH, n.d.)

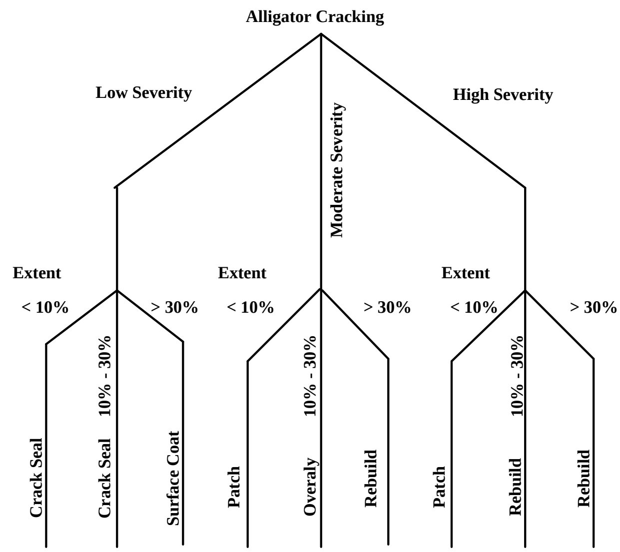
Road Characteristics and Distresses	Assessment Criteria
Corrugations	Corrugation severity is rated as low, medium, or high based on depth: low severity indicates corrugations are less than one inch (2.54 cm) deep; medium severity indicates corrugations are one to three inches (2.54 cm - 7.62 cm) deep; and high severity indicates corrugations are over three inches (>7.62 cm) deep. Corrugation extent is rated as low, medium, or high based on the percentage of surface area they cover: low extent indicates corrugations cover less than 10% of the area; medium extent indicates corrugations cover 10% to 30% of the area; and high extent indicates corrugations cover greater than 30% of the area.
Potholes	Pothole severity is rated as low, medium, or high based on depth and diameter: low severity indicates potholes are less than one inch (2.54 cm) deep and/or are less than one foot (30.48 cm) in diameter; medium severity indicates potholes are one to three inches (2.54 cm - 7.62 cm) deep and/or are one to two feet (30.48 cm - 60.96 cm) in diameter; and high severity indicates potholes are over three inches (>7.62 cm) deep and/or are over two feet (>60.96 cm) in diameter. Pothole extent is rated as low, medium, or high based on the percentage of surface area covered and by the number of potholes present: low extent indicates potholes cover less than 10% of the area and/or that there are less than five potholes present in a 100 foot (30.48 m) area; medium extent indicates potholes cover 10% to 30% of the area and/or that there are five to ten potholes present in a 100 foot (30.48 m) area; and high extent indicates potholes cover greater than 30% of the area and/or that there are greater than 10 potholes present in a 100 foot (30.48 m) area.
Rutting	Rut severity is rated as low, medium, or high based on depth: low severity indicates ruts are less than one inch (2.54 cm) deep; medium severity indicates ruts are one to three inches (2.54 cm - 7.62 cm) deep; and high severity indicates ruts are over three inches (>7.62 cm) deep. Rut extent is rated as low, medium, or high based on the percentage of surface area covered: low extent indicates ruts cover less than 10% of the area; medium extent indicates ruts cover 10% to 30% of the area; and high extent indicates ruts cover greater than 30% of the area.
Loose aggregate	Loose aggregate severity is rated as low, medium, or high based on depth: low severity indicates loose aggregate berms are less than two inches (5.08 cm) deep; medium severity indicates loose aggregate berms are two to four inches (5.08 cm - 10.16 cm) deep; and high severity indicates loose aggregate berms are over four inches (>10.16 cm) deep. Loose aggregate extent is rated as low, medium, or high based on the percentage of surface area covered: low extent indicates loose aggregate berms cover less than 10% of the area; medium extent indicates loose aggregate berms cover 10% to 30% of the area; and high extent indicates loose aggregate berms cover greater than 30% of the area.
Cross-section	Cross-section condition is rated as good, fair, or poor based on the crown or slope of a road (if any) and how it moves water: good condition indicates there is little to no ponding water, therefore there is a good crown; fair condition indicates there is some ponding water, therefore little or no crown; and poor condition indicates there is extensive ponding water, therefore depressions.
Drainage	Drainage condition is rated as good, fair, or poor based on the presence of water: good condition indicates clear, clean ditches and gutters; fair condition indicates some ponding water or erosion on the side of the road; and poor condition indicates there is running water on the road and ponding water on the side of the road.
Dust	Dust condition is rated as good, fair, or poor based on visibility obstruction: good condition indicates dust forms a thin cloud but does not obstruct visibility; fair condition indicates a moderately thick cloud of dust forms that partially obstructs visibility; and poor condition indicates a thick cloud of dust forms that severely obstructs visibility.

Record Keeping

Paper records can be used to record severity, extent, and condition data for each road segment. Alternately, the RSMS software can be used to store data during collection with use of a light pen and data sheet overlay on a touch sensitive tablet. The RSMS software incorporate a geographic information system (GIS) to store data associated with specific road segments (Goodspeed, 2011).

The RSMS system is intended to be used with a decision tree to help map out a potential maintenance option for a road segment, based on the type and extent of distresses. An example decision tree for alligator cracking on an asphalt surface is shown in Figure 2 below. Similar decision trees can be formed with individual agencies' decision policies; however, the system does not dictate the form of these trees, so individual application is left to the end user (Goodspeed, 1994).

Figure 2. RSMS: Example decision Tree (Goodspeed, 1994).



Data Collection Rate and Equipment

RSMS data collection requires minimal collection equipment. At a minimum, data collection requires the data sheets to record start and end mileage of the road segment and the particular distresses and characteristics described by the severity, extent, and condition (Goodspeed, 1994). The use of the RSMS software allows the collection of data via a handheld computer tablet for direct entry into a GIS database which speeds data entry. According to the University of New Hampshire, a trained rating team using hand held GIS devices can collect rating data for a town of approximately 50 road miles in approximately two days (Goodspeed, 2011).

Figure 3. RSMS hand held data collection unit (UNHTT, 2010).

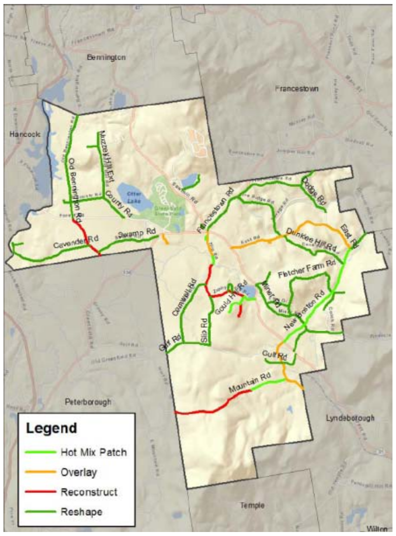


Figure 4. RSMS inventory summary screen shot (UNH TTC, 2011).

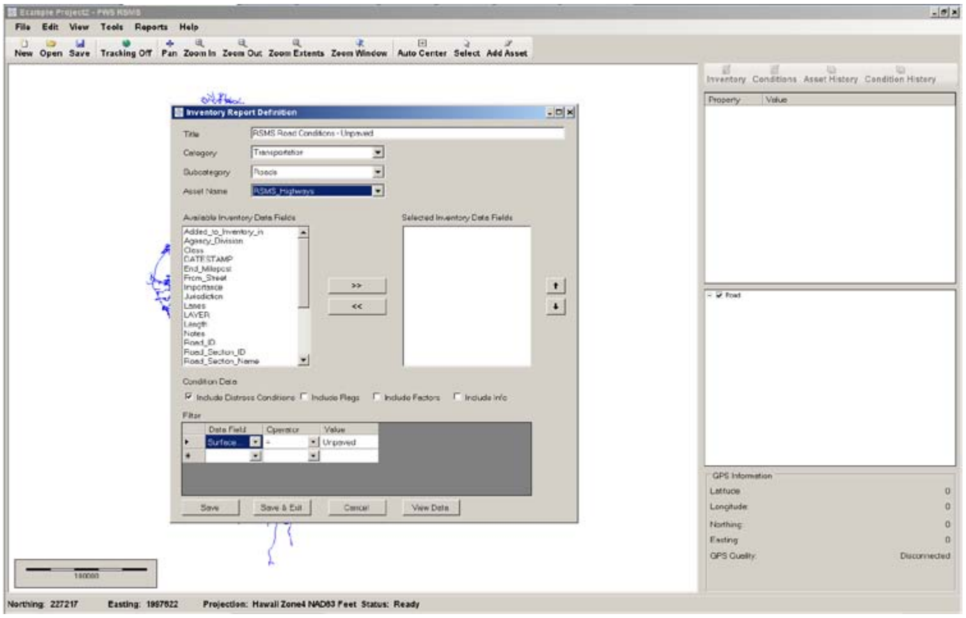


Figure 5. RSMS unpaved road inventory screen shot (PWS Solutions, 2011).

Summary

The RSMS system has many users in the United States and other countries. The assessment system is quick to deploy and provides a full census of the entire length of the road system and, as such, is not subject to the limitations of sampling. Criteria used to assess road characteristic and distress severity and extent are quantitative and easy to use. Other road condition criteria are based on qualitative descriptions which may lead to subjective ratings for these factors.

VISUAL: Standard Visual Assessment Manual for Unsealed Roads, TMH12

Overview

The Standard Visual Assessment Manual for Unsealed Roads (TMH12) was developed by CSIR Transportek for the Committee of Land Transport Officials (of South Africa) in 2000. This system was created to standardize ratings for maintenance requirements across provinces of South Africa, to allow a basis of comparison between jurisdictions (Jones, 2003). This distress identification system is used by the South African National Society, Ltd. to maintain the South African road network (SANRAL, n.d). A South African Act of Parliament established SANARL in 1998 as an independent company to manage, maintain, and develop roads for its sole shareholder, the Minister of Transport (SANRAL, n.d).

CSIR Transportek developed the Standard Visual Assessment Manual for Unsealed Roads system to provide guidelines that can be used nationally to rate an entire network of gravel roads. This system presents the user with three levels of assessment from which to choose, depending on their needs. The basic level of data acquisition for network level management assesses eight distresses that are evaluated visually to determine their severity or “degree” as it is referred to in this system. In the intermediate assessment level, users can collect additional information on the extent of these distresses by estimating the percentage of the road segment that they cover. The advanced level of data collection for this system includes additional parameters, so the user can tailor the assessment to their needs for use in a gravel road management system, for project management, or research. Users acquire data for this system from periodic assessments of road distresses and material properties using a combination of visual assessment, field examination, and testing (Jones, 2000; Jones, 2003; WCPA, 2007).

The assessment method requires the road network to be divided into segments using fixed points such as bridges, intersections, or installed markers (Jones, 2003). This method of segmentation allows for easy field identification of segment beginning and ending points, by relying on physical landmarks. However, it may reduce the homogeneity of rating segments since landmark placement is driving segmentation rather than road characteristic. The length of segments is recommended to be between 1.5 to three miles (2.5 km - 5 km) long (Jones, 2003). Road segments are rated as one contiguous segment (one rating per segment) with the rater allowed to make observation notes about locations that don’t conform to the overall condition of that segment(Jones, 2000).

Rating System Range

At the basic level in this system, road segment distresses are classified the by their severity (referred to as "degree") for network level management. The eight distresses evaluated for the basic assessment include potholes, corrugations, rutting, loose material, stoniness, erosion, loss of gravel, and dust. Potholes, corrugations, rutting, loose material, stoniness, and erosion are classified into numbered categories from 0 through 5, with 0 indicating the distress is not present and 5 indicating a high level of distress. Loss of gravel and dust are classified into named categories with three levels of severity. These categories are: thickness of the gravel layer, quality of the gravel layer, shape of the road profile, ability to drain water and roadside drainage, ability of traffic to navigate the road, quality of ride, and the amount of moisture present in the road. In the advanced level of this system, additional assessment categories are added. (Jones, 2000; Jones, 2003).

Distress severity information is primarily collected through visual assessment. Raters can stop and exit the vehicle to perform direct measurements when necessary. Specifics describing how the severity level for each distress is determined are shown in Tables 10 through 19 below (Jones 2000; Jones, 2003).

1. Potholes: Potholes are assessed based on their average depth in the road segment according to Table 10 below.

Table 10. Pothole degree (adapted from Jones, 2000).

Degree	Description
0	**Not present**
1	Depressions are slightly visible but cannot be felt while riding.
2	< 1 in (< 20 mm) deep
3	Large depressions that affect safe travel, ~1 to 2 in (20 to 50 mm)
4	~ 1 to 3 in (50 to 75 mm) deep
5	Pothole are dangerous requiring action, > 3 in (>75 mm)

2. Corrugations: The degree of severity of corrugations determined by riding in a vehicle traveling at an average speed and determining their effect of rider comfort. Additionally, a pick can be used to scrape corrugations and information should be noted whether they are fixed or loose. Table 11 below shows the criteria used for rating this distress.

Table 11. Corrugation degree (adapted from Jones, 2000).

Degree	Description
0	**Not present**
1	Cannot be felt while riding.
2	Can be heard and felt while riding but no reduction in vehicle speed is necessary.
3	Can be heard and felt while riding and reduction in vehicle speed is necessary.
4	Significant speed reduction is necessary.
5	Path of least resistance on the roadway is chosen because safety is compromised.

3. Ruts: Rut depth can be determined visually from a visual assessment or a straight edge and measuring tape can be used, depending on the accuracy desired. Rut severity is classified based on their average depth as shown in Table 12 below.

Table 12. Rutting degree (adapted from Jones, 2000).

Degree	Description
0	**Not present**
1	Ruts are slightly visible.
2	< 1 in (20 mm) deep
3	1 to 1.5 in (20 to 40 mm)
4	1.5 to 2.5 in (40 to 60 mm)
5	Rutting affects directional stability of the vehicle, > 2.5 in (60 mm)

4. Loose material: Aggregate berms of loose materials can be directly measured using a pick to scrape paths through the material to allow thickness to be measured. The severity of loose material is classified based on the thickness of the material on the road surface. Table 13 below illustrates the criteria for evaluating loose material.

Table 13. Loose Material degree (adapted from Jones, 2000).

Degree	Description
0	**Not present**
1	Loose material is just visible.
2	Loose material < 1 in (20 mm) deep
3	Loose material 1 to 1.5 in (20 to 40 mm)
4	Loose material 1.5 to 2.5 in (40 to 60 mm)
5	Loose material > 2.5 in (60 mm)

5. Stoniness: Stoniness is the measure of oversize stones that are left on the roadway when fines have migrated elsewhere. Stones can be fixed or loose as shown in Table 14 and 15. Assessment is most commonly conducted within a vehicle traveling at an average speed.

Table 14. Stoniness degree - fixed (adapted from Jones, 2000).

Degree	Description
0	**Not present**
1	Slightly visible but cannot be heard or felt while riding.
2	Protruding stones can be felt and heard, but speed reduction is not necessary. Blading is not affected.
3	Speed reduction necessary. Road is bladed with difficulty.
4	Protruding stones require evasive action
5	Vehicles avoid protruding stones or drive slowly. Road cannot be effectively bladed.

Table 15. Stoniness degree - loose (adapted from Jones, 2000).

Degree	Description
0	**Not present**
1	Few loose stones 1 to 2 in (26 – 50 mm). Vehicle can change lanes safely.
3	Many loose stones 1 to 2 in (26 - 50 mm) or few loose stones 2 in (> 50 mm). Stones influence the vehicle when changing lanes.
5	Rows of loose stones 1 to 2 in (26 – 50 mm) or many loose stones 2 in (> 50 mm). Any lateral movement of the vehicle poses a significant safety hazard.

6. Erosion: Erosion depth of the road surface can be determined visually, by ride quality, or by using a straight edge and ruler, depending on the accuracy desired by the user. Erosion length

(longitudinal erosion) and width (transverse erosion) are both recorded. Erosion severity is evaluated in each direction independently and is classified as shown in Table 16.

Table 16. Erosion degree (adapted from Jones, 2000).

Degree	Longitudinal Erosion Description	Transverse and Diagonal Erosion Description
0	**Not present**	**Not present**
1	Evidence of water damage	Minor evidence of water damage
2	Channels < 1 in (20 mm) deep	Seen, but not felt or heard - channels ¼ in deep x 2 in wide (10 mm deep x 50 mm wide)
3	Channels 1 to 1.5 in (20 to 40 mm) deep	Can be felt and heard – speed reduction necessary – 1 in x 3 in (30 mm x 75 mm)
4	Channels 1.5 to 2.5 in (40 to 60 mm) deep	Significant speed reduction necessary - 2 in x 6 in (50 mm x 150 mm)
5	Channels > 2.5 in (60 mm) deep	Vehicles drive very slowly and attempt to avoid them > 2.5 in x 10 in (> 60 mm x 250 mm)

7. Loss of gravel: Loss of gravel is assessed by noting the percentage of road surface that the subgrade is exposed, as shown in Table 17.

Table 17. Loss of gravel degree (adapted from Jones, 2000).

Degree	Description
None	No general stone protrusion or no exposure of subgrade.
Isolated	Less than 20% exposure of the subgrade over the length of the segment.
General	20 to 100% exposure of the subgrade over length of segment.

8. Dust: Degree of dust is assessed by viewing visibility conditions created from a traveling vehicle at 40 mph (60 km/hr) in the rear view mirror or by a fixed observer viewing a passing vehicle. Criteria for assessing the degree of this distress are shown in Table 18 below.

Table 18. Dust degree (adapted from Jones, 2000).

Degree	Description
None	No loss of visibility.
Minor	Some loss of visibility – no discomfort.
Severe	Dangerous loss of visibility – significant discomfort.

The intermediate level of this system records the extent of the eight distresses discussed above in the basic level assessment. The extent of a distress gives a visual representation of where specific distresses are present and can be used to monitor the spread of the distress on the road segment. The extent of distress on the road segment is assessed by percentage of coverage in levels 1 through 5, where 1 signifies isolated occurrences and 5 signifies extensive occurrences. Distress locations can be marked on a drawing of the road segment and the extent can be determined by referencing Figure 6. Table 19 associates the visual descriptions of extent as shown in Figure 1 to percentage of occurrence (Jones, 2000).

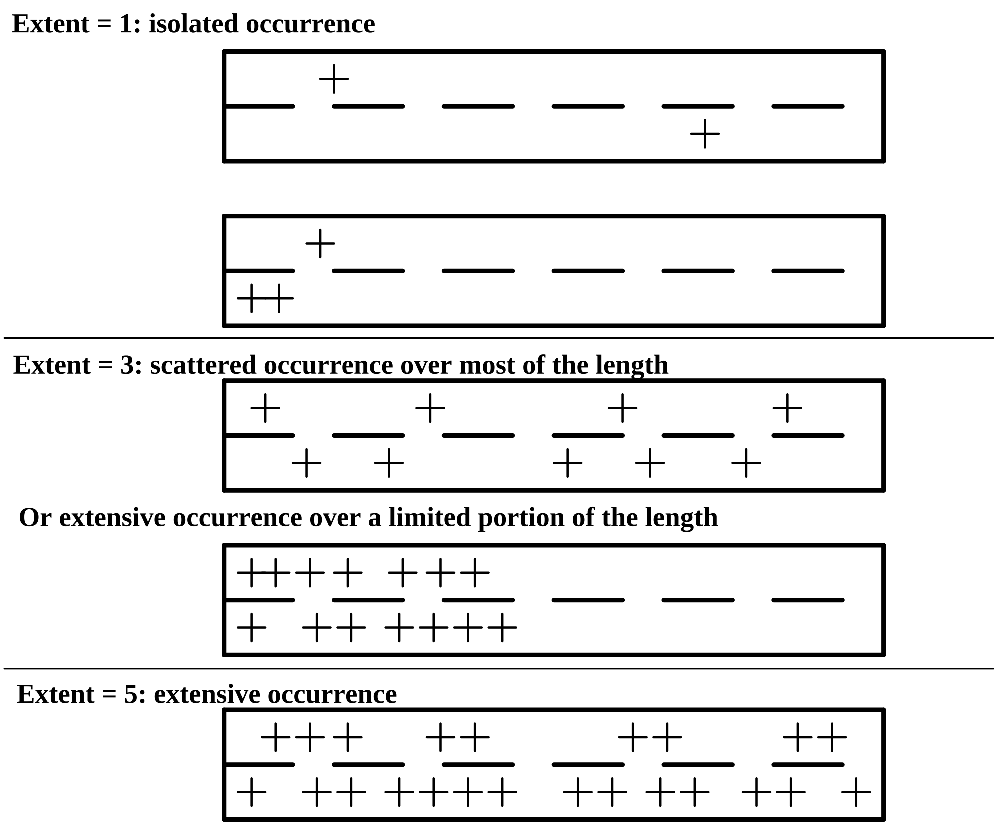


Figure 6. Distress extent (adapted from Jones, 2000).

Table 19. Distress extent (adapted from Jones, 2000).

Extent	Distress Description	% of Extent
1	The distress occurs as isolated instances. The distress is not represented throughout the entire segment length being evaluated. Distresses are caused by localized changes in the material, subgrade or drainage conditions. Distresses may be located at points of heavy wear: intersections, steep grades or sharp curves.	< 5%
2		5% to 20%
3	The distress occurs as intermittent instances, over most of the segment length, or occurs extensively over a limited portion of the segment length. When the distress occurs over most of the segment length, problems are usually associated with the material quality or maintenance procedures. When the distress occurs over limited portions, the problem is usually a result of local material variations or drainage problems.	20% to 60%
4		60% to 80%
5	The distresses occur extensively usually because of poor quality or insufficient wearing course material, or inadequate maintenance.	80% to 100%

In the advanced level of this system, additional road characteristic are assessed including thickness of the gravel layer, quality of the gravel layer, shape of the road profile, ability to drain water and roadside drainage, ability of traffic to navigate the road, quality of ride, and the amount of moisture present in the road (Jones, 2003).

9. Gravel quantity/ thickness: This parameter is assessed on a 1 to 5 scale based on the coverage and thickness of the gravel surface as shown in Table 20.

Table 20: Visual assessment of gravel quantity and thickness (adapted from Jones, 2000).

Extent	Distress Descriptor	Description	in (mm)
1	Plenty	Good shape, and no stone protrusion	> 5 in (>125 mm)
2	Sufficient	No exposures of subgrade, but some stone protrusion	4 – 5 in (100 – 125 mm)
3	Isolated exposures	Less than 25 per cent exposure of the subgrade	2 – 4 in (50 – 100 mm)
4	Extensive exposures	Up to 75 per cent exposure of the subgrade	1 – 2 in (25 – 50 mm)
5	None	75 to 100 per cent exposure*	0 - 1 in (0 - 25 mm)
*Complete subgrade exposure should be carefully examined so it is not confused with the adequacy of the gravel layer.			

10. Gravel quality: The gravel quality factor is assessed on a 1 to 5 scale based on the criteria listed in Table 21.

Table 21: Visual assessment of gravel quality (adapted from Jones, 2000).

Rating	Descriptor	Description
1	Very good	Evenly distributed range of particle sizes and sufficient plasticity that the material will leave a shiny streak when scratched with a pick. No significant cracking, raveling and/or excessive oversize
2	Good	Minor raveling or cracking and/or minimal
3	Average	Cracking, loose material or stones clearly visible.
4	Poor	Poor particle size distribution with excessive oversize. Plasticity high enough to cause slipperiness. Raveling is sufficient to cause loss of traction.
5	Very poor	Poorly distributed range of particle sizes and/or zero or excessive plasticity. Cracking and/or quantity of loose material/stones are significant and affect safety of road user. Excessive oversize.

11. Road profile/shape: This factor can be classified in to a 1 to 5 scale using the criteria shown in Table 22 below.

Table 22: Visual assessment of road profile (adapted from Jones, 2000).

Rating	Descriptor	Description
1	Very good shape	Well-formed camber (about 3 – 4%)
2	Good shape	Good camber (about 2 %)
3	Flat	Some unevenness with camber mostly less than 2%
4	Uneven	Obvious development of irregularities that will impede drainage and form depressions
5	Very uneven	Development of severe irregularities impeding drainage and likely to cause extensive localized ponding. Water tends to flow to the center of the road or individual lanes

12. Road drainage: Drainage is classified into one of five categories (rating 1 to 5) by using the criteria shown in Table 23.

Table 23: Visual assessment of drainage (adapted from Jones, 2000).

Extent	Descriptor	Description
1	Well above ground level	Edges of road are at least 300 mm* above natural ground level with effective side drains
2	Slightly above ground level	Road is between 50 and 300 mm above natural ground level. Side drains are present. Stormwater could cross in isolated places.
3	Level with ground	Road is generally at ground level with ineffective side drains. Stormwater could cross in most places.
4	Slightly beneath ground level	Isolated areas of the road are below natural ground level. No side drains are present and localized ponding of water will occur.
5	Canal	Road is the lowest point and serves to drain the entire area.
*If the road structure has drainage pipes in the subgrade, the road structure should be at least 500 mm above the ditch flowline.		

13. Trafficability (the ability of traffic to navigate the road) is subjectively rated with either a 1 or a 5 as summarized in Table 24below.

Table 24: Trafficability (adapted from Jones, 2000).

Rating	Descriptor	Description
1	Acceptable	Traffic can pass the road at reasonable speeds.
5	Unacceptable	Traffic speed is hampered by potholes, areas of ponding, debris and vegetation.

14. Riding quality/safety: Raters subjectively determine ride quality by evaluating roughness during travel at a range of speeds and classifying the road segment into a 1 to 5 rating as shown in Table 25. Roughness is a function of maintenance, material, traffic, and weather.

Table 25. Riding quality/safety (adapted from Jones, 2003).

Rating	Descriptor	Description
1	Very good	Estimated comfortable/safe speed in excess of 60 mph (100 km/h)
2	Good	Estimated comfortable/safe speed between 50 – 60 mph (80 and 100 km/h)
3	Average	Estimated comfortable/safe speed between 40 – 50 mph (60 and 80 km/h)
4	Poor	Estimated comfortable/safe speed between 25 – 40 mph (40 and 60 km/h)
5	Very poor	Estimated comfortable/safe speed less than 40 km/h (25 mph)

15. Moisture condition: Moisture condition is a qualitative assessment of the overall level of soil moisture in road materials. This parameter is rated either dry or wet. This parameter can be used to provide context for other rating factors.For example if a road segment was rated as wet, one would not expect dust to be significant. No direct guidance is given for rating criteria for this factor, however the system does indicate that the parameter can either be visually assessed or determined from field tests where more accurate assessments are required.

Record Keeping & Equipment

The Standard Visual Assessment data collection requires minimal collection equipment. When data are collected, they are recorded on assessment forms with spaces for recording the presence and degree of each distress. An example assessment form is included as Figure 7 below. If data are to be collected for use in a gravel road management system, project, or research assessment, it is suggested that they be collected when road segments are dry and that the date be recorded for consistency if data are collected annually (Jones, 2003).

UNSEALED ROAD ASSESSMENT FORM												
Evaluator		Date										
Road No		Section										
Start km		End km		Position								
Segment No		Start km		End km								
General performance	1	2	3	4	5	Moisture	Wet	Dry				
Gravel quantity	1	Plenty	2	Sufficient	3	Isolated exposures	4	Extensive exposures	5	None		
Gravel quality	1	Very good	2	Good	3	Average	4	Poor	5	Very poor		
Influencing factors		Clay	Sand	Gravel/stones								
Road profile/shape	1	Very good (4%)	2	Good (2%)	3	Flat	4	Uneven	5	Very uneven		
Drainage from the road	1	Well above ground	2	Slightly above	3	Level with ground	4	Slightly below	5	Canal		
Riding quality/safety	1	Very good (>100 km/h)	2	Good (100 km/h)	3	Average (80 km/h)	4	Poor (60 km/h)	5	Very poor (40 km/h)		
Influencing factors	Corrugation	Loose material	Stoniness	Potholes	Ruts	Erosion						
Maintenance action	Local repairs	Blading	Heavy blading	Regravelling	Reshaping	Drains						
	Degree							Extent				
Potholes	0	1	2	3	4	5		1	2	3	4	5
Rutting	0	1	2	3	4	5		1	2	3	4	5
Erosion - transverse	0	1	2	3	4	5		1	2	3	4	5
Erosion – longitudinal	0	1	2	3	4	5		1	2	3	4	5
Corrugation	0	1	2	3	4	5		1	2	3	4	5
Loose material	0	1	2	3	4	5		1	2	3	4	5
Stoniness – embedded	0	1	2	3	4	5		1	2	3	4	5
Stoniness - loose	0	1	2	3	4	5		1	2	3	4	5
Dustiness	0	1	2	3	4	5						
Slipperiness	Acceptable	Unacceptable										
Skid resistance	Acceptable	Unacceptable										
Trafficability	Acceptable	Unacceptable										
Isolated problems	Potholes	Subgrade exposure	Transverse erosion	Longitudinal erosion	Rough area	Slipperiness						
Comments												
Inventory check												
Material	Basic crystalline	Acid Crystalline	High Silica	Arenaceous	Argillaceous	Diamictite						
	Metalliferous	Carbonate	Pedocrete	Fer	Cal	Gyp	Sil	Transported				
Road width	<8m	8-10m	>10m	Road type	Gravel	Earth	Treated					

Figure 7. Sample assessment form for the Visual Assessment Manual for Unsealed Roads (TMH12) method (Jones, 2000).

Data Collection Rate, Speed, & Cost

Data collection per day should not exceed approximately 80 miles (130 km) of road or approximately three 3-mile (5 km) segments per hour for 8 hours. Data collection speed should be approximately 25 mph (40 km/h) or less, unless otherwise specified as in the case of dust collection where the recommended speed is approximately 37 mph (60 km/h). Raters should exit the vehicle for observations at least one time per segment. A ruler, straight edge, and pick are necessary for directly measuring the degree of some distresses as indicated in the *Rating System Range* section above. It is possible that raters may want to travel as slow as 12.5 mph (20 km/h) so they can stop and exit the vehicle more frequently to collect more data that can increase data quality (Jones 2000; Jones, 2003). The authors of this study were contacted to obtain information regarding data collection costs. Costs could not be obtained in time for submission of this document but will be included in later documentation when available.

Data collection for network level management should be collected as specified by the road owning agency. It is recommended that data for a gravel road management system be collected annually and as specified for projects or research (Jones 2000; Jones, 2003).

Data & Applications

The Standard Visual Assessment Manual for Unsealed Roads (TMH12) was written to collect data for use at several levels. Applications include network level management, gravel road management systems, projects, and research. Data collected can be used for a distress and extent rating as discussed here (Jones 2000; Jones, 2003).

Severity ratings are collected for use in various gravel road management systems. However, instructions on data use are not given in detail. Road raters can document data on forms provided in the manual or forms can be developed by the agency. It is suggested that users be trained prior to rating roads due to the amount of the data being collected and the complexity of the forms. This method recommends that training sessions be held annually and after the road network is rated, quality control should be performed on 10% to 15% of the rated segments (Jones, 2000).

Summary & Costs

The method is very detailed and suggests a large quantity of detailed information be collected using visual identification. The system does not require any sophisticated data collection equipment and suggests that data can be collected relatively quickly. The rating manual indicates that data from this method are intended to be used in a number of management systems; however, there are no concrete examples for management system use of the data, leaving the user to formulate their own. The system lacks key criteria to allow a rater to discern between rating levels for many of the distresses, so the user is left to make their own criteria or rate subjectively. The recommended road segmentation method (by landmark) is attractive because it does not require a developed mile post system or the use of GPS equipment. , However, because road segments are divided based on geographic features, they may not be homogenous causing difficulty in producing a representative rating.

The basic framework of this system has been modified and adapted to satisfy needs of other South African transportation agencies such as the Visual Assessment of Gravel Roads system used by the Provincial Government of the Western Cape of South Africa. Both of these assessment systems are nearly identical (WCPA, 2007). The authors of this study were contacted to obtain information regarding data collection costs. Costs could not be obtained in time for submission of this document but will be included in later documentation when available.

VISUAL: Subjective Rating System - Central Federal Lands Highway Division

Overview

The Federal Lands Highway Technology Program (FLHTP) was developed by the Central Federal Lands Highway Division of the Federal Highway Administration (FHWA) to monitor unpaved road stabilization products to determine which were the most effective and least costly (Surdahl, 2005). This program studied conditions on several stabilized road test sections at the Buenos Aires National Wildlife Refuge and the Seedskadee National Wildlife Refuge over a two-year period to determine the effectiveness of stabilization products (Surdahl, 2005; Woll, 2008). The Central Federal Lands Highway Division of the Federal Highway Administration (FHWA) published the studies relating to these projects in 2005 and 2008 respectively (Surdahl, 2005; Woll, 2008). As part of these studies the Federal Lands Highway Technology Program developed a subjective assessment system and an objective rating system to assess the quality test sections of unpaved roads by dividing them into half a mile to one mile segments (0.80 km - 1.6 km) for analysis (Surdahl, 2005; Woll, 2008).

Subjective Rating System

The subjective assessment system includes a visual rating system which evaluates five distress parameters for each segment of road. Road segments are rated for each of the five distresses (dust, washboarding, raveling, rutting, and potholing) by comparing them to a control segment. Ratings are in the form of an 11 point (0 to 10) rating scale for each distress parameter, where a rating of 5 indicates identical distress levels when compared to the control segment. Ratings above a 5 indicate less distress than the control section, while lower ratings indicate higher distress than the control segment. The rating system is entirely subjective with no criteria for determining specific rating levels other than a rater's professional opinion. The assessment activities are duplicated, with four or more raters independently evaluating the same road sections for all of the parameters. Scores from all raters are averaged to create a single set of distress scores for each road segment. An overall average rating is created by averaging the scores of all the distresses. Descriptions of distress parameters are included below. An example compilation of distress parameters to create a visual overall average score is shown in Table 26.

Table 26. Federal Lands Highway Technology Program – Road conditions and distresses assessed (adapted from Surdahl, 2005).

Road Characteristics and Distresses	Assessment Criteria
Dust	The dust level of each section is rated relative to the baseline section. A two-vehicle caravan is used to monitor dust with the raters riding in the trailing vehicle.
Washboarding	Washboard ratings are visually assessed by comparing them with a baseline road section on a 1to10 scale.
Raveling	Raveling ratings are visually assessed in comparison with the baseline road section on a 1 to 10 scale.
Rutting	Rutting ratings are collected in comparison with the baseline road section on a 1 to 10 scale.
Potholes	Pothole ratings are collected in comparison with the baseline road section on a 1 to 10 scale.

Table 27 illustrates an example of the objective rating system the data collected from the Buenos Aires National Wildlife Refuge study. It illustrates how the average score is determined from the combination of the individual distress scores. In this example, test section IV served as the baseline which was given a rating of 5. The ratings reported for each test section in this study were averaged from ratings acquired independently by three raters every six months (Surdahl, 2005; Woll, 2008).

Table 27. Rating parameter summary (adapted from Surdahl, 2005).

Test Section	Dust Overall Average Value	Washboard Overall Average Value	Ravel Overall Average Value	Rutting Overall Average Value	Pothole Overall Average Value	Visual Overall Average Value
I	7.0	7.3	7.2	6.1	5.0	6.5
II	8.2	8.5	8.3	6.5	5.0	7.3
III	5.8	5.8	5.3	5.5	5.0	5.5
IV (control)	5.0	5.0	5.0	5.0	5.0	5.0
V	5.5	6.0	5.8	5.3	5.0	5.5
VI	6.0	5.8	5.8	5.4	5.0	5.6
VII	5.8	5.2	5.3	5.8	5.0	5.4

Record Keeping, Data Collection Rate, and Equipment

Three or four data collectors ride together for each visual assessment survey to determine subjective ratings for each distress. This system uses a visual survey, so assessment is accomplished from a slow-moving vehicle. Two vehicles are used for dust assessments. The lead vehicle travels at 25 mph to simulate traffic while a following vehicle caries the rating crew. Data collection equipment is minimal. The primary need is a method for storing data, which can consist of rating sheets or forms that allow raters to record the control segment that they are comparing segments against along with the ratings collected for the subject section (Surdahl, 2005; Woll, 2008). The authors of this study were contacted to obtain information regarding data collection costs. Costs could not be obtained in time for submission of this report but will be included in later documentation when available..

Summary

The Central Federal Lands Highway Division's subjective rating system was designed specifically to complete a comparative study for stabilization products on unpaved roads, although the system could be applied to any repeated measures research design. The system provides a complete method to compare multiple field test sections to determine qualitatively which treatments produce superior results. This system produced satisfactory data for a comparative research study. It is not a practical assessment system for use as an everyday tool for managing unpaved roads, due to the fact that its ratings are all relative to a control section.

Combination (Visual and Direct Measurement) Methods

COMBINATION: Objective Rating System - Central Federal Lands Highway Division

Overview

The Central Federal Lands Highway Division of the USDOT FHWA studied the impact of stabilizing products on unpaved roads in the Buenos Aires National Wildlife Refuge and the Seedskadee National Wildlife Refuge in 2005 and 2008 respectively (Surdahl, 2005; Woll, 2008). As part of these studies the Federal Lands Highway Technology Program developed an objective rating system in addition to the previously described subjective rating system for assessing the quality test sections of unpaved roads.

Objective Rating System

Road sections are divided into half a mile to one mile segments (0.80 km - 1.6 km) for analysis. Each segment has four, 25 foot (7.6 m) long test areas assigned randomly to it that represent the road segment (Surdahl, 2005; Woll, 2008). Physical measurements of five distresses (dust, washboarding, raveling, rutting, and potholing) are collected on each test area. An average physical measurement is calculated for each distress on the road segment using the results from each test area. The average physical measurement for each distress is converted into an eleven-point (0 to 10) scale, then the resulting scores are averaged to create an overall Objective Rating. Table 28 below shows an example of data collected using the objective system (Woll, 2008).

Table 28. Objective Ratings from Field Measurements (Woll, 2008).

Event	Dust		Washboard			Raveling			Rutting			Potholing			Objective Overall Rating (x10)
	Agreed Rating	Overall Rating	Avg. Depth (mm)	Rating	Overal Rating	Avg. Depth (mm)	Rating	Overal Rating	Avg. Depth (mm)	Rating	Overal Rating	Avg. Depth (mm)	Rating	Overal Rating	
8-mo.	6	5.3	0.0	10	8.8	18.6	6	6.3	0.0	10	8.5	0.0	10	9.3	76
11-mo.	5		6.0	8		9.8	8		2.8	9		17.0	7		
20-mo.	4		3.9	9		16.4	6		10.4	7		0.0	10		
23-mo.	6		7.7	8		20.4	5		7.9	8		0.0	10		
8-mo.	8	7.3	0.0	10	9.3	8.8	8	7.5	0.0	10	9.0	0.0	10	10.0	86
11-mo.	8		0.5	9		6.6	8		1.7	9		0.0	10		
20-mo.	4		0.5	9		12.3	7		5.0	8		0.0	10		
23-mo.	9		4.7	9		12.7	7		1.3	9		0.0	10		
8-mo.	7	6.0	0.0	10	9.3	14.8	7	6.8	12.4	7	8.3	0.0	10	10.0	81
11-mo.	5		4.4	9		12.8	7		8.2	8		0.0	10		
20-mo.	5		3.6	9		16.1	6		7.0	8		0.0	10		
23-mo.	7		4.4	9		12.7	7		0.0	10		0.0	10		
8-mo.	5	4.3	0.0	10	7.8	16.8	6	5.8	0.0	10	8.5	0.0	10	10.0	73
11-mo.	3		6.9	8		15.2	6		5.6	8		0.0	10		
20-mo.	4		10.4	7		23.3	5		8.9	8		0.0	10		
23-mo.	5		17.2	6		16.2	6		8.6	8		0.0	10		
8-mo.	6	6.5	0.0	10	9.5	17.8	6	6.8	0.0	10	8.0	0.0	10	10.0	82
11-mo.	5		0.0	10		9.3	8		5.5	8		0.0	10		
20-mo.	8		1.0	9		17.8	6		10.3	7		0.0	10		
23-mo.	7		0.8	9		12.8	7		14.1	7		0.0	10		
8-mo.	8	8.0	0.0	10	9.3	12.3	7	7.3	0.0	10	8.8	0.0	10	10.0	87
11-mo.	8		0.0	10		7.8	8		1.9	9		0.0	10		
20-mo.	7		3.8	9		14.8	7		2.6	8		0.0	10		
23-mo.	9		7.0	8		10.9	7		8.6	8		0.0	10		

Distress Parameters:

1. Dust: This parameter is assessed by a two vehicle team, with the lead vehicle traveling at 25 mph and the following vehicle completing the condition assessment.

Rating Description (Woll, 2008):
0 - Vehicle generating dust cannot be seen - Must stop for dust to clear
1 - Dangerous loss of visibility - Significant uneasiness at driving 25 mph
2 - Dangerous loss of visibility - Significant uneasiness at driving 25 mph
3 - Significant loss of visibility – Some uneasiness at driving 25 mph
4 - Significant loss of visibility – Some uneasiness at driving 25 mph
5 - Some loss of visibility – Little to no uneasiness at driving 25 mph
6 - Some loss of visibility – Little to no uneasiness at driving 25 mph
7 - Very little loss of visibility – No uneasiness at driving 25 mph
8 - Very little loss of visibility – No uneasiness at driving 25 mph
9 - A little low rising dust but no loss of visibility
10 - No Dust

2. Washboarding: This parameter is assessed by measuring the depth of six corrugations in a test area and averaging the depth. The average physical measurement for a test section is converted to a rating score based on the following criteria:

Rating Description (Woll, 2008):
0 - Wash boarding troughs are > 60 mm deep
1 - Wash boarding troughs are between 50 mm and 60 mm deep
2 - Wash boarding troughs are between 40 mm and 50 mm deep
3 - Wash boarding troughs are between 30 mm and 40 mm deep
4 - Wash boarding troughs are between 25 mm and 30 mm deep
5 - Wash boarding troughs are between 20 mm and 25 mm deep
6 - Wash boarding troughs are between 15 mm and 20 mm deep
7 - Wash boarding troughs are between 10 mm and 15 mm deep
8 - Wash boarding troughs are between 5 mm and 10 mm deep
9 - Wash boarding troughs are barely visible (< 5 mm deep)
10 - Wash boarding is not visible

3. Raveling: Sometimes referred to a loose aggregate, raveling results in the formation of linear berms of segregated loose aggregate particles in the less traveled areas adjacent to wheel paths, and typically run longitudinally along the road for significant distances. Raveling is measured on the aggregate berms on the outside of the wheel paths on both sides of a road test area. Depth measurements of the loose aggregate are averaged for the road segment. The average physical measurement for a test section is converted to a rating score based on the following criteria:

Rating Description (Woll, 2008)
0 - Loose material > 60 mm thick
1 - Loose material between 50 mm and 60 mm thick
2 - Loose material between 40 mm and 50 mm thick
3 - Loose material between 30 mm and 40 mm thick
4 - Loose material between 25 mm and 30 mm thick

5 - Loose material between 20 mm and 25 mm thick
6 - Loose material between 15 mm and 20 mm thick
7 - Loose material between 10 mm and 15 mm thick
8 - Loose material between 5 mm and 10 mm thick
9 - Loose material is barely visible (< 5 mm thick)
10 - Loose material is not visible

4. Rutting: Rutting is measured on the inside and outside wheel paths in a road test area using a straight edge and ruler. Depth measurements are averaged for the road segment. The average physical measurement for a test section is converted to a rating based on the following criteria:

Rating Description (Woll, 2008):
0 - Rutting is > 60 mm thick
1 - Rutting is between 50 mm and 60 mm thick
2 - Rutting is between 40 mm and 50 mm thick
3 - Rutting is between 30 mm and 40 mm thick
4 - Rutting is between 25 mm and 30 mm thick
5 - Rutting is between 20 mm and 25 mm thick
6 - Rutting is between 15 mm and 20 mm thick
7 - Rutting is between 10 mm and 15 mm thick
8 - Rutting is between 5 mm and 10 mm thick
9 - Rutting is barely measurable (< 5 mm thick)
10 - Rutting is not measurable

5. Potholes: This parameter is measured by recording the number of potholes in a test area and recording the average depth. Depth measurements are completed using a straight edge and ruler. The average physical measurement for a test section is converted to a rating based on the following criteria:

Rating Description (Woll, 2008):
0 - Road is not passable for most passenger cars
1 - Many potholes are evident > 100 mm deep
2 - Many potholes are evident ranging from 80 to 100 mm deep
3 - Many potholes are evident ranging from 65 to 80 mm deep
4 - Some potholes are evident ranging from 50 to 65 mm deep
5 - Some potholes are evident ranging from 35 to 50 mm deep
6 - Some potholes are evident ranging from 20 to 35 mm deep
7 - A few potholes are evident ranging from 10 to 20 mm deep
8 - A few potholes are evident ranging from 5 to 10 mm deep
9 - A few potholes are evident < 5 mm deep
10 - Potholes are not evident

Record Keeping, Data Collection Rate, and Equipment

This system uses precise measurements of distresses on a series of test areas within a road segment, so it is necessary to stop the survey vehicle frequently to complete the assessment. Two vehicles are used for dust assessments. The lead vehicle travels at 25 mph to simulate traffic while a following vehicle caries the rating crew. Distress measurements can be accomplished by a single data collector;but it may be necessary to have a traffic spotter for the safety of the data collection crew. Data collection equipment is minimal, and it includes basic straight edges and rulers to measure the depth of distresses, and some method for storing data, which can consist of rating sheets or forms that allow raters to record the measurements collected for the subject section (Woll, 2008).

Summary

The subjective rating system was designed specifically to complete a comparative study for stabilization products on unpaved roads. The system could be applied to any research project where precise measurements of distress propagation is of interest. This system could also prove practical as an assessment system used for managing unpaved roads, because it has very well defined rating and measurement criteria that are likely to produce a high degree of repeatability. Subjective rating is effective for use on both gravel and unimproved earth roads. Its average physical measurement is a combined distress measure that can be used as an overall network level metric to easily compare different road segments. The only drawback of this system for daily management is the degree of precision that is required (+/- 5 mm in most cases) for the distress measurement. This level of precision may not be required for daily management decisions, depending on the road condition indicator being assessed (see Deliverable 1-A for more information on measurement requirements, available at http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del1-A_RequirementsDocument_MichiganTechUnpavedRoadsr1.pdf).

COMBINATION: Unsurfaced Road Condition Index (URCI)

Overview

The Unsurfaced Road Condition Index (URCI) method was developed by the Department of the Army to manage roads on military facilities and to provide a basis for selecting and prioritizing maintenance activity. While the system was developed specifically for unpaved roads on military installations, this method has gained wide use for local and state government agencies and is used throughout the United States for asphalt and concrete pavements (Pavement Condition Index – PCI) (Eaton, 1987; Eaton 1987a; Department of the Army, 1995).

The UCRI method uses a sampling approach by segregating roads into distinct segments or branches that have similar characteristics including structure, traffic volume, construction history and road rank. The conditions of road segments are determined by analyzing representative sample units ranging in size from 1,500 to 3,500 square feet (140 to 325 square meters). Sample units are approximately 100 feet (30 meters) in length and one sample unit is required for every half of a mile (0.8 kilometer) of road (Department of the Army, 1995).

The UCRI method uses a combination of a visual assessment of road characteristics and a physical measurement of specific distresses to quantify the condition of gravel and earth roads. Unsurfaced road conditions change quickly, so it is recommended that data be collected at least four times per sampling unit per year during each season. This method measures seven characteristics and distresses.. The two road characteristics that are assessed visually can either be collected from a slow-moving vehicle or manually measured.The other five distresses must be measured manually, using a wheeled distance meter, surveying tape, or ruler (to measure depth). The UCRI method specifies procedures for measuring each distress (Eaton, 1987; Eaton 1987a; Department of the Army, 1995).

The five distresses used by the UCRI method each have measurable criteria that allow a user to classify the distress into either low, medium, or high severity bins. Unique curves are provided for each distress so users can determine a deduction value for each distress from a combination of its frequency and severity (low, medium or high) on the test segment. An example of a deduct value curve for the improper cross section factor is shown in Figure 8 below. Distresses higher in severity and frequency (density) accumulate more deduct values (Eaton, 1987; Eaton 1987a; Department of the Army, 1995).

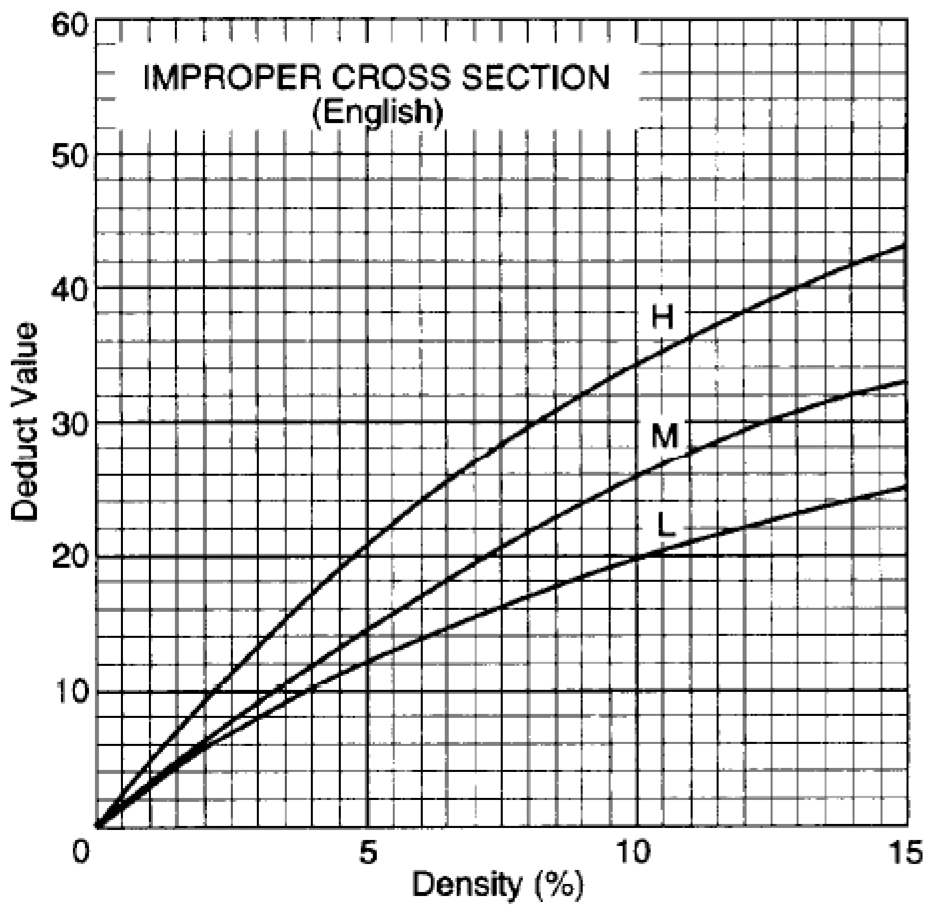


Figure 8. Improper cross section factor deduct value curves (Eaton 1987a).

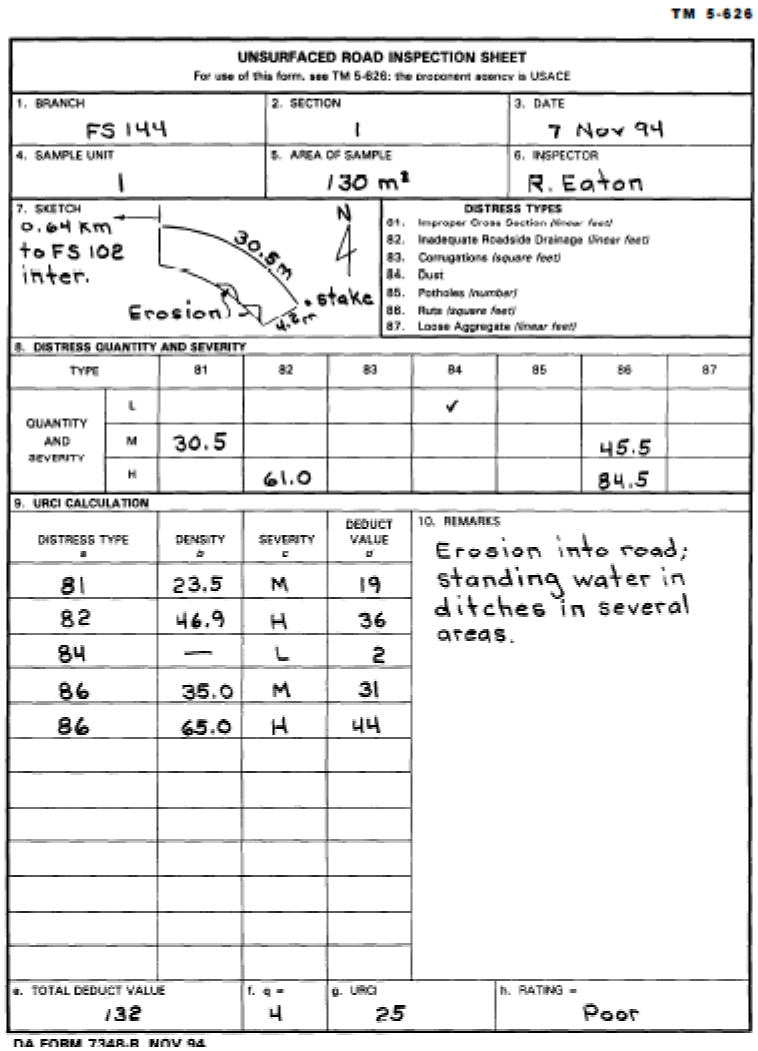
Deduct values for each of the seven factors are combined and then subtracted from 100 total possible points to create a combined index score. The UCRI system has a maximum score of 100 points for a perfect road segment and a minimum score of zero for completely failed sections of road. The combined index score can be used as a network level metric to compare different sections of road, while the individual scores for each of the seven road characteristics and distresses, shown in Table 29 below, can be used to determine appropriate maintenance or rehabilitation options for the specific road segment (Department of the Army, 1995).

Table 29. Department of the Army (UCRI) – Road conditions and distresses assessed (Department of the Army, 1995).

Road Characteristics and Distresses	Assessment Criteria
Improper Cross Section	Minimal evidence of ponded surface water warrants a low severity rating while large amounts of ponded water or severely depresses cross sections warrant either medium or high severity rating in this category. The length of roadway exhibiting each of the three severity levels of this factor is recorded and used as a measure of density.
Drainage	Drainage features that allow water to pond, are eroded, or are overgrown with vegetation are classified into either low, medium or high severity. The length of roadway exhibiting each of the three severity levels of this factor is recorded as a measure of the factor's density.
Corrugations	Corrugated surface areas are classified into the following three bins: corrugations up to one inch (2.5 cm) deep are low severity, corrugations one inch to three inches deep (2.5 cm - 7.6 cm) are medium severity, and corrugations greater than three inches (>7.6 cm) are high severity. The square area of each bin of corrugated surface is measured to determine density.
Dust	If dust is present but visibility is not obscured, the factor is considered low severity.
Potholes	Potholes are classified as either low, medium or high severity based on a matrix of the frequency of their occurrence and classified into diameter and depth ranges of: less than two inches (5.1cm) , two to four inches (5.1 cm - 10.2 cm) , and over four inches (>10.2 cm).
Ruts	Ruts are classified based on their depth in the following three bins: ruts up to one inch deep (2.5 cm) are low severity, ruts one inch to three inches deep (2.5 cm - 7.6 cm) are medium severity, and ruts greater than three inches (>7.6 cm) are high severity. The total surface area is measured for each rutting depth bin for the sample unit.
Loose Aggregate	Loose aggregate berms are classified into three bins: berms of loose aggregate less than two inches deep (<5.1 cm) are low severity, berms of loose aggregate two to four inches (5.1 cm - 10.2 cm) are medium severity, and berms of loose aggregate over four inches (>10.2 cm) deep are high severity.

Record Keeping

Information collected on each sample unit is recorded on the Unsurfaced Road Inspection Sheet or form DA 7348-R. An example of DA 7348-R is shown below in Figure 9. Measurements on the extent and severity of the seven road characteristics and distresses (cross section, drainage, corrugations, dust, potholes, ruts, and loose aggregate) are retained individually for each test section. The total calculated deduct values and resulting UCRI are also recorded for each road section (Department of the Army, 1995).



TM 5-626

UNSURFACED ROAD INSPECTION SHEET
For use of this form, see TM 5-626; the proponent agency is USACE

1. BRANCH	2. SECTION	3. DATE
FS 144	1	7 Nov 94
4. SAMPLE UNIT	5. AREA OF SAMPLE	6. INSPECTOR
1	130 m²	R. Eaton

7. SKETCH

DISTRESS TYPES
81. Improper Cross Section *(linear feet)*
82. Inadequate Roadside Drainage *(linear feet)*
83. Corrugations *(square feet)*
84. Dust
85. Potholes *(number)*
86. Ruts *(square feet)*
87. Loose Aggregate *(linear feet)*

8. DISTRESS QUANTITY AND SEVERITY

TYPE		81	82	83	84	85	86	87
QUANTITY AND SEVERITY	L				✓			
	M	30.5					45.5	
	H		61.0				84.5	

9. URCI CALCULATION

DISTRESS TYPE a	DENSITY b	SEVERITY c	DEDUCT VALUE d
81	23.5	M	19
82	46.9	H	36
84	—	L	2
86	35.0	M	31
86	65.0	H	44

10. REMARKS
Erosion into road; standing water in ditches in several areas.

e. TOTAL DEDUCT VALUE	f. q =	g. URCI	h. RATING =
132	4	25	Poor

DA FORM 7348-R, NOV 94

Figure 9: UCRI calculation sheet – US Army form DA 7348-R (Department of the Army, 1995).

Data acquired can be managed with a paper filing system outlined by the method that consists of a file for each test section organized by road section name. Records for the UCRI system can also be recorded using the Micro PAVER program for unsurfaced roads (Eaton, 1987; Eaton 1987a; Department of the Army, 1995) (note that this is an old DOS-compatible program). Distress data can be used to determine the appropriate maintenance repair for a specific segment of road using a condition matrix that relates specific distresses and severities to an appropriate repair. Table 30 below illustrates the basic decision support system that can be used with the UCRI method.

Table 30. Maintenance alternatives and corresponding distress categories, severity codes determined from UCRI, and cost codes adapted from the Unsurfaced Road Maintenance Management method (Eaton, 1987; Eaton 1987a; Department of the Army, 1995).

Distress Number	Distress	Severity code	Cost code*	Description
81	Improper cross section	L	B	Grade only.
		M	B/C	Grade only/grade and add material (water or both), and compact. Bank curve. Adjust transitions.
		H	C	Cut to base, add aggregate, shape, water, and compact.
82	Improper roadside drainage	L	B	Clear ditches every 1-2 years.
		M	A	Clean out culverts.
			B	Reshape, construct, compact or flare out ditch.
		H	C	Install underdrain, larger culvert, ditch dam, rip rap, or geotextiles.
83	Corrugations	L	B	Grade only.
		M	B/C	Grade only/grade and add material (water or aggregate or both), and compact.
		H	C	Cut to base, add aggregate, shape, water, and compact.
84	Dust stabilization	L	C	Add water.
		M	C	Add stabilizer.
		H	C	Increase stabilizer use. Cut to base, add stabilizer, water, and compact. Cut to base, add aggregate and stabilizer, shape, water, and compact.
85	Potholes	L	B	Grade only.
		M	B/C	Grade only/grade and add material (water, aggregate, or 50/50 mix of calcium chloride and crushed gravel), and compact.
		H	C	Cut to base, add aggregate, shape, water, and compact.
86	Ruts	L	B	Grade only.
		M	B/C	Grade only/grade and add material, and compact.
		H	C	Cut to base, add aggregate, shape, water, and compact.
87	Loose aggregate	L	B	Grade only.
		M	B/C	Grade only/grade and add material, and compact.
		H	C	Cut to base, add aggregate, shape, water, and compact.
*Cost code guide: A = labor, overhead; B = labor, equipment, overhead, C = labor, equipment, materials, overhead.				

Note: Performance and stability will vary considerably with traffic volume and type, drainage, and subbase.

Equipment, Cost, Speed, Record Keeping

Pavement test sections can be rated visually at 25 mph (40.2 km/h). Direct measurements should be taken using a hand odometer or measuring wheel to acquire lengths of distresses and areas to be calculated, as necessary. Straight edges and rulers are necessary to measure pothole depths, ruts, and loose aggregate. The URCI guide and Unsurfaced Road Inspection Sheet or form DA 7348-R is needed (Department of the Army, 1995). Estimates suggest that data can be collected for the average 100 foot (30.5 m) test section by conducting a windshield survey at 25 mi/hr (40 km/hr with a one person data collection team. The vehicle speed may be adjusted depending on the condition of the road (Eaton, 1987; Eaton 1987a; Department of the Army, 1995).

The counterpart to the UCRI rating system used for paved roads is called the Pavement Condition Index (PCI) that was developed by the Army Corps of Engineers. Automated systems have been developed that use sensor mounted vans to collect PCI data on asphalt and concrete pavements. Automated data collection has been proven to collect PCI data on paved surfaces at the same cost or less than manual data collection, as well as increasing safety (Cline, 2003). Three technologies have advanced data collection progressively over the last decade (Cline, 2003). These include continuous 35 mm analog camera film, digital camera image files, and digital line scan imagery (Cline, 2003). These methods have been tested in a pilot study where pavement and unsurfaced data were collected.

An example of automated data collection is shown in Figure 10 below. Here a boom-truck mounted camera system equipped with an electronic controller and light system traveling at 60 mph (96.6 km/h), images that cover a 16 foot (4.9 m) width with resolution to capture cracks of 0.04 inch (1 mm) width can be captured using continuous 35 mm analog camera film. Digital camera files and digital line scan imaging are collected using similar equipment (Cline, 2003).

Figure 10. Boom truck mounted camera system equipped with an electronic controller and light system (Cline, 2003).

Costs to manually collect data using automated systems ranged from \$0.70/yd^2 to \$0.10/yd^2 for 25,000 to 100,000 yd^2 and greater respectively. Costs to automatically collect data (1 day), process, and develop a report for a 405,000 yd^2 project was approximately \$0.10/yd^2 (Cline, 2003). \$0.10/ yd^2 for 100,000 yd^2 to 405,000 yd^2 is approximately \$1400 per mile of 24 feet (7.3 m) wide road (Cline, 2003).

Summary

The URCI method is a well-established condition rating system that has very specific criteria for determining unsurfaced road ratings;this method is likely to provide a high degree of repeatability in measurements. The system is adaptable for both low-tech paper filing methods and more formalized systems using the Micro PAVER computer program. Data collection for the URCI system does not require any specialized tools but does require relatively detailed measurements to be collected, which add to the data collection time. The system relies on a sample unit to represent the condition of approximately one half mile of road. The use of sample units greatly reduces the data collection requirements when compared to data collection for the entire road segment. However, it also adds a degree of risk in the sampling selection, since poor sample selection can result in data that are not representative of the overall road segment.

Indirect Data Acquisition Methods

INDIRECT DATA ACQUISITION: Road Roughness Using Accelerometer Technology by Opti-Grade®

Overview

The Forest Engineering Research Institute of Canada (FERIC) developed the Opti-Grade® system to collect roughness data on unsealed roads for management of grading operations of forest industry logging roads. The FERIC is a research institute that provides the forest industry with research on forest operations and safety. Eighteen FERIC members in five Canadian provinces took part in the Opti-Grade study in 2001. Since the study the Opti-Grade system has become commercially available.

The Opti-Grade system includes the installation of an acceleration sensor, a GPS unit, and data logging system that is mounted on haul trucks. The system uses the acceleration sensor to detect the vehicle's response to road roughness by detecting vibrations. This allows the system to continuously collect roughness data while the vehicle is in service traveling its normal haul route. Data recovered from the system are used for maintenance analysis through a proprietary software system that interprets the roughness and position data and produced schedules to direct motor graders to roads that require maintenance based on a pre-selected roughness threshold (Brown, 2003).

Data Collection Rate and Equipment

The Opti-Grade technology consisted of an acceleration sensor for acquiring roughness, a GPS unit, and a data logging device. The equipment is installed on vehicles that routinely travel the road network to be monitored. The number of vehicles equipped with the data collection technology depends on the size of the network to be monitored and the desired data collection interval. Because the system collects data using in-service vehicles, the data collection speed can effectively be very high and is limited only by the operation speed of the collection vehicle. Operation costs were not available for the Opti-grade system; however, the purchase price of the system was quoted at $20,000 Canadian dollars in 2003 (Brown, 2003).

The Opti-Grade system records peak acceleration (roughness) data for the highest one second interval in a five second group. This provides a peak roughness value for every 165 feet (50 m) to 575 feet (175 m) of road depending on vehicle speed The Opti-Grade system also collects position, travel direction, speed and time data for each roughness measurement that allows the road network to be analyzed for areas in need of maintenance (Brown, 2003).

Data from the Opti-Grade vehicle units are recovered and stored on a personal computer. The Opti-Grade system includes proprietary software to plot the location of roughness data on a base map and to evaluate the data sets to determine areas where road roughness exceeds a user specified parameter. The software develops candidate projects for grading operations by determining the location and length of road segments that require a maintenance intervention. The software also includes tools to compare driver speed with roughness to determine threshold conditions where road roughness is impacting driver speed (Brown, 2003).

Similar Systems

The Longitudinal Profiling System from International Cybernetics Corporation is used to collect roughness data for the Saskatchewan Highways and Transportation agency on paved an unpaved roads in during annual data collection events. This system consists of infrared laser sensors, accelerometers, and a distance measuring instrument mounted to the front of a data collection van. The system collects modified International Roughness Index (IRI) data as described by the National Cooperative Highway Research Programs (NCHRP) Report 228 for two simultaneous wheel tracks (Smith, 1997, Lazic, 2003).

Summary

The Opti-Grade system collects large volumes of road roughness and vehicle speed data using in service vehicles. The system has proved useful in realizing savings for unpaved maintenance by precise direction of road grading activities (Brown, 2003). The system appears to work well on a small road network that is routinely travelled by instrumented vehicles, such as the case of logging haul roads; however, it is not apparent how this system would be utilized in larger road networks where the frequency of travel by instrumented vehicles may be less frequent, such as a typical county road system.

INDIRECT DATA ACQUISITION: Ground Penetrating Radar

Overview

The City of Saskatoon uses the current pavement management system of Saskatchewan Highways and Transportation where data is collected with the INO Laser Rut Measurement System and the Longitudinal Profiling System on their urban system, but studies have shown use of GPR is necessary to acquire additional structural data to make decisions on a project or semi-network basis (Prang, 2007). One case study included a road surface of ‘in situ composite granular surface with spot overlays’ (Berthelot, 2008). GPR use has been tested on the project and network levels for the Finnish National Road Association (Saarenketo, 2000).

Equipment, Record Keeping

Materials possess dielectric permittivity properties that GPR is able to measure. The GPR apparatus used in the Saskatoon study was a 1GHz pulsed transmitter with air-coupled antennae mounted on a truck. It collected the dielectric permittivity at different points along the road surface (Prang, 2007). The data acquired were translated by comparing it to reference information to provide layer differences such as moisture content and amount of fines in conjunction with thicknesses (Saarenketo, 2000; Prang, 2007;

Prang, 2007). Some example dielectric values and their corresponding descriptions of the quality of a wearing course surface are listed in Table 31 (Saarenketo, 2000).

Table 31. Gravel road wearing course classification and corresponding dielectric constant values (Saarenketo, 2000).

Dielectric Value	General condition/proposed treatment
< 8	Dusty material, wearing course erosion. Fines or dust treatment needed.
8 - 12	The wearing course is in the optimum moisture content window with low moisture. Additional gravel and fines for preservation could be added.
12 - 16	The wearing course is in the optimum moisture content window with highest moisture and highest amount of fines. Road drainage should be evaluated. New material could be added with the proper amount of fines.
> 16	Material contains too many fines, water adsorption is apparent. Problems may occur during thaw, surface may be slick during rain. Road drainage should be evaluated.

Other techniques used in conjunction with GPR can provide a more complete analysis of the structural health of the road. When a falling weight deflectometer (FWD) is used in conjunction with GPR data, peak deflection and structural index can be computed for road segments (Prang, 2007). Comparing GPR with maps created using GPS data in the Saskatoon study confirmed moisture and drainage conditions of the road (Saarenketo, 2000).

GPR systems must be connected to acquisition software and configured correctly. Additionally if GPS is used in conjunction with the GPR, synchronization is necessary. Signal characteristics and calibration for error reduction make a considerable difference in quality data acquisition and translation (Pereira, 2006).

Cost

GPR and FWD surveys provide data with additional structural benefits for approximately the same cost per unit as visual and automated (semi-automated) surface condition rating (Pang, 2007).

Data & Applications: Summary

Benefits: The City of Saskatoon uses GPR and FWD to accurately measure structural damage allowing more accurate structural deterioration to be predicted by network models. Pavement and structural preservation can be performed at accurate times increasing service life for the system. Network preservation costs are reduced (Berthelot, 2008).

Limitations: The most significant variability in a gravel road is in the wearing course surface thickness in the transverse direction. Data must be collected on a road section long enough to statistically overcome the variability that is inherent in the road (Saarenketo, 2000).

INDIRECT DATA ACQUISITION: Remote Sensing – Unmanned Aerial Vehicle (UAV)

Overview

South Dakota State University conducted a study in conjunction with the US Department of Transportation to develop a remote sensing system using an unmanned aerial vehicle that would support cost effective acquisition of unpaved road surface distress data for transportation agencies (Zhang, 2011).

The UAV system had the ability to gather high resolution imagery and measure unpaved road surface distresses using feature point extraction techniques and threshold algorithms that corresponded to known actual distresses (Zhang, 2011).

Equipment, Record Keeping, Data, & Application

The system used for acquiring data included an unmanned helicopter, GPS, an inertial measurement unit (IMU),and a digital camera. The images were processed to reconstruct a 3D road surface model which was used to derive distresses and report them to a road management system (Zhang, 2011). The study showed promise, but did not serve as a complete evaluation of the capabilities of a UAV to assess unpaved road condition.

Costs

Although this was a low-cost system, theactual cost and time for were not documented (Zhang, 2011).

Summary

While not commercially available, the system demonstrated the potential to collect quantitative assessment measures in an automated fashion. This method may be faster, less expensive, and generally more reliable (and repeatable) than other methods. The technology is mature, but undeveloped.

Benefits: Accurate and detailed unpaved road surface distress information was provided. This system could be used to acquire other road information such as geometrics.
Limitations: Image processing to extract the 3D models can be time consuming depending on the size of the road network. Once the 3D data are available, extracting distress depends on adequate lighting and contrast. Some features were hard to observe from the air, such as ditches covered with grass. It was suggested that an additional sensors be used to penetrate grass (Zhang, 2011).

INDIRECT DATA ACQUISITION: Survey – Ultralight Aircraft

Overview

An ultralight aircraft method for surveying was developed and pilot studies conducted by the Council of Scientific and Industrial Research (CSIR) Transportek for road agencies in Africa (Jones, 2006).

Surveying using ultralight aircraft was developed to ease access to remote locations for corridor studies. Previously, conditions such as harsh terrain combined with available time availability have hindered studies for new route corridors in southern Africa. Two pilot studies were conducted using ultralight aircraft. One included collecting data for a 1700 mile (2,750 km) corridor route for the Trans Kalaharia

Highway in Botswana with the ultimate route planned to go through Mozambique, South Africa, and Nambia. The other included collecting data for a 90+ mile (145 km) M1 Highway corridor through Mozambique (Jones, 2006). These corridor studies not only surveyed the possible routes, but also material that could be possibly available for construction use (Jones, 2006).

Method, Equipment, Record Keeping

To collect data, the investigator must first become familiar with the topography, roadway plan, vegetation, location of the route, etc. Then,an ultralight aircraft flown at an altitude of from 650 feet to 1640 feet (200 m - 500 m) , is used to observe important features. These are verified (and locations recorded) with GPS coordinates. Locations are described and rated by the investigator using a tape recorder so they can be prioritized for the best possible route location. Photos are taken as necessary. An ultralight aircraft is shown in Figure 11 below (Jones, 2006).

Figure 11. Ultralight aircraft for collection of survey data (Jones, 2006).

Time & Costs

In one pilot study, a 37 mile (60 km) road section was surveyed during a three hour flight with an additional two day field inspection necessary to verify information. No costs were incurred in takeoff and landing in this case because existing infrastructure was used for takeoff and landing. To compare costs and time, a ground survey was conducted in the same location with duration of two months. An example cost comparison of a ground survey versus the ultralight survey is shown in Table 32 below.

Table 32. Cost comparison: ground survey versus ultralight data collection (adapted from Jones, 2006).

	Ground Survey		Ultralight Survey		Ground Survey ($)	Ultralight Survey ($)
	Units	$/day	Units	$/day		
Geologist	60	560	3	560	33,600	1,680
Assistants	120	280	6	280	33,600	1,680
Vehicle	60	50	3	50	3,000	150
Backhoe loader	30	100	2	100	3,000	200
Subsistence	180	80	12	80	14,400	960
Ultralight	0	200	3	200	0	600
Ultralight pilot	0	500	3	500	0	1,500
Total					**87,600**	**6,770**

A suitable location with material was not located during the ground survey. Eleven sites with material available for construction were located during the aerial survey (Jones, 2006).

Time & Costs

Ultralight survey methods significantly reduce data collection time and scouting time. Additionally, these methods significantly reduce costs according to the 2006 Jones study.

Summary

This report on the state of the practice of unpaved road assessment has reviewed and described several currently available methods and more research-based methods used in the U.S. as well as other countries. Included were visual, combined visual and direct measurement methods, and indirect data acquisition methods. Visual methods described in this report are the unimproved PASER and gravel PASER methods, the Road Surface Management System, the Standard Visual Assessment Manual for Unsealed Roads, and the Central Federal Lands Highway Division subjective rating system. Combined visual and direct measurement systems described here are the Central Federal Lands Highway Division objective rating system and the Department of the Army's Unsurfaced Road Condition Index. Indirect data acquisition methods described here are an accelerometer-based method (road roughness using Opti-Grade accelerometer technology), ground penetrating radar, the Zhang unmanned aerial vehicle study, and an ultralight aircraft survey example.

The purpose of this report was to describe the current state of the practice rather than to recommend a particular assessment method. However, while writing the Requirements Definition report (Deliverable 1-A), the project team found the Department of the Army's URCI method to be a good candidate method to focus on for this project because it offers: a clear set of measurement requirements, the realistic possibility of collecting most of the condition indicator parameters, and the potential applicability to a wide variety of U.S. unpaved roads. The project team looks forward to feedback on this method and the others described in this state of the practice report.

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Michigan Technological University

Characterization of Unpaved Road Condition Through the Use of Remote Sensing

Deliverable 3-A: Remote Sensing the Phenomena of Unpaved Road Conditions

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www.mtri.org/unpaved

Deliverable 3-A: Remote Sensing the Phenomena of Unpaved Road Conditions

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Purpose of this Document

This document describes the kinds of phenomena, both fundamental (e.g. color) and emergent (e.g. long, linear, patterns due to rutting), which will be important to be able to sense for understanding and evaluating the conditions of unpaved roads. The resulting descriptions of useful phenomena will be used in specifying the sensor(s), as well as in the choice of image processing algorithms. The design of the system is based, first, on the physics of the sensing process.

In addition, this document serves to define precisely the definitions of terms that will be used throughout the rest of this program to describe image characteristics that will serve as discriminants of road distress.

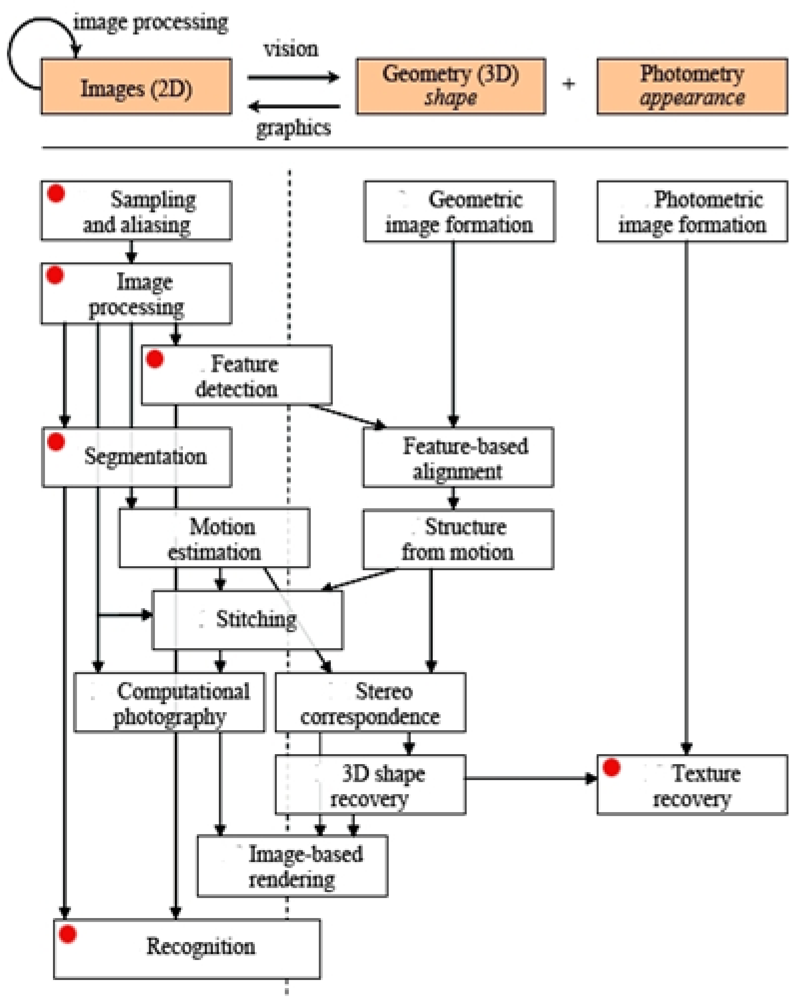
Motivation

Unpaved road condition can be assessed visually; the texture, color, shapes, surface imperfections, and other characteristics allow us to identify and classify various problems with the road. What can be measured is produced by the interaction of light with the road surface. These are the phenomena that are important. These fundamental phenomena combine to form textures, patterns, and other features that we would recognize as a “distress”. In this document, we will be discussing both the fundamaental physics-based phenomena (e.g. spectral reflectance), as well as the emergent features (e.g. texture) that result from variations in those phenomena.

This process of measuring and extracting information from the images needs to be performed automatically. The observable phenomena are the data with which we have to work, and these must be understood in order to choose the best system/algorithm combinations. This process of sensing, and then making sense of the images automatically, is termed “machine vision” [24, pp. 3].

The problem of reconstructing the characteristics of a scene from imperfect and/or incomplete measurements is usually referred to as an “inverse” problem. Machine vision falls into this category. Because there are many possible reconstructions from any set of partial measurements, this is a difficult problem. Although a human 2-year-old can, for example, count all the animals in a picture, this is extremely problematic for a computer. The same is true for unpaved road conditions; while a person can almost instantly recognize and characterize, say, corrugations in a road surface, getting a computer to do this is not a solved problem, and will be imperfect.

Machine vision has been improving gradually; over the last 15 years, we have seen an impressive gain in automatically measuring and understanding images. The figure below[24, pp 20] is an attempt to show how various operations in machine vision are related to our problem of sensing certain physical characteristics of the surface.



The blocks with the red dots indicate those parts of the road-characterization process that are influenced by the combination of phenomena and surface features. In our application, the problem becomes one of determining the important observable features, measuring them, and converting those measurements to information about the road condition. This later process will be considered in a subsequent task, but it is important to keep the goal in mind when considering the types of phenomena that we can sense, and the types that we want to sense to be able to solve the problem.

The process begins with the (much easier) forward model, by understanding how the incident (sun)light interacts with the surface, then enters the optics, where it is altered, and finally strikes the sensor, where some part of it is measured. The resulting images will have characteristics unique to the types of distresses we want to measure; color, texture, contrast, long-range patterns, etc.

The remainder of this document will detail the kinds of image characteristics (both fundamental and emergent) which are important to sense, to be able to identify distresses.

The Surface Characteristics

The road surface is all that we can measure in the optical spectrum; the subsurface structure may affect the surface, but we cannot sense it directly. There are a variety of observable characteristics which can be used to extract distresses from optical images.

Color

While roads themselves may be many colors, depending on the material content and the conditions, the spectral characteristics of the surface may change when a distress is present. Before we consider the particular spectral changes of interest, some background on color content is introduced.

Background

Human color perception is based on the incidence of visible light (with wavelengths in the 400 to 700 nm range) upon the retina. Since there are three types of color photoreceptors in the retina, each with a different spectral response curve, all colors can be completely described by three numbers. In 1931, the Commission Internationale de l'Eclairage (CIE) adopted standard curves for the color photo-receptor cone cells of a hypothetical standard observer, and defined the CIE XYZ tristimulus values, where all visible colors can be represented using only positive values of X, Y and Z. Since the creation of the CIE XYZ, other color spaces have been established to specify, create and visualize color information. The RGB (red-green-blue) color space, as used by graphic displays, can be visualized as a cube with red, green and blue axes. Different applications (e.g. printing) have different needs which can be handled better using different color spaces (in the case of printing, the CYMK). We will be considering only RGB in this discussion, since this is the most common one for camera images.

Road Surface Color

Road surfaces come in many colors, and it is unlikely that absolute color will be a strong characteristic of any particular distress. However, color contrast changes can be characteristic of surface changes. These changes from one area to another may be normal, or may result from distresses. In either case, we need to be able to characterize the color changes in a consistent way. Later, we will decide whether particular changes are associated with particular distresses.

We have collected sample images of various road surfaces. To be able to compare colors quantitatively, we placed a gray-card (of known color content) in the scene; the images, regardless of the lighting, can then be corrected to compare colors, as needed. The images below show how lighting and camera effects can change the measured color in a scene (see Figures 1 and 2).

Figure 1: Example of how lighting and camera effects can change the measured color of a scene.

Note that the identical gray-cards in the scenes above in Figure 1 appear to be different colors. This is probably due to camera white-balance errors due to lighting differences. If we were using uncorrected (absolute) color as a metric, we might be led to believe the scene on the left had a "bluer" surface than it actually does; some color correction would be needed to compare the spectra of these two images. A corrected version is shown below in Figure 2, in which the grays are equalized. It can be seen that the surface is much more yellow than blue, once corrected.

Figure 2: Example images with the grays equalized; this reveals that the surface on the left is much more yellow than it originally appeared in the digital image.

This correction is needed during evaluation, to determine how much lighting affects color changes (e.g., if a cloud obscures the sun during a measurement, what is that effect, versus a "real" surface color change). If lighting/color effects are important in determining certain distresses, then the design of the sensor system must include a way of characterizing the lighting, as well imaging the surface.

Texture

While color is a purely single-pixel property of images, texture involves a spatial extent; a single pixel has no texture. If texture is defined in the frequency domain, the texture of some particular location in the image is characterized by the frequency content in a neighborhood.

The texture is itself produced by some spatial change in color or contrast that has a characteristic spatial extent. It is important that we be able to sense all textures of interest (which comes down to a spatial resolution requirement). In our case, the road surface will have a number of textures, some of which will be characteristic of roads in good condition, and some of which will be characteristic of a damaged surface. The key here is in being able to measure, abstract, and associate various textures with various road states.

Numerous approaches for the representation of textured images have been proposed, ranging from the means and variances of a filter bank output [7, 13], wavelet coefficients [20], wave-packets [14], fractal dimension [2], or parameters of an explicit Markov random field model [3, 18]. Comparative studies on this subject can be found in [6,19,20]. Gabor filters are often used for texture analysis and have been shown to exhibit excellent discrimination properties over a broad range of textures [12, 13, 25]. These will be evaluated in a later task, but an example of segmentation using a Gabor filter is shown below in Figure 3.

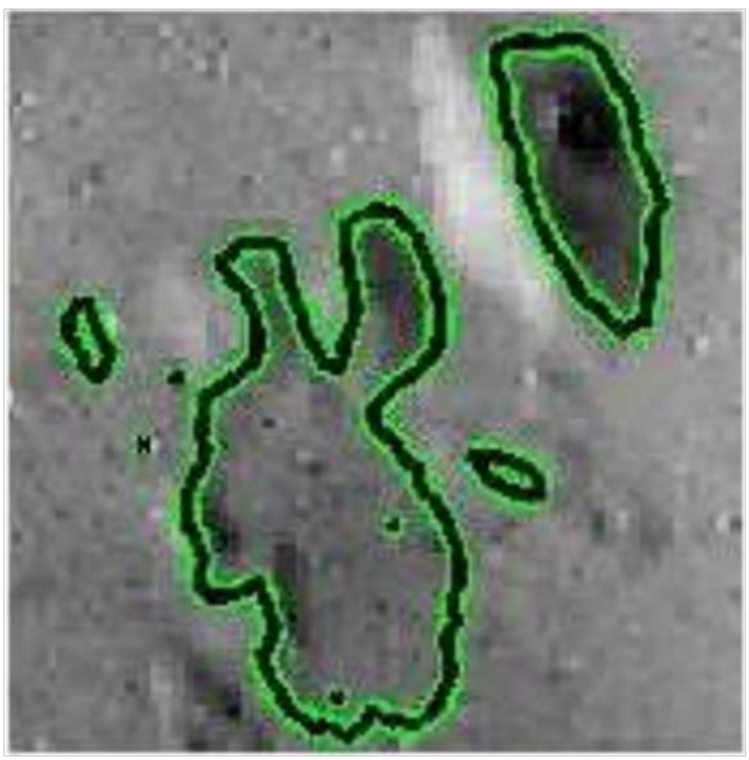


Figure 3: An example of segmentation using a Gabor filter.

As with many filtering operations, the filter bank used must be tuned to the texture being extracted. The local (small area) surface texture may change when a distress is present. That is, the texture of a surface which is losing (or has lost), for example, its coarse material will indicate damage, and filters would be designed for this.

Textures of Interest

The presence of aggregate as part of the road surface will produce a characteristic texture. This texture will change based on the size of the aggregate and its composition. Loose aggregate is expected to contain much coarser material, and thus have a different characteristic texture than a packed surface.

As road surfaces lose material, it is expected that the texture will change; the differential textures from one section of road to another can be used to differentiate the surface condition. Whether these changes reflect damage, or impending damage, will be determined once measurements commence.

Since the current requirements on surface features specify that certain distresses need to be measured to an accuracy of 1-2 inches (see the requirements definition report at http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del1-A_RequirementsDocument_MichiganTechUnpavedRoadsr1.pdf), the sensor itself must be capable of sensing at least half that spatial resolution; this is the Nyquist-Shannon sampling criterion[23]. This sampling should include texture.

Patterns

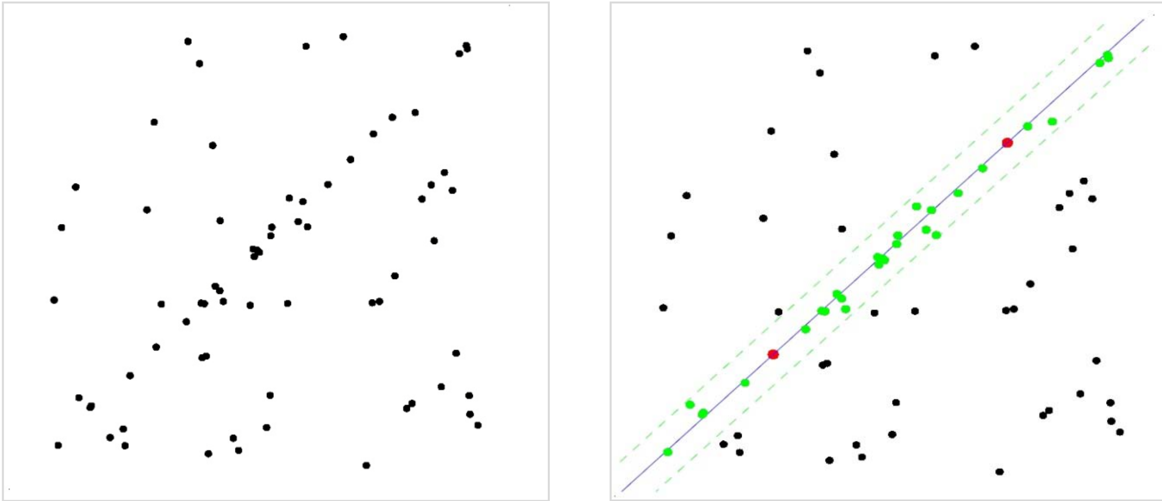
Related to textures are what we will term “patterns”. These tend to be repetitive combinations of textures that can be either long-range, or local, and are characteristic of road surface features.

Long-range spatial patterns may characterize certain distresses. For example, corrugations are characterized by repetitive contrast changes across the road surface, while rutting is characterized by longitudinal (along the direction of travel) edges in the image. Both, however, are linear features that emerge from contrast changes due to material variations . Other such patterns include ovals (characteristic of potholes).

There are several important properties of the patterns that, while not physical phenomena, are key to differentiating the damages. These are:

1. The location of the patterns on the road: lines in the traveled lane will tend to be rutting, while lines outside that lane are likely to be berms of displaced material.
2. The orientation: ruts only form in the direction of travel, while washboarding only forms across the direction of travel.
3. The scale: ruts tend to be on the order of a tire-width, while washboarding tends to be much wider. These types of scale-dependent characteristics have been widely used in multiresolution techniques such as wavelet analysis [14, 20].

There are several common ways of detecting patterns, including successive approximation (where curves are recursively divided into smaller lines), Hough Transforms (in which edges “vote” for plausible curve fits), and Random Sample Consensus (RANSAC) (in which randomly selected edgles are tested against shape hypotheses) [24, pp 224]. An example of detecting a line using RANSAC is shown below in Figure 4.



Samples of some 2-D measurements **Best line after pair-wise testing of all possible lines**

Figure 4: An example of detecting a line using Random Sample Consensus (RANSAC) .

In the data above, left, the human eye can discern a linear feature, but computer algorithms to isolate that feature will have various trade-offs between performance and execution time. RANSAC, for example, is more efficient of memory, but can take much longer to run. The choice is problem-dependent, and must be determined once data have been gathered.

Profile

The profile of the road surface is a 3-dimensional characteristic. That is, it can be described by the position on the road surface (both in the travel direction, and side-to-side), and the height at each position. This 3-D information is useful in determining not only long-range details, such as loss of crown, but also local patterns that may develop. The mean profile depth may be used in local regions as one metric of surface condition. The change of this from the center to the edge of the road can be used to determine crown.

The problem is one of determining, inexpensively but accurately, this mean profile depth from a series of 2-D images. This has been an active area of machine vision research for decades[24]. Since our sensor will be moving rapidly, and we have no plans to loft a stereoscopic sensor, we will be using a method call “structure from motion” [4], which recovers both the scene and the camera motions from a series of static images without assuming anything about the cameras, scene content, or correspondence between images.

One possible method of doing this is to use a set of scale-invariant image features [17], and obtain the optimal motion and structure by minimizing the reprojection errors between the observed and predicted image points using Levenberg-Marquadt optimization[16]. This method will be evaluated to determine the requirements on the sensor to be able to achieve the sampling needed to meet the texture and profile requirements. An example of such a reconstruction is shown below in Figure 5.

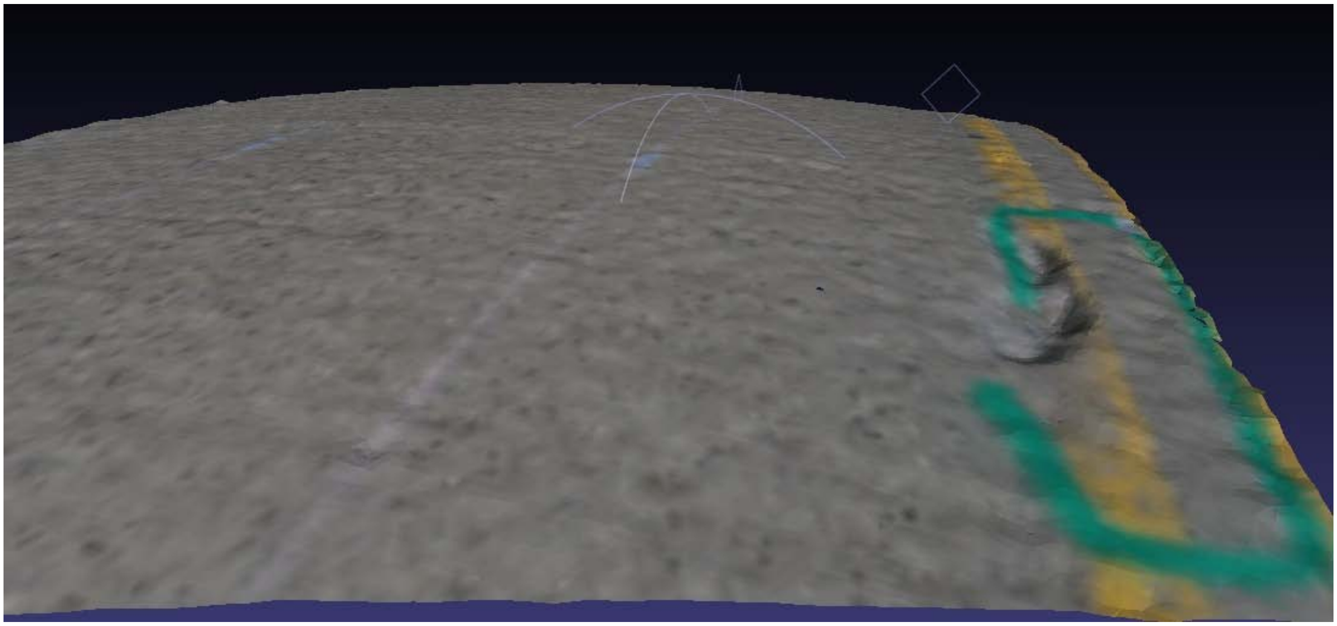


Figure 5: An example of a 3-D reconstruction for a road surface using structure from motion methods.

This is a view of a 3-D reconstruction of a section of the Freer Road bridge, showing both texture, and a large pothole (center right). It is difficult to illustrate in a 2-D format, but detailed depth information can be extracted from this reconstruction. Both road crown and local characteristics can be extracted from these types of 3-D features.

Polarimetric backscatter

It has been shown that road surface defects have characteristic radar polarizations[15], as well as polarimetric signatures in the infrared[9]. It is possible that optical polarization, while weak, may serve as a way to detect loss of surface material. This effect is being investigated in the laboratory at this time; weather conditions so far have prevented field measurements from being made. Preliminary indications are promising. The picture below shows the laboratory equipment which will be used to collect the polarization data.

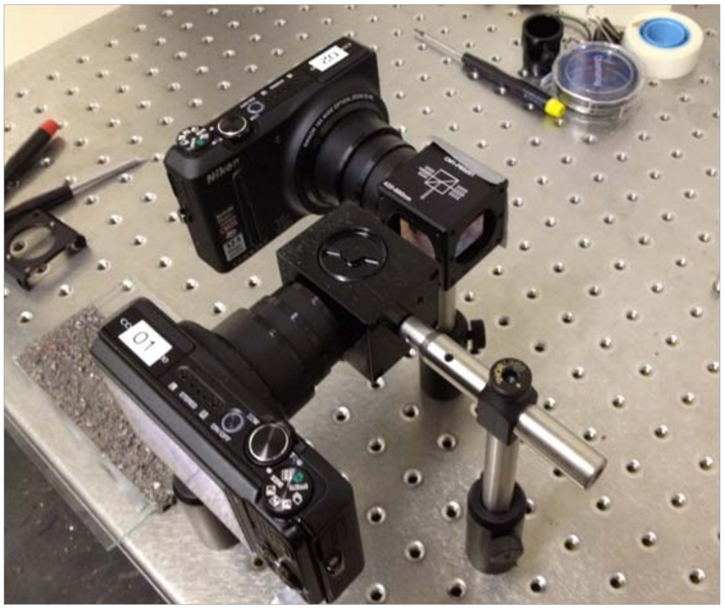


Figure 6: Example of the camera setup being used in the laboratory to investigate the potential of optical polarization in helping to detect loss of surface material.

The system consists of two cameras observing the same field-of-view through a polarizing beamsplitter. Once properly aligned, the two images can be compared on a pixel-by-pixel basis for difference in polarization.

Summary

The only characteristics that can be sensed optically are surface phenomena. These include color, texture, patterns, profile (i.e. 3-D structure), and polarization. The requirements on distress measurements have been detailed previously; the phenomena associated with these distresses will need to be determined once data become available. This document has described explicitly those phenomena for which we will be testing once the sensor is designed and built. This will inform the sensor selection, which is the focus of the next report, Deliverable 4-A, "Candidate and Recommended Remote Sensing Platforms for Unpaved Road Condition Assessment."

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Characterization of Unpaved Road Condition Through the Use of Remote Sensing

Deliverable 4-A: Sensor Selection for use in Remote Sensing the Phenomena of Unpaved Road Conditions

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Deliverable 4-A: Sensor Selection for use in Remote Sensing the Phenomena of Unpaved Road Conditions

Purpose of this document

This document describes the process of selecting the sensor(s) that will be needed to measure the relevant parameters required to estimate unpaved road condition and includes details on the candidate sensors that were evaluated as part of this process.

Motivation

Unpaved road condition can be assessed visually: the texture, color, shapes, surface imperfections, and other characteristics allow us to identify and classify various problems with the road. The things that we can measure are produced by the interaction of light with the road surface. These are the phenomena that are important. These combine to form textures, patterns, and other features that we would recognize as a "distress". The sensor needs to measure these distresses at a resolution and rate that will meet the system requirements (detailed in Deliverable 1-A, the "Requirements for Remote Sensing Assessments of Unpaved Road Conditions, available at http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del1-A_RequirementsDocument_MichiganTechUnpavedRoadsr1.pdf). In this document, we will be discussing the process of sensor selection, and the sensor(s) that have been identified as candidates for our subsequent system design.

Summary of sensor requirements from Deliverable 1-A

Field-of-View

The field-of-view (FOV) of the sensor depends on the range to the road and the focal length of the lens. From our requirements, we see that the FOV needs to be twice the width of a typical road (plus drainage), or about 72'.

Focal Length

Given the nominal altitude of the collection (~100' - 400'), that corresponds to a focal length of 61mm – 244mm, which is in the range of standard telephoto lenses.

Resolution

From the requirements on the various distresses, the smallest size needed is ~1". For a 61mm lens with a FOV of 72', and applying the Nyquist Sampling criterion [1] one would need a sensor with 1728 pixels across the road to measure +/-1" [2]. This would be about the size of a 4Mp (megapixel) camera. Since typical COTS (commercial off-the-shelf) digital cameras with resolution of 16Mp are widely available, this should not be a problem (i.e. almost any camera would provide sufficient resolution). Alternatively, if we use a camera with a larger sensor (i.e. more pixels) then the focal length of the lens can be reduced and still maintain the required ground sample distance (1"). The advantage of using a lens with a shorter focal length is that it is lighter, gathers more light (making exposures faster, for less motion-blur), and has better depth-of-field (making focus less of an issue). This argues that we should try to obtain the sensor with the largest number of pixels, so that we can relax the optical requirements.

Frame-Rate

The fastest frame rate needed would be for a sensor mounted on a manned, fixed-wing, aircraft, flying just above stall-speed (~60 mph). For an along-track FOV (field of view) of 94', and a 50% overlap in consecutive images, this corresponds to collecting images at 2.3 frames per second. If the overlap is larger (which may be needed for full 3D reconstruction, say 75% overlap, the frame rate becomes 3.5 fps (frames per second).

Additional Requirements

There are several other requirements on the camera:

1. It must have a remote trigger to allow software control of the image collection
2. All possible collection scenarios should be possible with a single lens

Sensor Types

All optical sensors must convert photons of visible light into electrons. These electrons accumulate in each cell (pixel) of the sensor and are counted, producing the intensity values of the image.

There are two main types of sensors commonly available: charge-coupled devices (CCD) and complimentary metal-oxide semiconductor (CMOS). In a CCD array, which is an analog device, the accumulated charges in each cell are shifted from one cell to the next (in a sort of "bucket brigade") to the edge of the sensor array where the charge is measure and converted to a digital count; in CMOS sensors, each cell has circuitry around it that measure the voltage induced by the photons, and can be read individually. Because of the very different ways the charges are sensed, these sensor types have very different characteristics. We should understand how these characteristics might affect our ability to measure road conditions.

The most important differences [3] between the sensors are:

- CCD arrays can produce high-quality, low-noise images; CMOS arrays tend to be more susceptible to noise.
- CMOS sensors tend to be less sensitive to light, since each pixel has several components near it, which photons strike but are not measured.
- CCDs typically consume much more power (100x) than CMOS sensors.
- CMOS can be fabricated more easily, and tend to be cheaper than CCD sensors.
- CCD have been around longer, and are a more mature product, tending to possess higher quality than CMOS sensors.

- CCDs tend to be susceptible to smear from bright light sources.
- CMOS tends to be affected by "rolling shutter" artifacts (a process that is often used to increase the sensitivity).
- CCDs have about 2x better dynamic range than CMOS.
- CMOS can be faster, because all camera functions can be placed on-chip.

Neither sensor type has a clear advantage. CMOS imagers offer better integration, lower power consumption, and smaller size (and weight). CCD imagers have superior quality at the expense of system size and power consumption. Total cost is approximately equal. The question is: for our application, will this make any difference?

Consider the typical collection of data for rural road condition assessment. Data will be collected during the day, in good weather (no rain, light winds). This means sensor noise should not be an issue, since noise contributions are less (signal-to-noise ratio (SNR) is higher) under typical daylight illumination [4]. Further, many CMOS sensors have adopted a technique (back-illumination) which improves the sensitivity at low light levels. Exposure times can be adjusted to eliminate motion blur and still provide sufficient SNR, by appropriate choice of forward speed and lens characteristics. The conditions under which the data will be collected do not extend to those areas where sensor differences manifest themselves.

In summary it appears that while there are significant differences in sensor technology, for the purposes of this program they are not important differences. We will not be using this as an exclusionary factor in choosing an imager.

Candidate Sensors with Recommendation

Table 1 below contains a subset of the information which we used to indicate which sensors might be appropriate. Many of the cameras have very similar features. The first requirement, though, is that they be able to be controlled remotely. The cells that are shaded grey are those cameras that while very capable in other respects, lack this remote control feature. These are excluded from consideration, as are cameras that have reached the end of their production life (and will no longer be supported), shown in red. All cameras that are shaded green (a total of 22 models) are possible candidates. They range in price from $600 - $35,000, with the more expensive cameras generally having one (or more) exceptional capabilities (e.g. RED Epic can collect full-resolution images at 120fps. This is much faster than most of the others, and its price reflects this).

In order to evaluate the sensor, we will choose one that is more capable than some, and less capable than others. That is, one that lies somewhere in the middle in capability. Then, once data are collected, we can evaluate whether more, or less, capability is desirable.

The sensor that we have chosen for initial testing is the Nikon D800, the first line in Table 1. This camera has a full-sized (FX) sensor with 36.3Mp and a full-speed frame rate of 4fps. It more than meets all our requirements as known at this time. It is one of the heavier cameras (1kg), and with a prime lens, the total camera should weigh less than 1.5kg. Detailed specifications for this recommended sensor are shown in Appendix A.

Table 1: Comparison of Candidate Sensors

No single lens will fit our requirements		No Remote Trigger Option						
		Discontinued						
Manufacturer	Model	Mp	Price (USD)	Max FPS (at fu	Max FPS (full r	Sensor Width	Sensor Heigh	Remote Trig
Nikon	D800	36.3	$2,999.95	4	4	7360	4912	Yes
Nikon	D3X	24.5	$7,999.95	5	5	6048	4032	Yes
Canon	EOS 5D Mark III	23.4	$3,499.00	6	6	5760	3840	Yes
Canon	EOS-1Ds Mark III	21.1	$6,999.00	5	5	5616	3744	Yes
Canon	EOS 60Da	19	$1,499.00	5.3	5.3	5200	3462	Yes
Canon	EOS-1D X	18.1	$6,800.00	12	12	5184	3456	Yes
Canon	EOS 7D	18	$1,699.99	8	8	5184	3456	Yes
Canon	EOS 60D	18	$999.99	5.3	5.3	5184	3456	Yes
Canon	EOS Rebel T2i EF-S	18	$699.99	3.7	3.7	5184	3456	Yes
Canon	Eos Rebel T3i EF-S	18	$849.99	3.7	3.7	5184	3456	Yes
RED	Epic	14.3	$34,500.00	120	120	5120	2700	Yes
RED	Scarlet-X	14.3	$9,700.00	30	30	5120	2700	Yes
Nikon	D4	16.2	$5,999.95	10	10	4928	4280	Yes
Nikon	D7000	16.2	$1,199.95	6	6	4928	3264	Yes
Nikon	D5100	16.3	$849.95	4	4	4928	3264	Yes
Canon	EOS-1D Mark IV	16.1	$4,999.00	10	10	4896	3264	Yes
Nikon	D300s	12.3	$1,699.95	7	7	4288	2848	Yes
Nikon	D90	12.3	$899.95	4.5	4.5	4288	2848	Yes
Nikon	D5000	12.3	$629.95	4	4	4288	2848	Yes
Canon	EOS Rebel T3	12.2	$549.99	3	3	4272	2848	Yes
Nikon	D700	12.1	$2,699.95	5	8	4256	2832	Yes
Nikon	D3S	12.1	$5,199.95	9	9	4256	2832	Yes
Pentax	645D	40	$9,995.95	1.1	1.1	7264	5440	No
Sony	NEX-7	24.3	$1,349.99	10	10	6000	4000	No
Sony	a77	24.7	$1,399.99	8	8	6000	4000	No
Sony	a65	24.3	$998.00	8	8	6000	4000	No
Canon	EOS 5D Mark II	21.1	$2,499.00	3.9	3.9	5616	3744	No
Pentax	K-5 Black	16.3	$1,099.00	7	7	4928	3264	No
Pentax	K-01	16.49	$899.00			4928	3264	No
Sony	NEX-5N	16.1	$699.99	10	10	4912	3164	No
Sony	TX66	18.2	$349.99			4896	3672	No
Sony	TX200V	18.2	$499.99			4896	3672	No
Nikon	D3100	14.2	$646.95	3	3	4608	3072	No
Sony	TX55	16.8	$289.99			4608	3456	No
Nikon	P510	16.1	$429.95			4608	3456	No
Nikon	P310	16.1	$319.00			4608	3456	No
Nikon	S9300	16	$346.95			4608	3456	No
Pentax	Optio WG-2 GPS	16	$399.00	1	1	4608	3456	No
Pentax	Optio VS20	16	$184.95	1	1	4608	3456	No
Sony	TX20	16.2	$329.99			4608	3456	No
Pentax	Q	12.4	$749.95	5	5	4000	3000	No
Nikon	1 V1	10.1	$896.95	5	5	3872	2592	No
Nikon	1 J1	10.1	$649.95	5	5	3872	2592	No
Nikon	D3000	10.2	$499.95					
Sigma	SD1	46	$2,299.00	6	6	14400	9600	Yes
Olympus	E-5	12.3	$1,699.99			4032	3042	Yes

Candidate Lenses with Recommendation

The choice of lenses depends on the exposure characteristics (i.e., we want the fastest practical shutter speeds to minimize motion blur), the focal length and sensor resolution (we need to have sufficient ground-sample spacing at the collection standoff to meet the measurement requirements).

For a flight altitude on 400', and a ground-sample spacing of 0.5", that is a scene-size (FOV) of 200', which corresponds to a lens focal length of 90mm. At a standoff of 100', with about that FOV, that would be a 44mm lens. If we needed a single lens with a range of say, 40mm-90mm, there are several practical choices, shown in Table 2.

Table 2: Lens Comparison

Nikon	Nikkor	18-200mm	f/3.5-5.6G	$846.95
Nikon	Nikkor	28-300mm	f/3.5-5.6G	$949.95
Canon		28-300mm	f/3.5-5.6L	$2,689
Canon		18-200mm	f/3.5-5.6 IS	$629
Tamron		18-200mm	f/3.5-6.3 XR Di-II	$299.00
Tamron		18-270mm	f/3.5-6.3 Di II VC PZD AF	$649
Sigma		18-250mm	f/3.5-6.3 DC OS HSM	$479
Tamron		28-300mm	f/3.5-6.3 XR Di LD	$419
Sigma		18-200mm	f/3.5-6.3 II DC OS HSM	$499
Tamron		28-300mm		$629
Tamron		AF18-270mm	f/3.5-6.3 Ei-II VC LD Asph. AF (IF)	$449.95
Sony		18-200mm	f/3.5-6.3	$898
Tamron		18-200mm	f/3.5-6.3 Di III VC	$739
Sony		DT 18-250mm	f/3.5-6.3	$648.00
Sony		SAL-18200 18-200mm	f/3.5-6.3	$548.00

If we want a "faster" lens (i.e. a lens with a larger aperture, capable of capturing more light), then there are no single lenses that span the desired focal lengths. However, two lenses would be a possible compromise:

- Nikon AF-S 50mm f/1.4 (or f/1.8) $480
- Nikon AF-S 85mm f/1.4 (or f/1.8) $1229

These lenses have at least 8x the light-gathering capacity, which means that, for a given illumination, they can maintain quality at 1/8th the exposure time (further reducing motion blur).

For test purposes, we will be recommending and using the 50mm f/1.4 lens, based on these specifications.

Deliverable 4-A: Sensor Selection for use in Remote Sensing the Phenomena of Unpaved Road Conditions

Figure 1: Nikkor AF-S 50mm f/1.4

Appendix A: Detailed Sensor Characteristics

The Nikon D800 has the following details specification [5].

Body type	
Body type	Mid-size SLR
Body material	Magnesium alloy
Sensor	
Max resolution (px)	7360 x 4912
Effective pixels	36.3 megapixels
Sensor photo detectors	36.8 megapixels
Other resolutions	6144 x 4912, 6144 x 4080, 5520 x 3680, 4800 x 3200, 4608 x 3680, 4608 x 3056, 3680 x 2456, 3600 x 2400, 3072 x 2456, 3072 x 2040, 2400 x 1600
Image ratio w:h	5:4, 3:2
Sensor size	Full frame (35.9 x 24 mm)
Sensor type	CMOS
Processor	Expeed 3
Color space	sRGB, Adobe RGB
Color filter array	Primary Color Filter
Image	

ISO	100 - 6400 in 1, 1/2 or 1/3 EV steps (50 - 25600 with boost)
White balance presets	12
Custom white balance	Yes (5)
Image stabilization	No
Uncompressed format	.NEF (RAW)
JPEG quality levels	Fine, Normal, Basic
File format	• NEF (RAW): 12 or 14 bit, lossless compressed, compressed or uncompressed • TIFF (RGB) • JPEG
Optics & Focus	
Autofocus	• Phase Detect • Multi-area • Selective single-point • Tracking • Single • Continuous • Face Detection • Live View
Autofocus assist lamp	Yes
Digital zoom	No
Manual focus	Yes
Number of focus points	51
Lens mount	Nikon F mount
Focal length multiplier	1×
Screen / viewfinder	
Articulated LCD	Fixed
Screen size	3.2"
Screen dots	921,000
Touch screen	No
Screen type	TFT Color LCD with 170 degrees wide-viewing angle
Live view	Yes
Viewfinder type	Optical (pentaprism)
Viewfinder coverage	100 %
Viewfinder magnification	0.7×
Photography features	

Minimum shutter speed	30 sec
Maximum shutter speed	1/8000 sec
Exposure modes	• Programmed auto with flexible program (P) • Shutter-priority (S) • Aperture priority (A) • Manual (M)
Built-in flash	Yes (pop-up)
Flash range	12 m (at ISO 100)
External flash	Yes (Hot-shoe, Wireless plus sync connector)
Flash modes	Auto, On, Off, Red-eye, Slow sync, Rear curtain, High-speed sync
Flash X sync speed	1/250 sec
Drive modes	• S (single frame) • CL (continuous low speed) • CH (continuous high speed) • Q (quiet shutter-release) • MUP (mirror up) • Self-timer
Continuous drive	Yes (4 fps in FX format, max 6fps in DX)
Self-timer	Yes (2 to 20 sec, 1 to 9 exposures at intervals of 0.5, 1, 2 or 3 sec)
Metering modes	• Multi • Center-weighted • Average • Spot
Exposure compensation	±5 EV (at 1/3 EV, 1/2 EV, 1 EV steps)
AE Bracketing	(2, 3, 5, 7 frames at 1/3 EV, 1/2 EV, 2/3 EV, 1 EV steps)
WB Bracketing	Yes (2 to 9 frames in steps of 1, 2 or 3)
Videography features	
Format	• MPEG-4 • H.264
Microphone	Mono
Speaker	Mono
Resolutions	1920 x 1080 (30, 25, 24 fps), 1280 x 720 (60, 50, 30, 25 fps), 640 x 424 (24 fps)
Storage	
Storage types	Compact Flash (Type I), SD/SDHC/SDXC UHS-I compliant
Storage included	None
Connectivity	
USB	USB 3.0 (5 GBit/sec)
HDMI	Yes (Mini Type C)
Wireless	None

Remote control	Yes (Optional, wired or wireless)
Physical	
Environmentally sealed	Yes (Water and dust resistant)
Battery	Battery Pack
Battery description	Lithium-Ion EN-EL15 rechargeable battery & charger
Weight (inc. batteries)	900 g (1.98 lb / 31.75 oz)
Dimensions	146 x 123 x 82 mm (5.75 x 4.84 x 3.23")
Other features	
Orientation sensor	Yes
Timelapse recording	Yes
GPS	Optional
GPS notes	GP-1

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Michigan Technological University

Characterization of Unpaved Road Condition Through the Use of Remote Sensing

Deliverable 5-A: Candidate and Recommended Remote Sensing Platforms for Unpaved Road Condition Assessment

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Purpose of this document

This document describes the process of selecting the platform(s) that will carry the sensors during data collections for unpaved road assessment. As described in the project's statement of work, chosen platforms will need to be economical, easy to use with minimal training, and able to make the needed measurements as conveniently as possible.

Motivation

Unpaved road condition can be measured by the selected sensor that was described in Deliverable 4-A, "Candidate and Recommended Remote Sensors for Unpaved Road Condition Assessment" (to be posted to http://www.mtri.org/unpaved/ one approved by the Program Manager). In this report, the selected sensor was the 36.3 megapixel Nikon D800 (7360 x 4912 pixels), with a full-sized (FX) sensor, 4 fps (frames per second) image collection rate, 1.5 kg weight with lens, $3,000 cost, and remote trigger capability, This sensor has size, weight, and power (SWAP) requirements. In this document, the project team will be discussing the process of platform selection, and the platform(s) that have been identified as candidates for our subsequent system design. As also described in the original project statement of work, two types of platforms will be considered: small, unmanned systems, and standard manned fixed-wing aircraft.

Summary of platform requirements

Altitude

The Federal Aviation Administration (FAA) requires that unmanned systems stay out of the national airspace, and must remain below 400ft. For the FAA factsheet that summarizes current regulations on unmanned aerial systems (UAS), please see http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=6287. For manned systems, for safety reasons, the aircraft should never fly below 500ft (navigable airspace includes all airspace 500 feet above ground level, see http://www.faa.gov/air_traffic/publications/atpubs/AIR/air0603.html).

Speed

The maximum speed considered is 60mph (for a manned aircraft). This is above the stall speed of a small manned fixed wing aircraft but slow enough to enable effective data collection.

Payload

The platform must be able to carry 5kg of payload, which consists of the camera, lens, battery, and control-system.

Range

The UAS is required to remain within line-of-sight under current FAA regulations, so the range is limited to several miles. A manned system has unlimited range, for the purposes of this program.

Additional Requirements

There are several other requirements on the platform:

1. It should be reliable
2. If a UAS, it should have an autopilot
3. It should be cost-effective

Platform Types

For unmanned systems, there are fixed-wind, rotary-wing, and aerostat aircraft. For manned systems, there are fixed-wing and rotary-wing platforms. These will be discussed separately.

UAS

The speed/altitude combination restricts us to either rotary-wing or aerostat types (the fixed-wing UAS cannot fly slowly enough to get the image overlap required to calculate critical indicators of unpaved road condition). For the payload required, the aerostat is extremely large (>10m), and would present serious problems in storage and deployment. For this reason, we will only be considering rotary-wing UASs.

Manned

Any manned platform, ranging from ultra-light aircraft to typical single-engine aircraft, will satisfy the requirements. The only factor we will consider is cost.

Candidate UAS Platforms

Table 1, below contains a subset of the information which we used to indicate which platform might be appropriate. All the platforms meet the basic requirements.

Table 1: Comparison of rotary-wing UASs

Manufacturer	Cost	Service location	Comments
Rotomotion SR2	**>$30k**	**France**	**Parent company located in North Carolina. Michigan Tech has purchased from them before, and had unpleasant problems with them.**
Viking Aerospace Wolverine III	**>$50k**	**Oregon**	**Good interactions with company, and good customer reviews.**
Bergen R/C Tazer 800	**<$15k**	**Michigan**	**Excellent service and customer reviews.**
Bergen eObserver	**<$20k**	**Michigan**	**Has gimbaled camera mount.**

Based on Michigan Technological University's previous experience with aquisition of a Rotomotion platform, they were excluded. Based on cost and reliability, the Viking platform was rejected. The platform chosen was the Tazer 800 (see Figure 1), over the eObserver, since a pointable camera mount was not needed. We were able to obtain two of the aircraft , with fixed camera mounts, for under $20k, one with an autopilot, and one without (which is the backup aircraft in case of mechanical problems with the first UAS). Details specifications are shown below (see Figures 1 and 2).

Figure 1: Overview of the selected Tazer 800 UAS platform.

Figure 2: Tazer 800 with fixed camera mount slung underneath.

Candidate Manned Aircraft

The choice a manned aircraft is going to be based solely on availability, which will vary by region, as well as the ability to mount the camera system in a way to look down. This will vary by aircraft, but any typical fixed-wing aircraft will suffice.

Costs to charter an aircraft vary by region, and aircraft type. A typical Cessna 206 rental has been found to cost between $600 - $2000 per hour, depending on the location. Typical mission profiles will last at least 1 hour, and as long as 2 hours. As we get closer to testing the system, we will obtain quotes from local agencies, to determine the cost more closely.

Summary

This deliverable report, 5-A, has described the platforms evaluated and selected for carrying the project's selected digital camera sensor so that the critical indicators of unpaved road condition can be assessed with the requirements described in Deliverable 1-A (see http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del1-A_RequirementsDocument_MichiganTechUnpavedRoadsr1.pdf). Both manned and unmanned platforms are capable of meeting the data collection requirements. For an unmanned aerial system platform, the Tazer 800 helicopter was selected as meeting data collection needs whereas unmanned fixed wing and aerostat platforms do not meet them. For manned systems, any typical manned fixed wing aircraft will be capable and the exact platform will depend on availability and cost. Upcoming deliverables will describe the software and algorithms needed to support processing of the collected imagery data into useful information, how these data will be made available through a Decision Support System, field deployment plans, and an overall performance evaluation.

Michigan Technological University

Characterization of Unpaved Road Condition Through the Use of Remote Sensing

Deliverable 6-A: A Demonstration Mission Planning System for use in Remote Sensing the Phenomena of Unpaved Road Conditions

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Contents

Purpose of this document

This document describes the process of planning a data collection mission. This will involve a review of where unpaved roads are in the collection area, a review of possible obstacles to flight operations, and the creation of a flight trajectory. This document is likely to be updated during the course of the program, based on user feedback, and the advice of domain experts.

Motivation

In order to be able to collect aerial road condition data, either from a manned or autonomous platform, one must know what needs to be collected (which roads are ready for inspection in a given area), what might interfere with that collection (obstructions to either flight or observation), and how best to collect the needed data. This process could be complicated, tedious, and expensive if conducted in the traditional manner. We are proposing to provide tools to assist the planner in this task, and in making a plan as quickly, and efficiently, as possible.

Mission Planning Sub-tasks

Asset Definition

We are only interested in measuring the condition of unpaved roads. While most people tasked with planning a collection mission will already know which roads are unpaved, having a visual way of locating possible target roads is useful. The planner will want to have a convenient way of displaying at least the following information as map overlays:

- Unpaved roads, and possible classification as gravel or bare-earth
- Conditions, if known, as of last inspection
- Date of last inspection
- Date and type of last remediation
- Public comments

Based on these (and possibly other) factors, the mission planner will select an area for data collection. The section below entitled "***Deriving an unpaved roads network as a major mission planning input using high-resolution aerial imagery***" describes in detail how an unpaved roads network can be created to define the asset that will be assessed by this project's sensor and platforms.

Flight Safety and Effectiveness Inspection

Before choosing a flight plan, the site needs to be evaluated for safe flight operations, as well as suitability for aerial collection. For example, the presence of high-voltage towers and distribution lines, the location of restricted airspaces, etc., will restrict the possible flight paths. Also, the presence of visual obstructions (trees, shadows, etc.) may make certain areas difficult (or impossible) to evaluate from the air.

This process needs to be defined separately for manned and unmanned collections; there are different requirements if the collection is to be performed by a manned sensor.

Manned Mission:

Although planning can be performed by anyone, a licensed pilot will need to review and approve any plan, to ensure that FAA regulations are followed, and adequate safety margins are included.

Unmanned Mission:

Unmanned collections take place at a lower altitude than manned flights, and have a larger number of possible obstructions (e.g. small radio towers, which would not be an issue for a manned platform, will be a possible obstruction for a small UAS).

Flight Trajectory Planning

The flight trajectory will be created by a tool called the Ground Station Control program, commercially available software that the project team has been evaluating. The trajectory will be based not only on the location(s) of the roads, but on the outcome of the previous flight-safety site assessment. The program has the ability, once programmed with a flight-plan, to automatically take-off, fly the mission, and auto-land. At any time, however, the operator can input flight adjustments using a joystick, or the safty-pilot can resume full manual control if needed.

The Ground Station Control program uses maps obtained from Google Earth to assist the user in accurate flight planning. An example of its use is given below.

First, the user brings up the tool, and selects the general area where a data collection is wanted. The typical view is shown below in Figure 1:

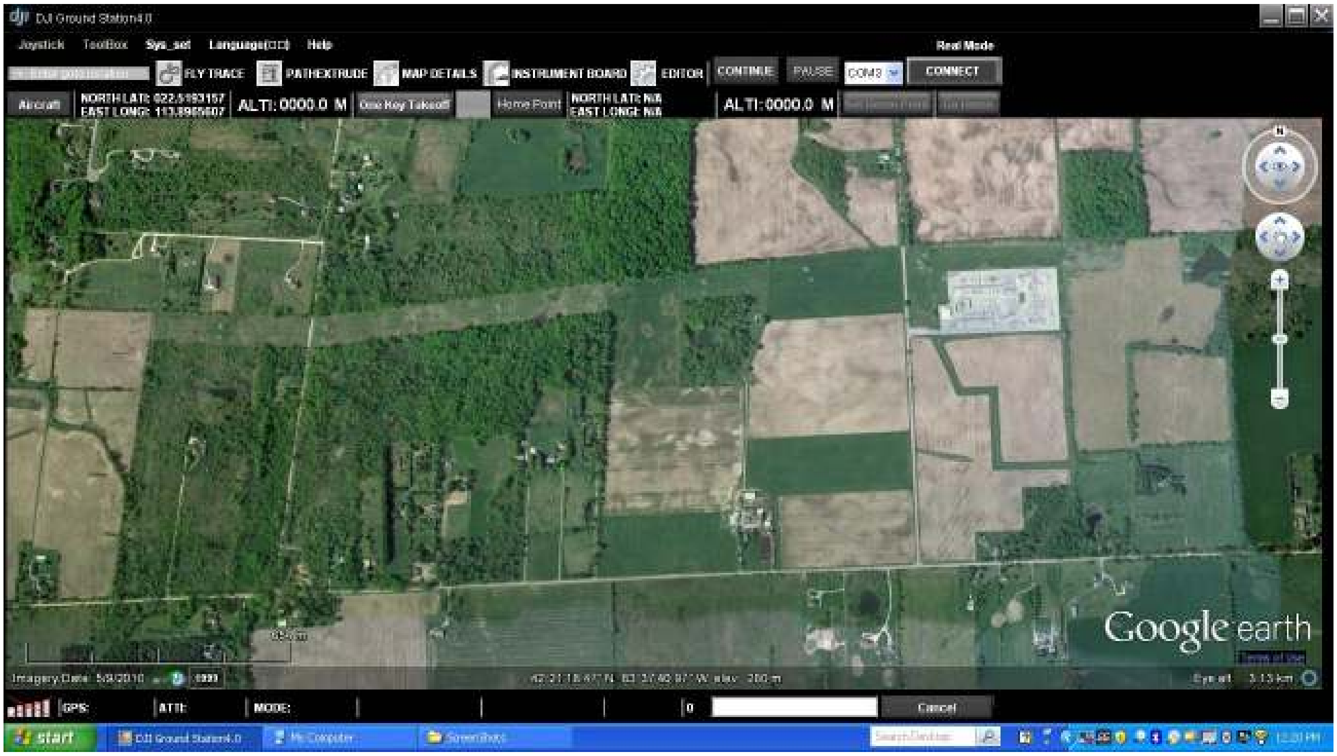

Figure 1: Typical view of opening screen in Ground Station program

Along with the usual Google Earth screen controls, there are a number of functions related to creating a flight trajectory and in-flight operations. The first thing a user will likely want to do is input a flight-plan consisting of a series of waypoints and associated flight parameters (altitude, speed, etc.). The screen showing an editing session in progress is shown below in Figure 2:

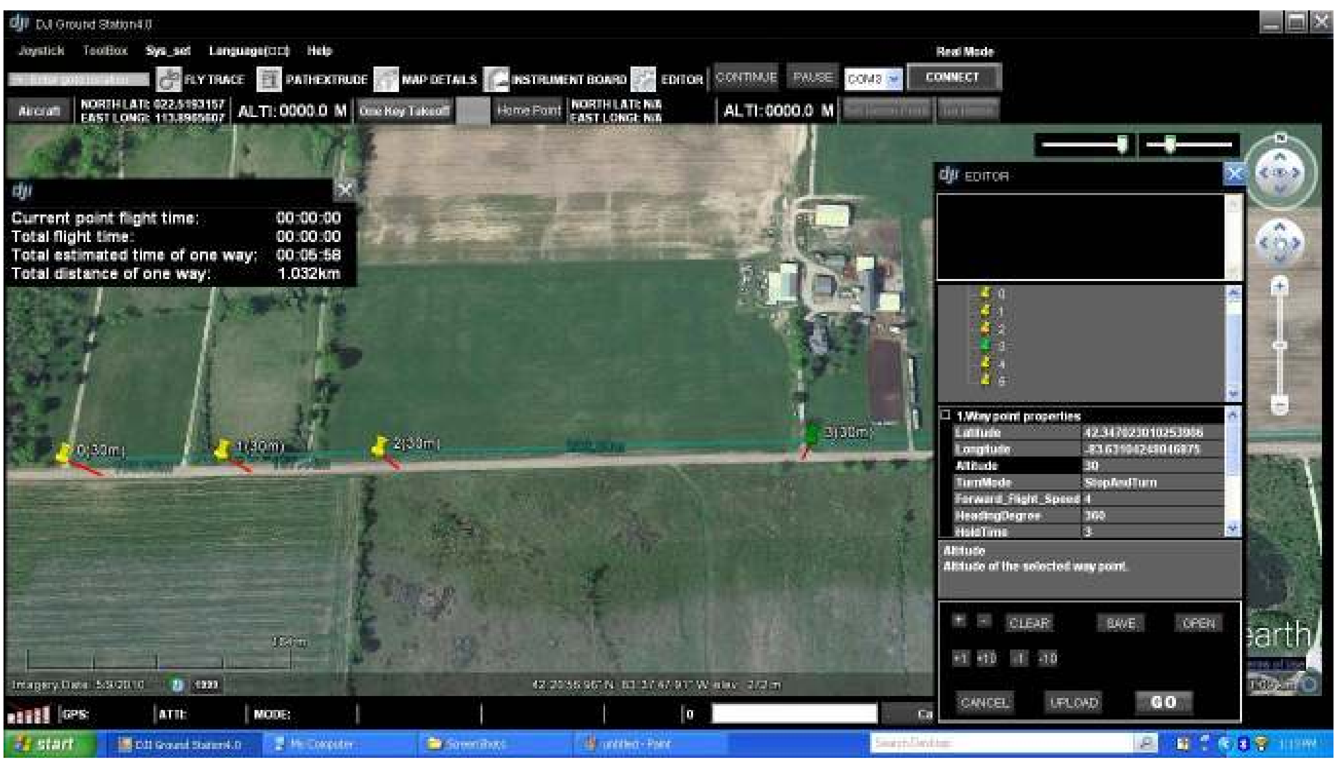

Figure 2: Editing session in the Ground Station program

For each waypoint, the user may select the altitude, loiter, speed to next waypoint, and type of turn (e.g. "stop and rotate to next heading", or "smooth curve", among others). The waypoint is shown as a "pushpin" icon in space, with a red vertical line descending to the ground directly below it. This gives the user some visual feedback concerning the overall height of the trajectory, and is useful where the terrain has changing altitudes. Also shown, on the left, is a summary of the current mission. During planning, only the estimated time and distance are shown; during a flight, the actual flight time is also distplayed.

A completed mission is shown below. The flight begins on the road at the left of the screen, proceeds down the road at an altitude of 30m for just under a kilometer, leaves the road to the south, and proceeds back to the starting point at an altitude of 50m.

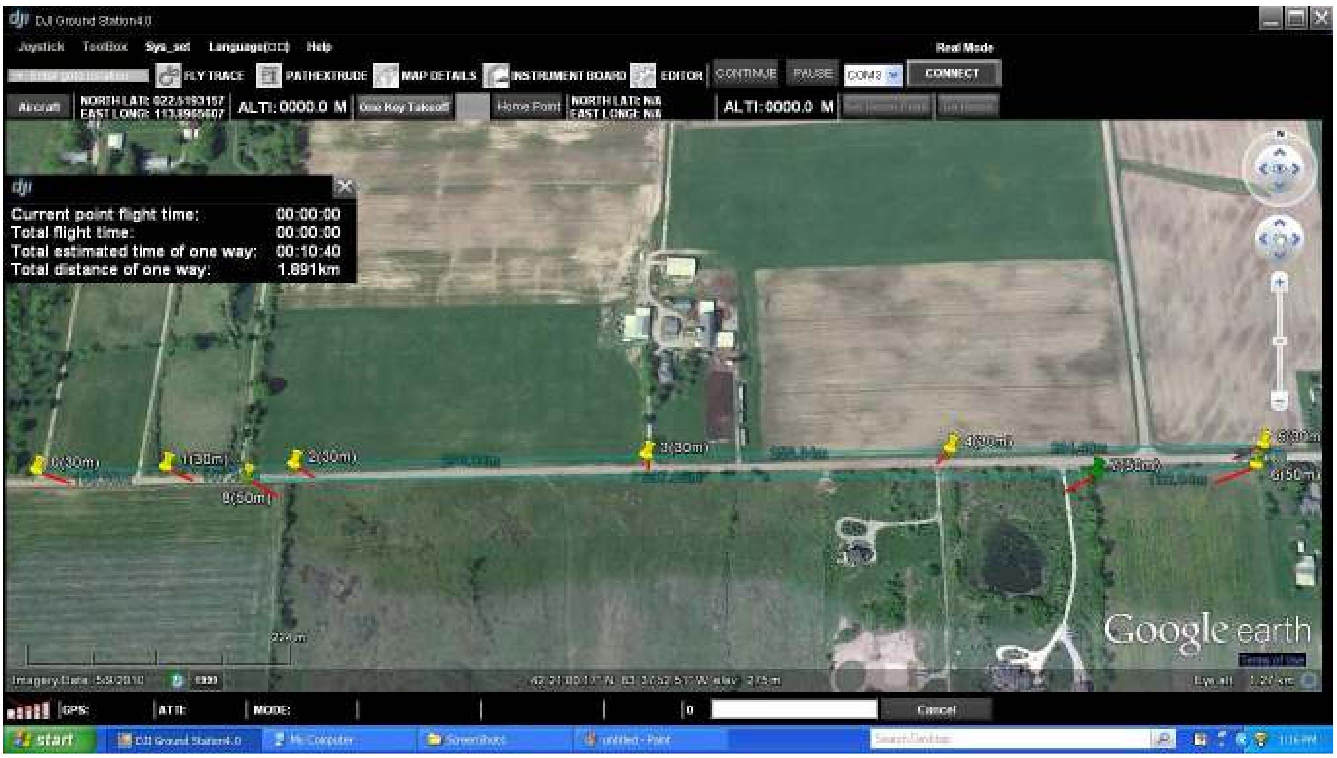

Figure 3: Complete flight path, looking down

It is possible to view the flight path from any angle and altitude, to help visualize the trajectory. An example of an alternate view is shown below:

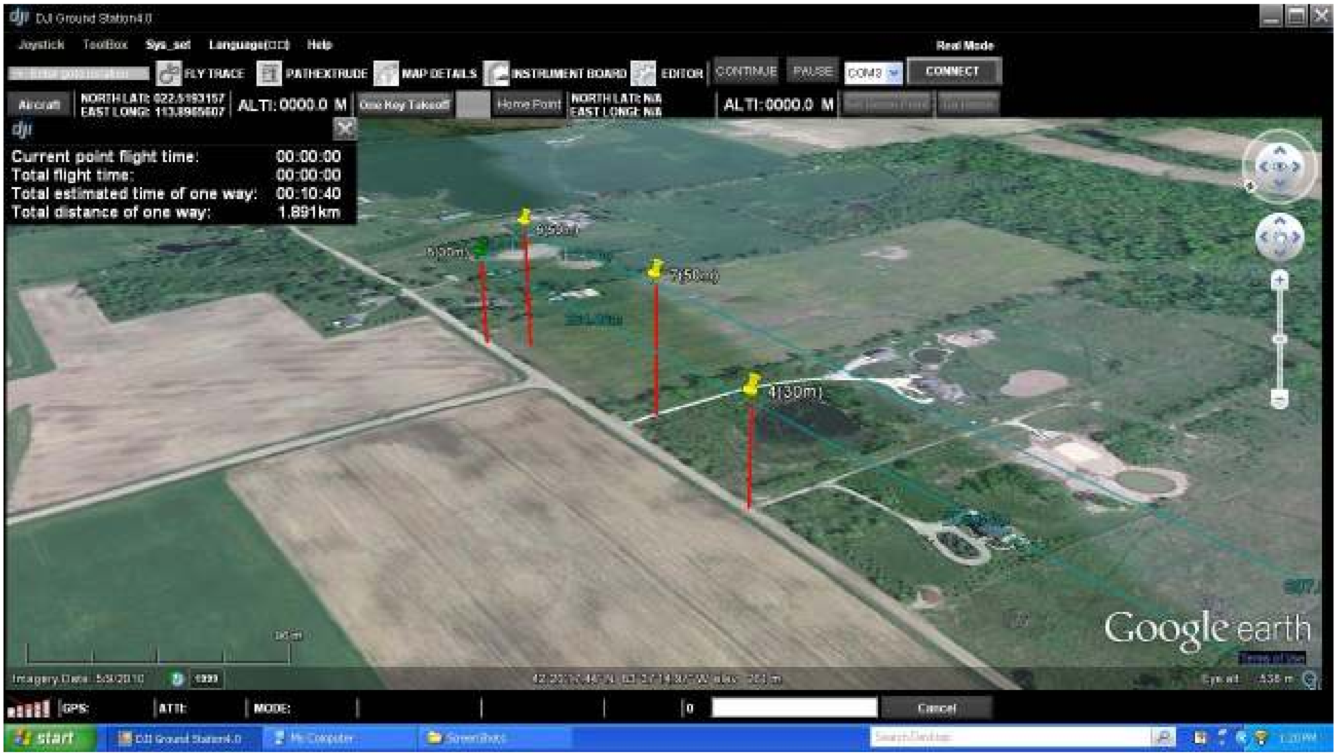

Figure 4: Oblique view of flight path

Once the flight path is chosen (which may be done anywhere), the user should inspect the actual location for possible obstructions that were not shown on the Google Earth images. In particular, communications towers and power distribution infrastructure change regularly, and the current Google Earth imagery may well be out-of-date.

The flight plan is loaded into the autopilot, and the mission is ready to begin.

Deriving an unpaved roads network as a major mission planning input using high-resolution aerial imagerylight Trajectory Planning

Overview of deriving an unpaved roads network

The mission of Task 6.2 from the project's Statement of Work was to derive an unpaved road network as a major input into the project's mission planning system from high resolution aerial imagery. The method should produce a roads network that would be easily adaptable to other mission planning systems as well. Through one of the project's cost-share partners at the Southeastern Michigan Council of Governments (SEMCOG), 30 cm spatial resolution aerial photography that covered the 7-county SEMCOG region in Southeast Michigan was made available for use for mapping of unpaved roads. The goal was to create an unpaved road network since the status of roads as unpaved vs. paved does not currently exist as part of the Michigan Framework Roads Network GIS layer and has been indicated as a priority by SEMCOG, Michigan's Transportation Asset Management Council (TAMC), and local government agencies such as the Road Commission for Oakland County (RCOC), all cost-share partners on this project. The final form was a road type layer that will form a major mission planning input for route definition and flight path analysis. Any deployed system (manned or unmanned) needs to know which roads it will be flying over, and understanding which ones are unpaved and in need of sensing by this project's system or systems is a basic requirement. By using a combination of Trimble's eCognition software and ESRI's ArcGIS software, a methodology to extract unpaved roads was derived by the project team and the status of a sample area of roads in two Michigan Counties was added to the Michigan Framework Roads Network attribute table. The classification was also able to demonstrate the ability to pull out unpaved roads that were not in the Michigan Framework Roads Network, which is helpful when not all unpaved roads were included in existing GIS layers.

Study area and aerial imagery data

The 30-cm aerial imagery included four different bands in the red, green, blue and infrared portion of the electromagnetic spectrum that were used to identify the unpaved roads within southeast Michigan. The classification was first applied to the northern rural region of Oakland County (Figures 5 and 6).

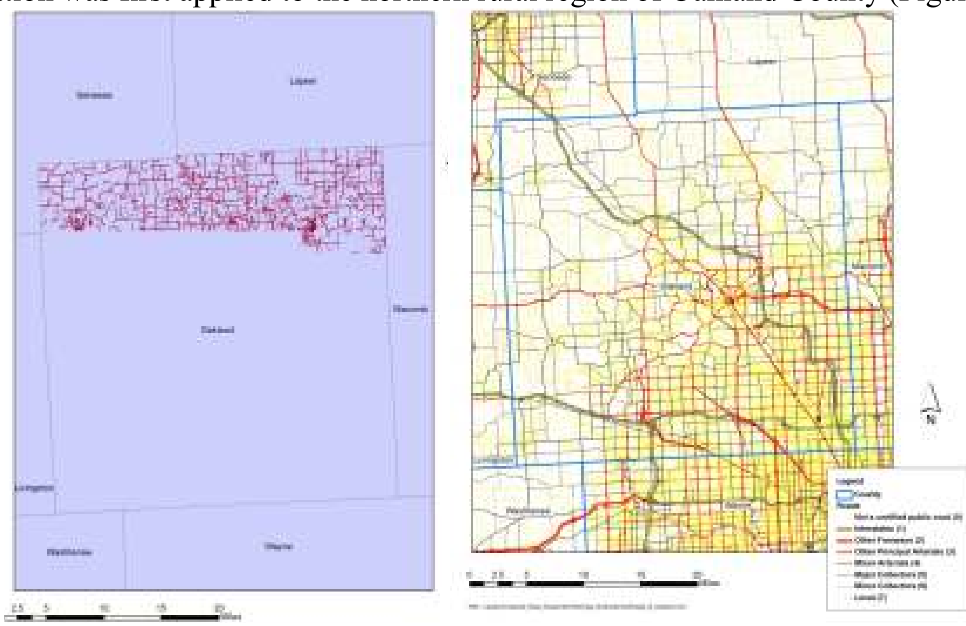

Figure 5. The location of unpaved roads classified in northern Oakland County from the SEMCOG 4-band aerial imagery and the existing Michigan Framework Roads Network for the area.

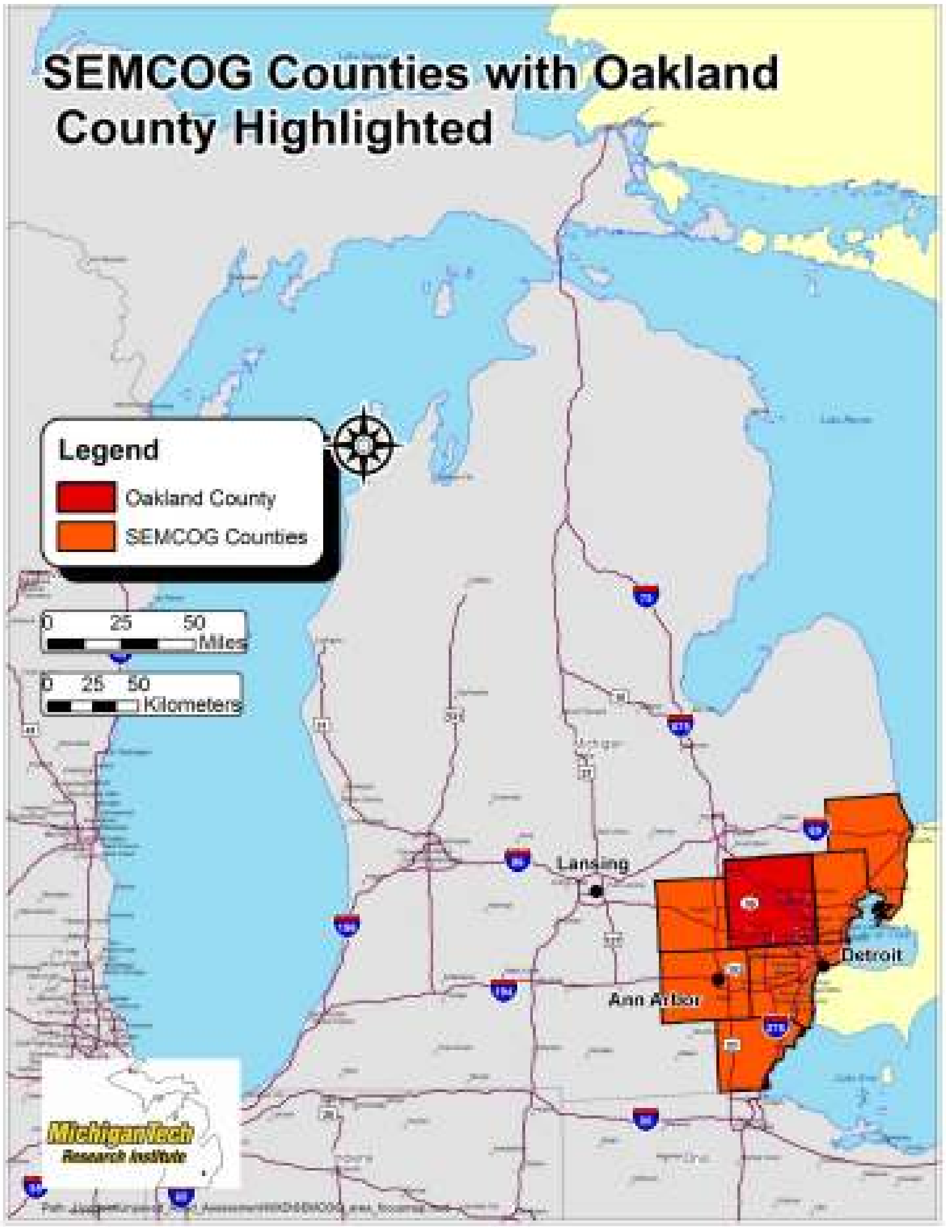

Figure 6: The Oakland County, Michigan initial unpaved roads asset mapping area in a regional context.

The methodology applied to the aerial images for Oakland County included segmentation in Trimble's eCognition object-based image classification software, applying the classification in eCognition, and then importing the unpaved road polygons into ESRI's ArcGIS for further analysis.

Methodology

Principal Component Analysis

Before applying the segmentation and classification of the unpaved roads, the images were mosaiced into 2x2 squares in ArcGIS and then a principle component analysis was performed on each mosaic. Principal component analysis (PCA) is based on an orthogonal transformation of the data to convert a set of data of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components (Joliffe 2002). The first principal component has the largest variance and accounts for as much of the variability as possible. Each succeeding component has the highest variance under the rule that it be orthogonal to (i.e., uncorrelated with) the preceding components. In this case, the principal component analysis was applied to the 4-band aerial mosaic imagery and three principle components were chosen as the output. The first principle component was used to mask out shadow regions from trees over the unpaved roads and could also be used to detect bare soil areas (Nobrega et al. 2008).

Segmentation to Detect Roads Network

Using Trimble's eCognition software, the aerial images were segmented using the object-based image analysis software to segment objects contained within the aerial images (roads, trees, lakes, fields and houses). The 4-band aerial images, principal component analysis (3 principal components) and a thematic layer that was a 30-foot buffer around the center line of the Michigan Framework Roads Network were imported into eCognition for the segmentation. The process involved a chessboard segmentation, a multi-resolution segmentation using a compactness of 10 and a shape and compactness of .9 and .1, respectively. The final segmentation piece was combining objects that had a maximum spectral difference of 5 between neighboring objects. The result was an image with the roads as objects of the segmentation that were then classified within a rule set in eCognition (Figure 7) from applied thresholds.

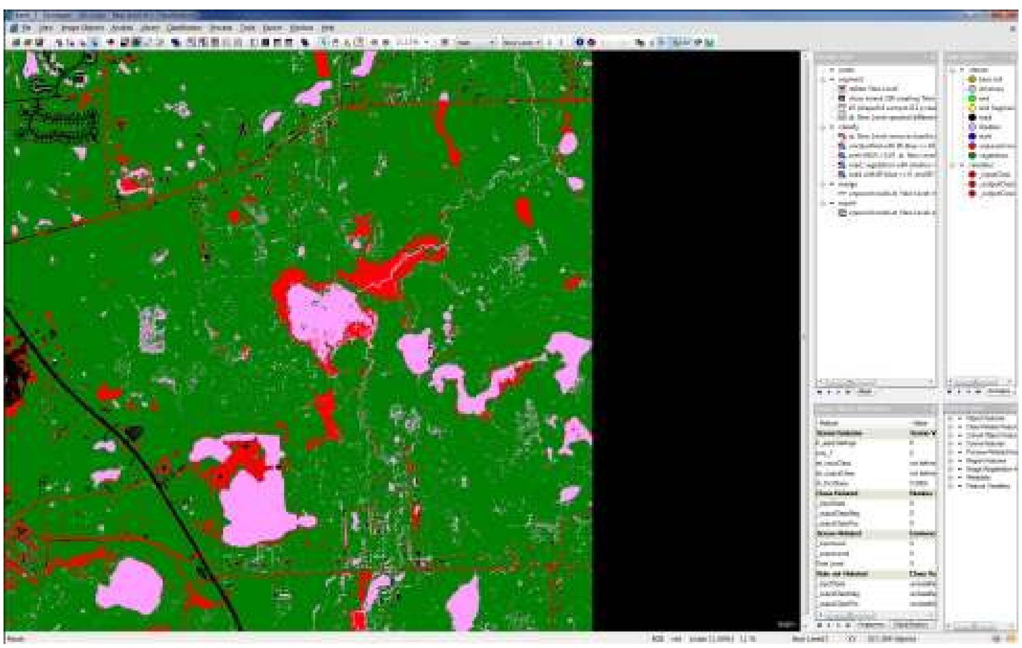

Figure 7. An example for the same mosaic in Figure 8 of the image classification and segmentation in eCognition.

Classification of Unpaved Roads

A rule set was developed in eCognition to classify the unpaved roads and to also classify objects that were not unpaved roads in order to extract the polygons for analysis in ArcGIS. This same rule set is also applicable through any computer programming language (i.e. MATLAB, IDL or Python), but without the added capability that eCognition has to extract "objects" from a set of geospatial images.

The first part of the classification development and the rule set was to pull out any areas that would be considered an impervious or semi-impervious object by taking the mean of the infrared channel minus the mean of the blue channel and calling anything that was greater or equal to 65, our imposed threshold, an impervious or semi-impervious object (this idea is based on input from Nobrega et al. 2008). Then the normalized data vegetation index was applied to aerial imagery to pull out the vegetation, where values that were greater than 0.07 were labeled vegetation, including any thing that was previously defined as semi-impervious or impervious. From the vegetation and roads values, objects with a value greater than -130 were classified as a shadow from the mean of the blue value in the object minus the first principle component (Nobrega et al. 2008). The last part of the classification was to identify objects as unpaved roads by taking the mean infrared band minus the mean of the blue and anything greater than zero, in addition to the mean of the infrared value minus the mean of the green value. When this value was greater than 2.5, then these objects were called unpaved roads, only for the objects already defined as impervious or semi-impervious. Figure 7 above, is an example of this process and the red, unpaved road polygons were exported to ArcGIS for further analysis and to label roads in Michigan Framework Roads Network as unpaved based on the above analysis methods. There was also minimal manual editing in ArcGIS for places where old asphalt, which is spectrally similar, was also called an unpaved road.

Labeling the Michigan Framework Roads Network in ArcGIS

The unpaved roads polygons that were detected and classified in eCognition were imported as a standard ESRI shapefile into ArcGIS (Figure 8). These polygons were set to the same projection as the Michigan Framework Roads Network and then intersected with a 30 foot buffer layer around the Michigan Framework Roads Network. The features were intersected in order to remove areas such as bare soils in a field that were being labeled as unpaved roads due to their spectral similarity. The first goal was to label the unpaved road in the attribute table and to calculate the percentage coverage of the eCognition polygons overlaid onto the Michigan Framework Roads vector. Only those road types that were National Functional Classification types 4, 5, 6, or 7 were assessed to see if the eCognition-based methods called them unpaved as they can be either paved or unpaved. Types 4, 5, 6, and 7 cover: Minor Arterials (4), Major Collectors (5), Minor Collectors (6), and Local (7) roads while Interstates (1), Other Freeways (2), and Other Principal Arterials (3) are nearly always paved and were excluded from further analysis. This was accomplished by converting the eCognition unpaved road polygons that were intersected with the Michigan Framework Roads Network into a line feature with the Polygon to Line tool. The line features and also the polygons of unpaved roads from eCognition were segmented due to tree cover, so unpaved roads are detected only where there are no trees or shadows.

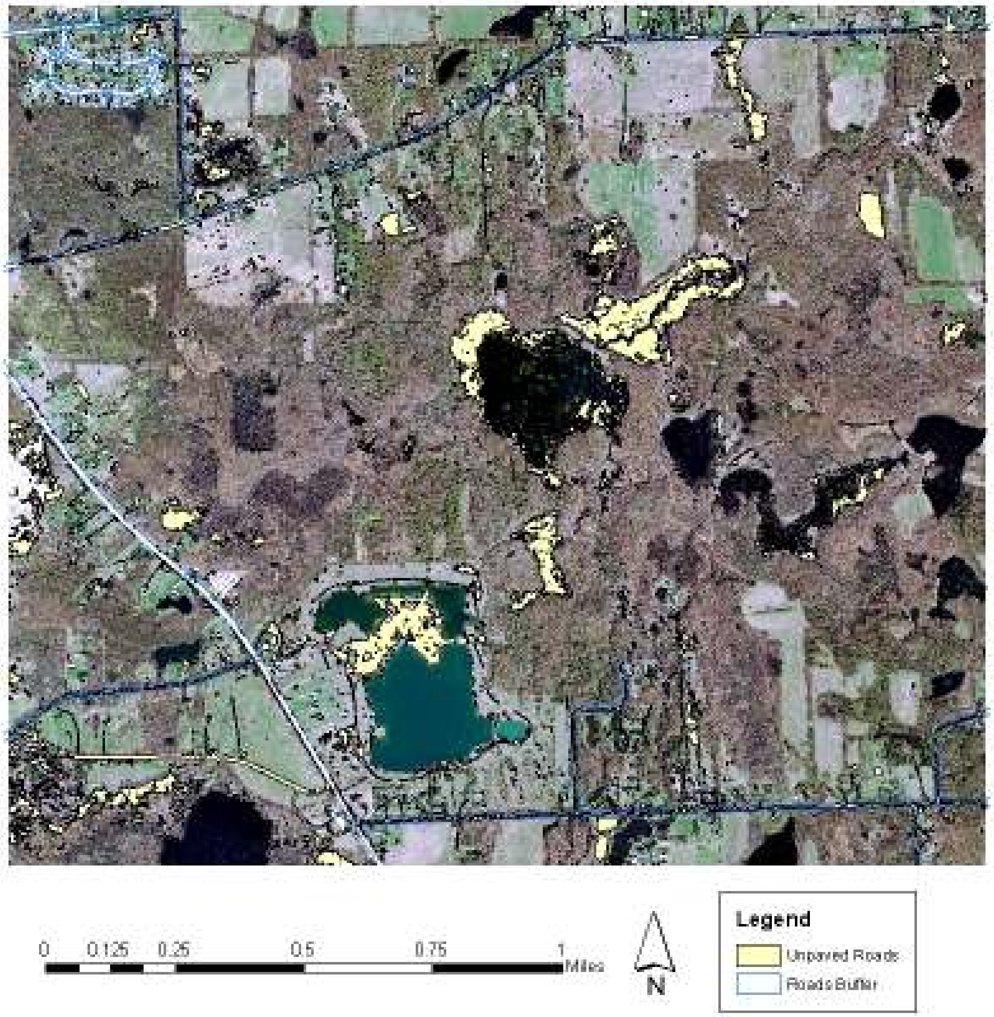

Figure 8. A 2x2 mosaic showing the initial unpaved roads polygons (yellow) and the Michigan Framework Roads Network 30 foot buffer that was intersected to get rid of polygons that were spectrally similar to unpaved roads but were not near the roads network.

The next step was to take those segmented unpaved roads from eCognition that were converted into a vector or a line feature and to open the attribute table. The length was recalculated for each line segment using the ArcGIS Calculate Geometry function. Using the LRS_LINK from the Michigan Framework Roads Network as a unique identifier, the total length for each eCognition unpaved road segment based on the LRS_LINK was calculated by using the Summarize tool after highlighting the LRS_LINK column for both the unpaved roads attribute table and the Michigan Framework Roads Network attribute table. The result was a sum of the segments along the each LRS_LINK or each part of the road. The final piece was taking that sum of the length along the LRS_LINK identifiers and dividing it by the length of the road within the Michigan Framework Roads Network to get the percentage of the road that was unpaved. NFC roads 4, 5, 6, and 7 were labeled as unpaved roads if they were a certain percentage of the total road length; >50% appears to be a valid rule for labeling roads as unpaved but can be adjusted depending on tree-coverage. An example of the appended attribute table is in figure 9. The end result is an example area of the Michigan Framework Roads Network that now contains information on whether or not the road is unpaved for the project's initial demonstration area of northern Oakland County (Figure 4). This GIS input that now shows where unpaved roads are located is ready for implementation in the mission planning system. The unpaved roads attributed GIS layer can also be converted to other geospatial data formats such as Google Earth-compatible KML (Keyhole Markup Language) files for easy integration into other mission planning software. It can also be integrated into asset management software such as RoadSoft GIS.

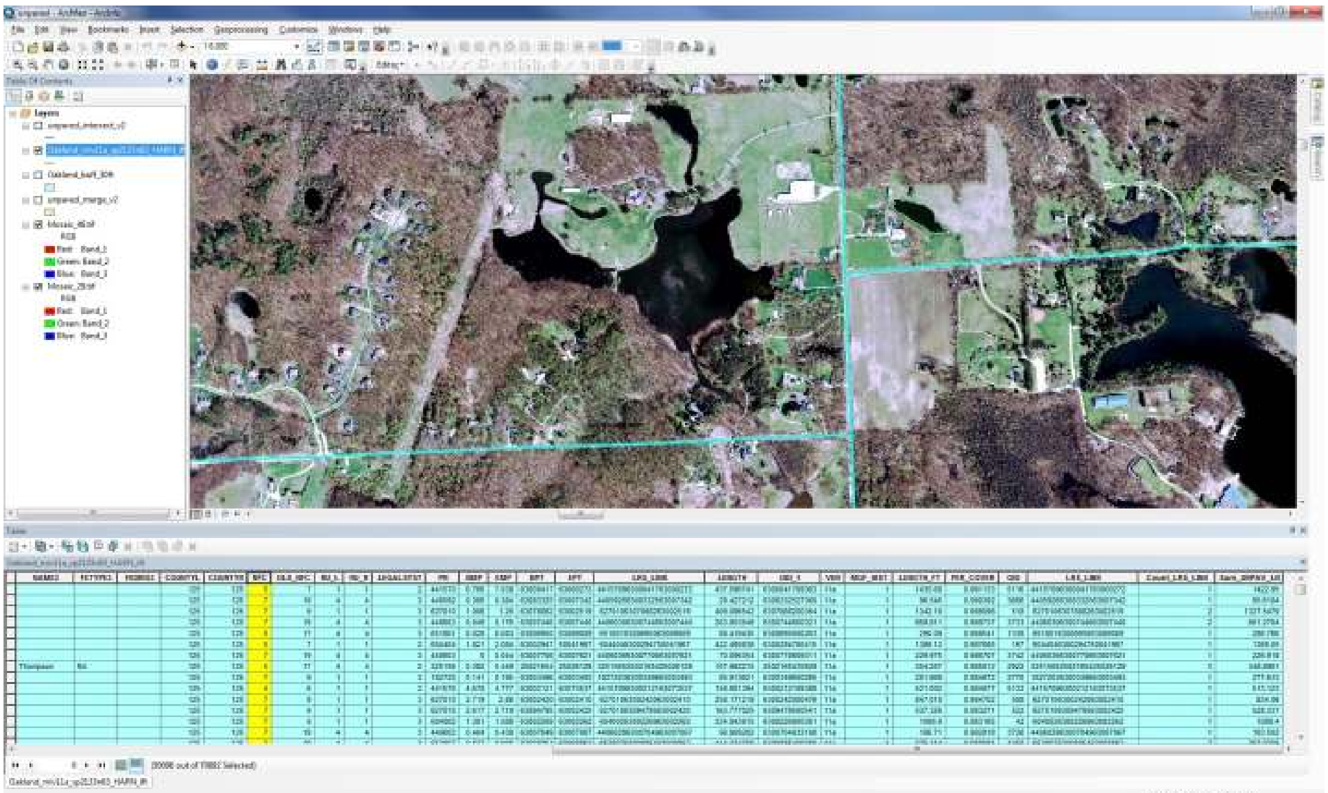

Figure 9. An example of the attribute table for the Michigan Framework Roads Network with a label highlighted for NFC road types 4 to 7 (yellow column) and attributed with the percentage of the road segments mapped as unpaved (far right column).

Next Steps

Mapping roads that are not in the Michigan Framework Roads Network

Object-based image classification also affords the ability to map unpaved roads that are not within an existing GIS layer such as the Michigan Framework Roads Network and this is an upcoming focus of the project. All of the pixels in the aerial image that are not associated with the Michigan Framework Roads Network will be removed and then only the roads not in the Michigan Framework Roads Network will be detected and classified. The resulting unpaved road polygons will then be added as ancillary data to the project's attributed copy of the Michigan Framework Roads Network and will also be possible to use as mission planning areas. Figure 10 is a brief example of this type of analysis.

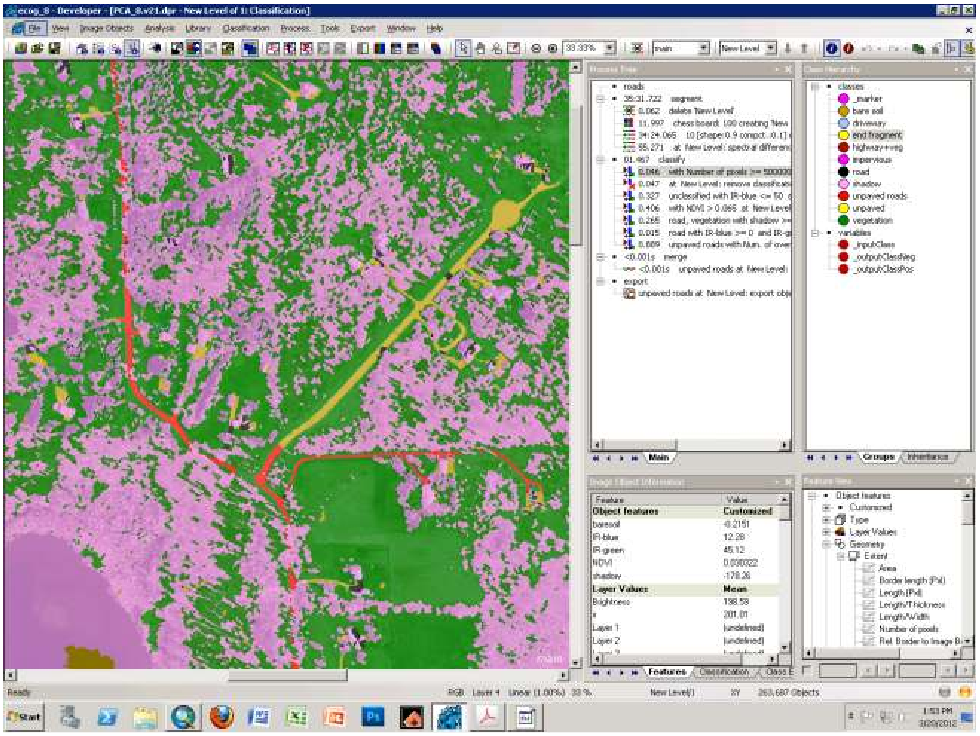

Figure 10. An example where the unpaved roads where identified outside of the Michigan Framework Roads Network with the eCogntion rule set. Red is the unpaved road from the Michigan Road Network and brown is the road that was not part of the network.

Masking Michigan Framework Roads Network and classifying and detecting those regions with increased accuracy

Upcoming improvements also involves taking the existing Michigan Framework Roads Network and only classifying the 30 foot buffer around the NFC 4, 5, 6, and 7 roads. This will allow us to increase the accuracy by tuning the threshold values for the unpaved roads classification. Then a Receiver Operating Characteristic (ROC) curve will be plotted to compare the probability of detection and the probability of a false detection based upon how well the algorithm is classifying unpaved roads (Hand and Till 2001). The ROC curves will help tune the road detection algorithm by finding the best segmentation settings as well as aiding in the classification rule sets in eCognition, to improve the accuracy of threshold values for pulling out the full extent of the unpaved roads. This analysis will continue over the next quarter and will build upon the mapping of unpaved roads for Oakland County and other southeast Michigan regions, such as Monroe County where relatively few trees exist in the more agricultural area (Figure 11 shows an example).

Figure 11. A "no-trees over roads" example image that will be the beginning basis of the ROC curves for detection and classification of unpaved roads under ideal conditions, improving the accuracy of the thresholds used to map the unpaved roads in eCogntion. The purple areas are the polygons from eCognition, the blue is the 30-foot Michigan Framework Roads Network buffer.

References

Hand, David J. and Robert J. Till. 2001. A simple generalization of the area under the ROC curve for multiple class classification problems. Machine Learning, Vol.45(2): 171-186.

Joliffe, I.T. 2002. Principal Component Analysis, Second Edition. Springer, 487 pgs.

Nobrega, R.A.A., C.G. O'Hara, J.A. Quintanilha. 2008. An objected-based approach to detect road features for informal settlements near Sao Paulo, Brazil. Chapter 6.4 in "Object-Based Image Analysis: Spatial Concepts for Knowledge-Driven Remote Ssensing Applications", 19 pgs.

Michigan Technological University

Characterization of Unpaved Road Condition Through the Use of Remote Sensing

Deliverable 6-B: A Demonstration Decision Support System for Managing Unpaved Roads in RoadSoft

Submitted version of:
July 27, 2012

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***Deliverable 6-B*: A Demonstration Decision Support System for Managing Unpaved Roads in RoadSoft**

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Purpose of this Document

This document will provide an example of how data collected from the remote sensing systems evaluated during this project can be integrated into a commercially available decision support system (DSS) software package for use by transportation infrastructure owners. This document will also act as a framework to provide guidance to the project team working on integration between the various data collection and analysis routines present in the remote sensing systems and the DSS being used for this demonstration (RoadSoft www.roadsoft.org). This document can also act as a starting point for integration of the remote sensing systems portion developed by this project with other commercially available DSS.

Motivation

One of the main goals outlined for the *Characterization of Unpaved Roads by Remote Sensing* project is to show that data collected through remote sensing can be effectively utilized in a decision support system for managing unpaved roads. Management of unpaved roads has historically been challenged by the lack of a method or system that provides decision support and allows for cost-effective data collection. Systems providing decision support or basic distress identification for unpaved roads have been developed, but data collection costs and quality have limited their effectiveness and adoption by unpaved road managers. It is the goal of this project to overcome these limitations by providing an example of how data can be collected cost effectively from remote sensing systems using a standard road assessment and inventory technique (Army Corps of Engineers Unpaved Road Condition Index system) and how this data can be integrated into a DSS. DSS make use of a variety of data, including asset inventory data, condition (distress) data, and project history data to allows users to more quickly make informed asset management decisions, and to see the impacts of these decisions on the long term health of their road network.

Distress Identification and Characterization

For the purposes of this project the Army Corps of Engineers Unsurfaced Road Condition Index (URCI) distress identification method has been selected for assessing the road quality. URCI distress data for unpaved roads will be collected by various remote sensing techniques during this project. The URCI method is described in *Technical Manual No. 5-626: Unsurfaced Road Maintenance Management* (Department of the Army, 1995). For a full listing of unpaved road distress identification methods identified by this project see *Deliverable 2-A: State of the Practice of Unpaved Road Condition Assessment* (Brooks, Colling, Kueber, Roussi, & Endsley, 2011) at http://www.mtri.org/unpaved/. The URCI method was selected for this project because it has a number of advantages over other assessment methods:

1. It provides a clear set of measurement criteria for each distress type utilized.
2. It is applicable to a wide variety of unpaved roads in the United States.
3. The majority of condition indicators (distresses) are amenable to data collection using remote sensing methods.
4. It has maintenance and rehabilitation decision support criteria developed in parallel with the rating method which give guidance to road managers based on conditions.
5. The method was specifically designed for use with representative samples of data as opposed to requiring a complete census of every mile of road, which increases the cost effectiveness of the method.

Characterization of Quantifiable URCI Distress Data

Distress data conforming to the URCI method includes the following distresses:

- Loss of road cross section
- Improper drainage (where possible)
- Potholes
- Ruts
- Corrugations
- Loose aggregate berms
- Dust (Department of the Army, 1995)

The only URCI distress type that was determined to be not feasible to collect with remote sensing techniques was dust. Dust was determined not to be a collectable or easy quantifiable distress using remote sensing techniques due to the need for a pilot vehicle to loft dust particles and the fact that the guidelines in the URCI method are subjective. Improper drainage was determined to be technically feasible to collect in areas where vegetation or tree cover was not excessively thick and the ground surface is visible. It was acknowledged that a clear view of the ground surface in ditch areas may not be present in many cases during the testing of the system in Michigan, but it may be more applicable in western plains states.

The requirements for the remote sensing system provided in *Deliverable 1-A: Requirements for Remote Sensing Assessments of Unpaved Road Conditions* (Brooks, Colling, & Roussi, 2011) were derived based on being able to identify and measure distresses from the URCI method in accordance with *Technical Manual No. 5-626*, at the proper sensitivity and precision to make use of the method in a DSS. Most of the URCI distresses are discretely quantifiable. These include potholes, ruts, corrugations and loose aggregate berms. As such, it is readily apparent how the requirements relate to the measurements of distresses required for the URCI method.

Two URCI distresses – loss of road cross section and improper roadside drainage – are somewhat subjective and require definitions to map between the requirements of the physical features that the remote sensing system will collect and the distress severity levels that the DSS will receive. The following section of the report will propose criteria to quantify different distress levels for loss of road cross section and roadside drainage. The criteria used for the quantification of these distresses should be reviewed and commented upon by the Technical Work Group during the earliest possible convenience.

Characterization of Loss of Road Cross Section Distress

Figure 1 below provides an illustration of the three severity levels of the loss of road cross section distress according to the URCI method. *Technical Manual No. 5-626: Unsurfaced Road Maintenance Management* describes the criteria for assessing severity levels for the loss of road cross section distress as the following:

> "*(1) At severity level L* [Low Severity]
> *(a) Small amounts of ponding water or evidence of ponding water on the road surface.*
> *(b) The road surface is completely flat (no cross-slope).*
>
> *(2) At severity level M* [Medium Severity]
> *(a) Moderate amounts of ponding water or evidence of ponding water on the road surface.*
> *(b) The road surface is bowl-shaped.*
>
> *(3) At severity level H* [High Severity]
> *(a) Large amounts of ponding water or evidence of ponding water on the road surface.*
> *(b) The road surface contains severe depressions".* (Department of the Army, 1995)

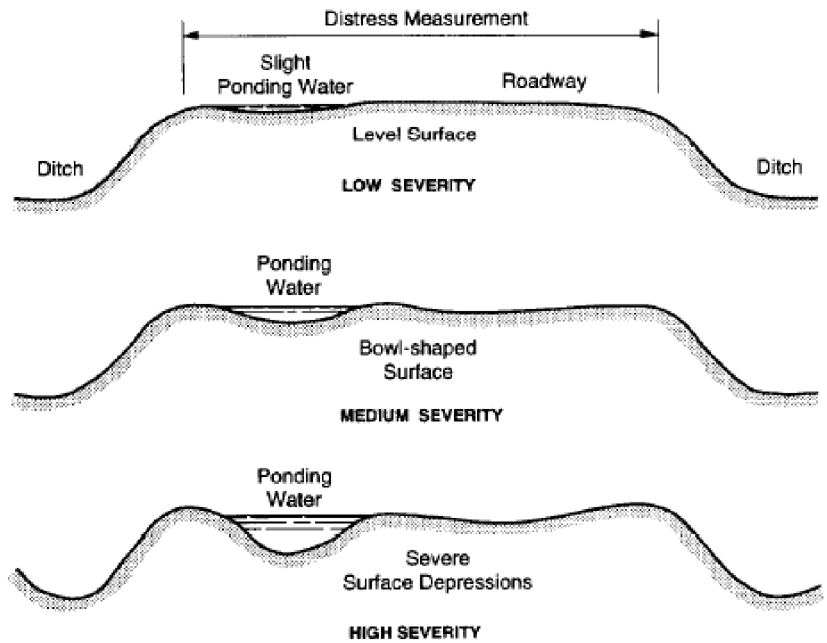


Figure 1: Illustration of URCI loss of cross section severity levels (Department of the Army, 1995)

The remote sensing system requirements outlined in *Deliverable 1-A: Requirements for Remote Sensing Assessments of Unpaved Road Conditions* for detecting a road's cross section are as follows:

> *The remote sensing system is required to measure the pavement cross slope between the centerline of the road to the edge of pavement where the beginning of the ditch slope start on both lanes of the pavement. The requirement is to measure the profile of the cross section of the road. For example, for a nine-foot wide lane, a 1% slope would drop approximately one inch (2.5 cm). Pavements that have negative slopes would indicate that the centerline of the pavement is lower in elevation than the edges of the pavement. Elevation points measured at the centerline of the pavement and the edge line of the pavement must be identified as such. Cross section elevation data must be recorded at intervals of at least every ten lineal feet (3.05 m) per sampling unit as measured with the direction of the road.* (Brooks, Colling, & Roussi, 2011)

The remote sensing system will be capable of measuring surface grade of each lane of an unpaved road, but the criteria defined in the URCI method does not provide quantifiable levels of grade that correspond to each distress level. The following criteria will be used during the post processing of the remote sensing data to categorize each road sampling location into the four URCI severities – No Distress, Low, Medium, and High – and will be done prior to exporting the data to the DSS.

No Distress Present

The cross section grade from the centerline of the road to the edge line of the pavement is at least 3% or more (centerline higher than edge line) for both lanes of the road.

This criterion is recommended based on guidance from the *Gravel Roads: Maintenance and Design Manual* (Scorseth & Selim, 2000) stating that ideally gravel roads should have a 4% cross slope for good drainage. The 3% minimum provides a margin of error for small local discontinuity in the cross slope grade while still providing for positive drainage.

Low Severity

The cross section grade from the centerline of the road to edge line of the pavement is less than 3% (centerline higher than edge line) but greater than 0% for at least one lane of the road.

The lower limit of this criterion is recommended based on the illustration from the *Technical Manual No. 5-626: Unsurfaced Road Maintenance Management* (Department of the Army, 1995) which indicates that at low severity the cross section would have an essentially level cross slope. While 3% to 0% cross slope is not technically “flat” it is a gradual enough cross slope to produce localized areas of ponding or drainage issues where there are localized areas of nonconformity in the grading, and both grade ranges are less than optimum.

Medium Severity

The cross section grade from the centerline of the road to edge line of the pavement is less than or equal to 0% (centerline higher than edge line) but is greater than or equal to -2% (centerline lower than edge line) for at least one lane of the road.

The lower limits of this criterion is recommended based on the illustration from the *Technical Manual No. 5-626: Unsurfaced Road Maintenance Management* (Department of the Army, 1995) which indicates that at medium severity the cross section would have an essentially “bowl shaped” cross slope, indicating a negative grade is possible (edges of the pavement higher than the centerline). A -2% grade would indicate that the edge of the pavement is approximately 2.4 inches higher than the centerline of the pavement assuming a 10-foot lane. This would provide for a significant capacity to pond water on the road surface and would require significant regarding to address.

High Severity

The cross section grade from the centerline of the road to edge line of the pavement is less than -2% (centerline lower than edge line) or more for at least one land of the road.

Differences in lane grade

In situations where the grade in one lane is worse (lower cross slope) than the other, the worst lane will drive the characterization. For example if one lane had a 4% cross slope and another had a 2% cross slope, the severity level would be “Low”.

Characterization of Improper Drainage Distress

Figure 2 below provides an illustration of the three severity levels of improper drainage according to the URCI method. *Technical Manual No. 5-626: Unsurfaced Road Maintenance Management* describes the criteria for assessing severity levels for the improper drainage distress as the following:

(1) At severity level L [Low Severity], *small amounts of the following exist:*
(a) Ponding water or evidence of ponding water in the ditches.
(b) Overgrowth or debris in the ditches.
(2) At severity level M [Medium Severity], *moderate amounts of the following exist:*
(a) Ponding water or evidence of ponding water on the road surface.
(b) Overgrowth or debris in the ditches.
(c) Erosion of the ditches into the shoulders or roadway.
(3) At severity level H [High Severity], *large amounts of the following exist:*
(a) Ponding water or evidence of ponding water in the ditches.
(b) Water running across or down the road.
(c) Overgrowth or debris in the ditches.
(d) Erosion of the ditches into the shoulders or roadway.

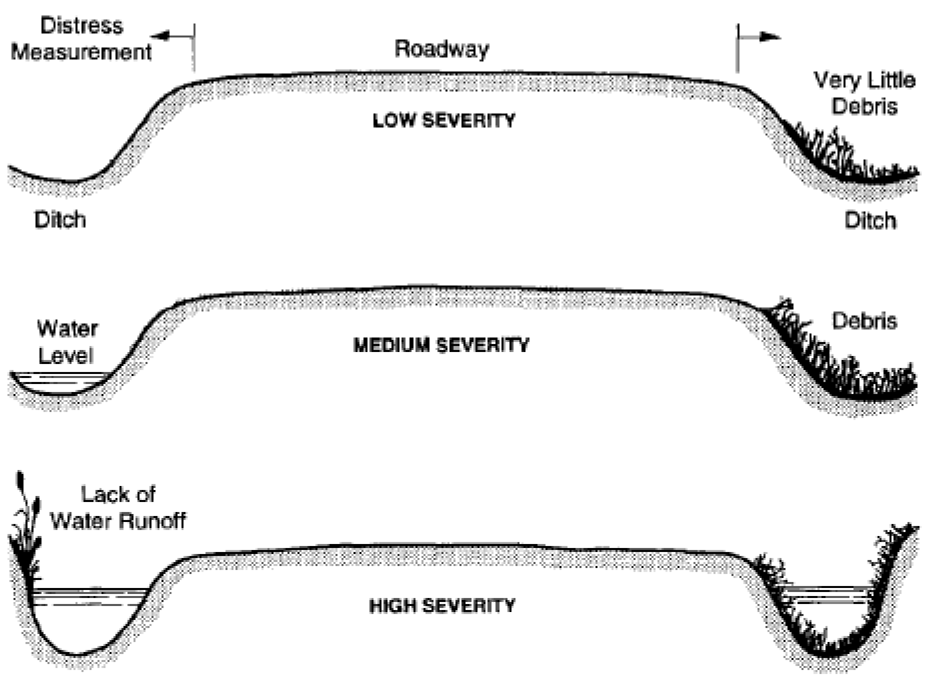


Figure 2: Illustration of URCI improper drainage severity levels (Department of the Army, 1995)

The remote sensing system requirements outlined in *Deliverable 1-A: Requirements for Remote Sensing Assessments of Unpaved Road Conditions* (Brooks, Colling, & Roussi, 2011) for detecting improper drainage are as follows:

> *The remote sensing system must be able to measure the elevations of the ditch fore slope and back slope (if present) for each ditch perpendicular to the direction of the road. Ideally for a well-constructed road the ditch bottom should be 6.0 to 12.0 inches (15.2 cm to 30.5 cm) below the bottom of the pavement. The system needs to be able to measure this difference. Elevation measurements must be collected for each ditch starting at the edge of pavement to a minimum of 15.0 feet (4.57 m) either side of the pavement and must be identified as being measured on the ditch surface. Ditch elevation measurements are required to measure elevation to a precision of +/- 2.0 inches (+/- 5.1 cm). Ditch section elevation data must be recorded at intervals of at least every ten lineal feet per sampling unit as measured with the direction of the road.*
>
> *The remote sensing system must be capable of sensing the presence of standing or running water in the ditch area. Water present in ditches will be noted by the section width of water surface present for each ditch and at least one elevation data point for the water surface at each ditch. Water elevation measurements are required to measure elevation to a precision of +/- 2.0 inches (+/- 5.1 cm), and width measurements are required to be measured with a precision of +/- 4.0 inches (+/- 10.2 cm). Where significant vegetation was present, this would prevent the measurement of the ditch depth and the presence of water.*

The remote sensing system will be capable of measuring surface grade of each lane of an unpaved road, and comparing it to the elevation of the ditch bottom. The criteria defined in the URCI method does not provide quantifiable levels of ditch elevation or surface water extent that correspond to each distress level. Therefore, the remote sensing system will categorize road sampling locations into one of four URCI severities primarily based on ditch and water elevation with relationship to the elevation of the edge of the pavement. The URCI severity levels for improper drainage will be assessed based on the following criteria:

No Distress Present

The elevation of the ditch bottoms, including any static vegetation on both sides of the road or the elevation of any water in the ditch, is at least 2.5 feet below the edge of the top surface of the pavement as measured at the edge of the pavement.

This criterion is recommended based on general ditch design. Typically ditches are designed to provide positive drainage to the pavement structure, and at a minimum provide a drainage flow line which is below the pavement's sub grade elevation. This design guidance is summed up by the Cornell Local Roads *Roadway and Roadside Drainage* (Orr, 2003) manual which states "as a rule of thumb, the ditch should be 12 inches below the bottom of the subgrade". The 2.5 foot depth for this criterion allows for a pavement thickness of 18 inches to be adequately drained, which is typically thicker than most unpaved road aggregate layers. The 2.5 foot free ditch depth also provides a reasonable minimum depth for ditching that has associated cross culverts that are typically designed so that their crown does not extend into the pavement.

Low Severity

The elevation of at least one ditch bottom, including any static vegetation or the elevation of any water in the ditch, is less than 2.5 feet below the edge of the top surface of the pavement but more than 1.5 feet below the edge of the top surface of the pavement as measured at the edge of the pavement. Each ditch will be evaluated as a separate measurement.

The minimum free (without water) ditch depth value for this criteria would indicate that many of the more thinly surfaced gravel pavements would be under the recommended guidance for drainage depth provided by *Roadway and Roadside Drainage* (Orr, 2003). The ditch depth provided by this criteria would indicate minimal clearance available for roadway cross culverts without protruding into the gravel layer (if any present) and having less than optimal cover.

Medium Severity

The elevation of at least one ditch bottom, including any static vegetation or the elevation of any water in the ditch, is less than 1.5 feet below the edge of the top surface of the pavement but more than 0.5 feet below the edge of the top surface of the pavement as measured at the edge of the pavement. Each ditch will be evaluated as a separate measurement.

Criteria proposed for this severity level would result in frequent saturation of any aggregate layers of the unpaved road and likely preclude the proper installation of culverts due to minimum ditch depth.

High Severity

The elevation of at least one ditch bottom, including any static vegetation or the elevation of any water in the ditch, is less than 0.5 feet below the edge of the top surface of the pavement as measured at the edge of the pavement. Each ditch will be evaluated as a separate measurement.

The criterion proposed for this severity level indicates that ditches are not functionally present or frequent saturation and ponding occurs on the driving surface.

Limitations of Collection

Heavily vegetated ditches may obscure the collection of elevation data for the improper drainage distress. Heavy grass or other vegetation that is likely to be in motion during data collection may give false ditch elevation in the case of heavier vegetation that is stationary due to the sensor perceiving the top of the vegetation as ground level.

Demonstration of DSS Process and Functions

DSS provide an interface for storing, organizing and analyzing large quantities of data that assists users in determining a course of action. The DSS that will be utilized for this project is commercially available product called RoadSoft which uses a geographic information system (GIS) interface to spatially locate and display data related to transportation assets.

Data from two specific remote sensing and analysis processes will export data to the DSS. The eCognition process will produce the unpaved road inventory information that the DSS will use to identify the unpaved road network. The remote sensing platform system will produce road distress data and inventory features data that the DSS will use to determine asset conditions.

The eCognition process produces the unpaved road inventory information while the Remote Sensing Platform System (RSPS) produces road distress data and inventory features data. The DSS receives both data sources in addition to data collected by traditional manual processes such as ground-based inspection by a technician (see ***Figure 3***). This data processing routing and the interaction of these data are outlined in the Data Transfer Format section of this document.

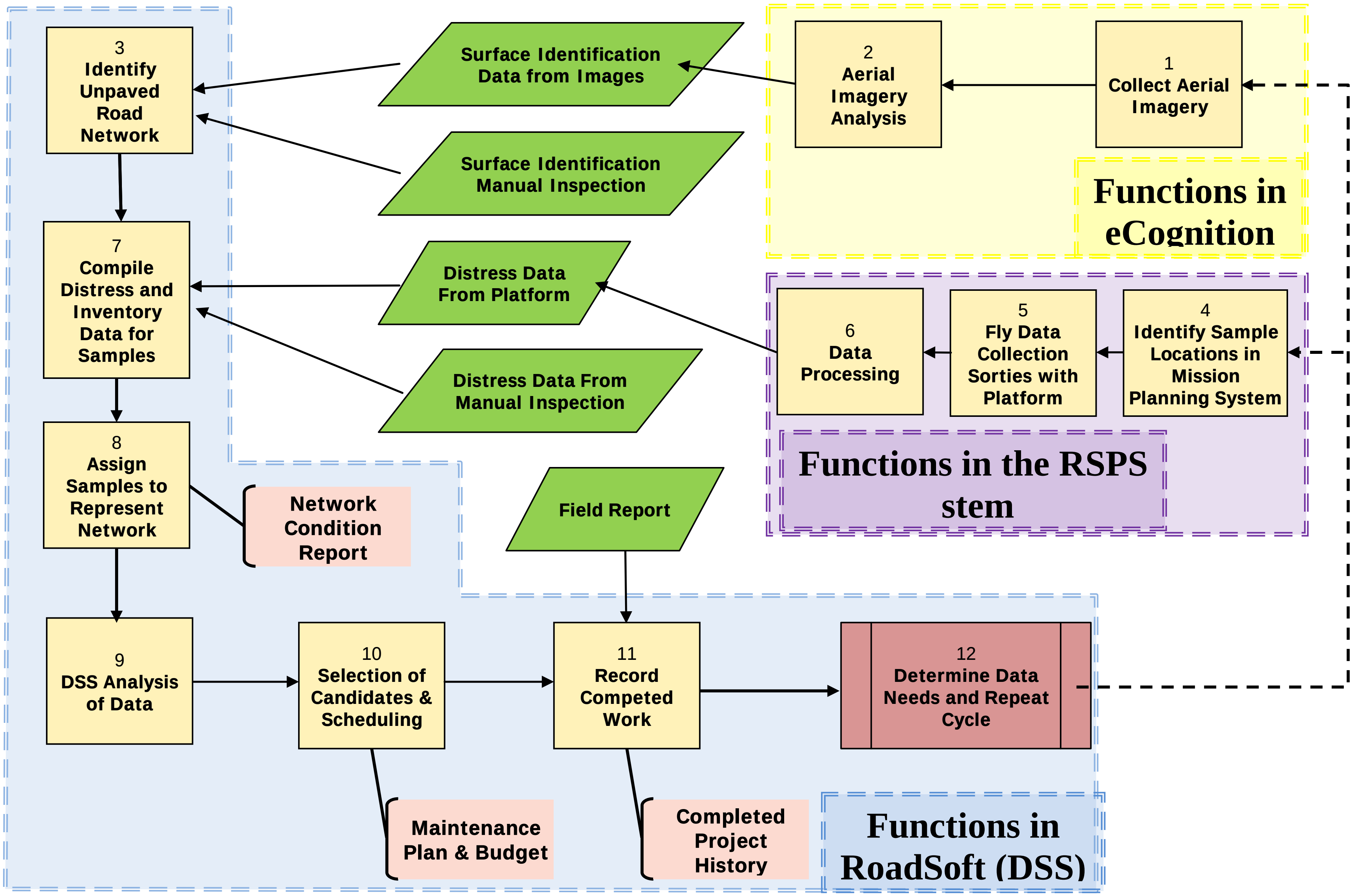


Figure 3: Road analysis process flow

eCognition System

The unpaved road inventory information will be generated from the analysis of high resolution, 4 band aerial photos using Trimble's eCognition software. This process is defined in *Deliverable 6-A: A Demonstration Mission Planning System for use in Remote Sensing the Phenomena of Unpaved Road Conditions* (Roussi, Brooks, & Vander Woude, 2012). Identification of the unpaved parts of the road network will be completed as the first step in data collection, since it is necessary to understand the location and extent of the unpaved road network prior to collecting further data. It is anticipated that users will update unpaved road inventory data through the remote sensing system on a relatively infrequent basis (every 3 to 5 years), since once the initial inventory is complete, project data received from construction projects will serve to maintain the inventory. As a result, an updated inventory from aerial photos will only be necessary when new roads are constructed or when project records age to the point that they no longer reflect field conditions.

Remote Sensing Platform System (RSPS)

The unpaved road condition data and road width information conforming to the URCI method will be collected from flown missions by directing the remote sensing platform to representative sampling locations within the unpaved road network. Sampling locations will be pre-determined road segments that have good visibility from the air, are representative of conditions on the group of roads that the segment represent, and will be approximately 100' in length. It is anticipated that unpaved road condition data collection may be updated through successive flights as much as four to five times per year, to once every year, depending on specific user needs and budgets.

Road Analysis Process Flow

The following section of the report will give a brief overview of the interactions between the eCognition process and the DSS, as well as the RSPS and the DSS (RoadSoft). Sections numbered below are listed with respect to the unit processes in ***Figure 3*** above.

1) Collect Aerial Imagery

Aerial imagery data files are collected by users for a geographic area of interest where the inventory of unpaved roads has not been collected or needs to be updated. The date that the aerial image is captured will be used as the effective date associated with the unpaved road surface inventory assessment when the data is passed to the DSS.

2) Aerial Imagery Analysis

Aerial imagery is analyzed using Trimble's eCognition software. This process is defined in *Deliverable 6-A: A Demonstration Mission Planning System for use in Remote Sensing the Phenomena of Unpaved Road Conditions* (Roussi, Brooks, & Vander Woude, 2012). The aerial imagery analysis will identify the Michigan Geographic Framework (MGF) road segments that are unpaved roads. The data export from the aerial imagery analysis will include a listing of the MGF physical reference number (PRNO), beginning mile point (BMP), and ending mile point (EMP) of each unpaved road segment, and date of the aerial photo used for the assessment. Location data for unpaved roads will also include the latitude/longitude coordinates for the end points of the unpaved road segments. The format for the data export from the aerial imagery analysis (eCognition process) is more fully defined in the Data Transfer Format section of this report.

3) Identify Unpaved Road Network

The DSS will utilize the unpaved road inventory data from the aerial imagery analysis to update its existing pavement surface inventory. Road segments in the DSS that are identified as being unpaved in the aerial imagery analysis, but that do not have a pavement type assigned in the DSS will be set as "pavement type=gravel". Road segments in the DSS that have an existing pavement surface type will only be assigned "pavement type=gravel" if the most current surface type information in the DSS is older than the aerial image date used for the analysis. ***Figure 4*** provides an example of an updated road inventory in the DSS.

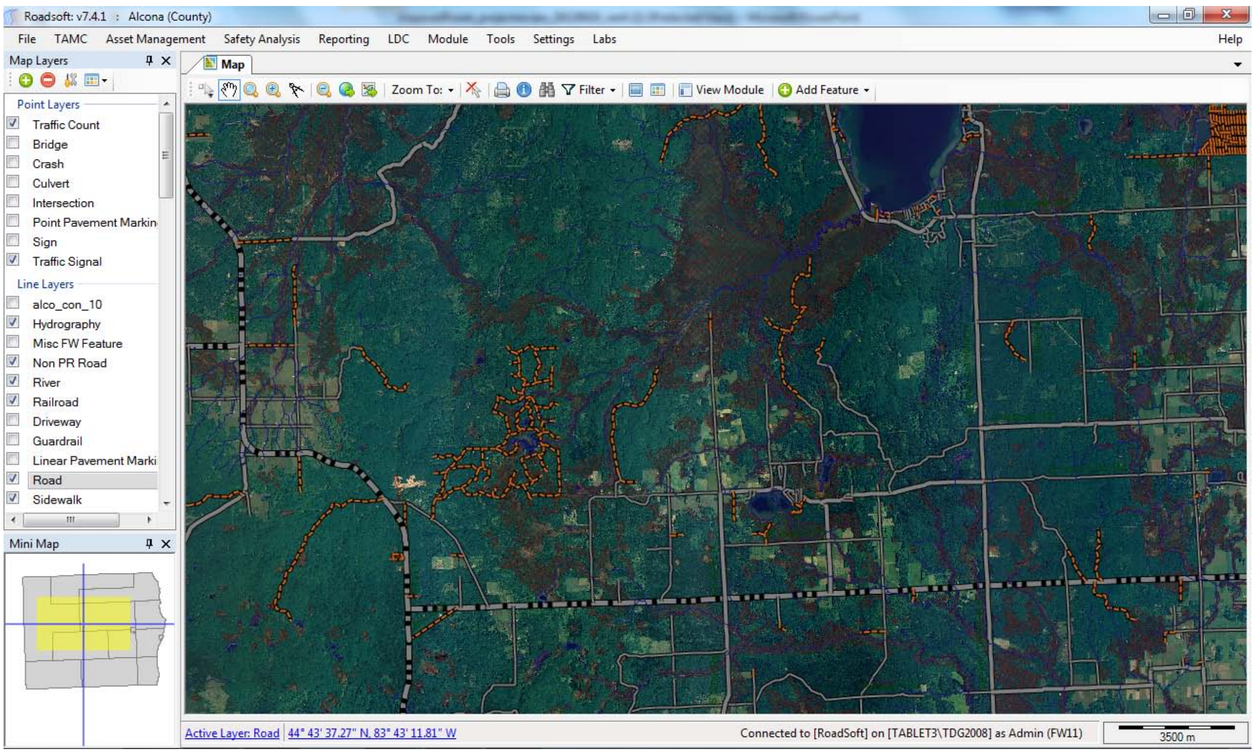


Figure 4: Example of an updated unpaved road inventory in the DSS (RoadSoft). Unpaved roads shown as brown dashes

4) Identify Sample Locations in Mission Planning System

Representative sample locations where the platform will be required to collect distress data will be user defined in the mission planning system that controls the platform. This process is defined in *Deliverable 6-A: A Demonstration Mission Planning System for use in Remote Sensing the Phenomena of Unpaved Road Conditions* (Roussi, Brooks, & Vander Woude, 2012). The selection of sampling locations will require some forethought and planning because samples will need to be representative of the larger road segments that the sample represents, as well as being visible from the air without overhead obstructions. Guidance on the selection of sample locations is described in *Technical Manual No. 5-626: Unsurfaced Road Maintenance Management* (Department of the Army, 1995).

5) Fly Data Collection Sorties with Platform

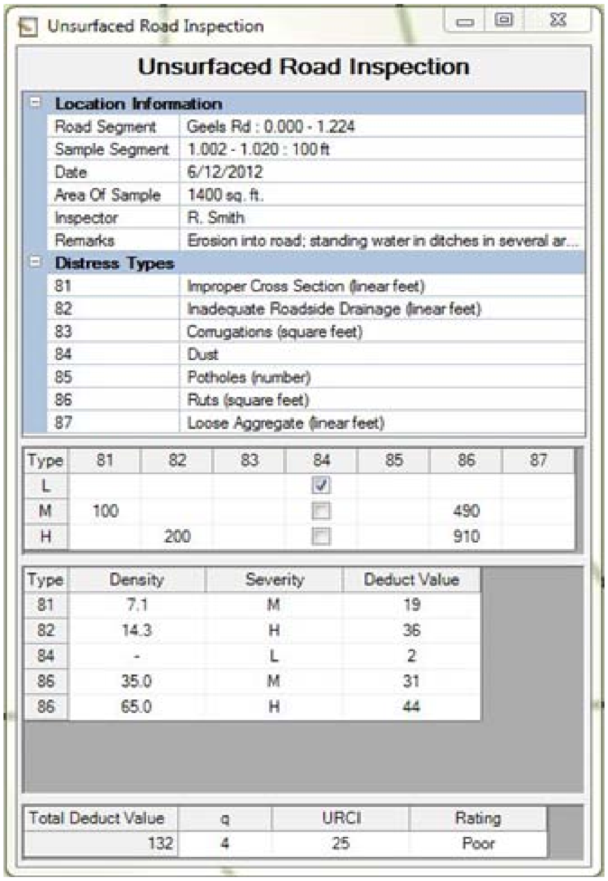
Field collection of distress data from the platform presumably will be collected during the warm weather months when most unpaved road distress is likely to take place. Data collection events would most likely be collected in a group for a specific agency over a relatively short period of time. Data collection events could be as infrequent as annually or as frequent as monthly depending on the agency's business process and budget for data collection.

6) Data Processing

Raw data collected by the remote sensing platform during distress data sorties will likely require a degree of post processing prior to export to the DSS. At the time of publishing of this deliverable the extent of the post-processing requirements is not clear. However it will be defined in deliverable *6C – Software and Algorithms to Support Unpaved Road Assessment*. Final processed data from the remote sensing platform will be in the form of URCI ratings for: loss of road cross section, improper drainage (where possible), potholes, ruts, corrugations and loose aggregate berms. It will also include the inventory feature of road width for each specific road sampling location. Average calculated road width will be received by the DSS at each sampling location based on intermediate measurements collected by the remote sensing platform.

7) Compile Distress and Inventory Data for Samples

Unpaved road distress and inventory (width) data from the remote sensing platform will be imported into the DSS to create an all-inclusive database of unpaved road information. Information from the remote sensing platform can be augmented with other distress or inventory data from manual field inspections as users deem necessary. An example of manual field collection of data would include dust distress measurements or estimations, since it was determined that it would be infeasible to reliably measure this distress with remote sensing to the extent necessary to make the data usable. The combined data set will provide the basis for road managers to carry out data-driven planning and asset management. ***Figure 5*** shows an example mockup of a data entry and evaluation screen in the DSS where URCI distress data will be visible for each sample segment.



Unsurfaced Road Inspection

Unsurfaced Road Inspection

Location Information	
Road Segment	Geels Rd : 0.000 - 1.224
Sample Segment	1.002 - 1.020 : 100 ft
Date	6/12/2012
Area Of Sample	1400 sq. ft.
Inspector	R. Smith
Remarks	Erosion into road; standing water in ditches in several ar...
Distress Types	
81	Improper Cross Section (linear feet)
82	Inadequate Roadside Drainage (linear feet)
83	Corrugations (square feet)
84	Dust
85	Potholes (number)
86	Ruts (square feet)
87	Loose Aggregate (linear feet)

Type	81	82	83	84	85	86	87
L				☑			
M	100			☐		490	
H		200		☐		910	

Type	Density	Severity	Deduct Value
81	7.1	M	19
82	14.3	H	36
84	-	L	2
86	35.0	M	31
86	65.0	H	44

Total Deduct Value	q	URCI	Rating
132	4	25	Poor

Figure 5: Example URCI distress form for a road sample segment

When the data collection cycle is complete for the unpaved road network, there is an opportunity for users to evaluate the network-level road conditions to determine how the historical management of the asset is impacting its overall quality. The DSS will include network-level road condition reports which will allow users to graphically display the change in road condition over time. ***Figure 6*** below provides an example of a network condition trend graph showing a decline in the quality of pavement condition over time.

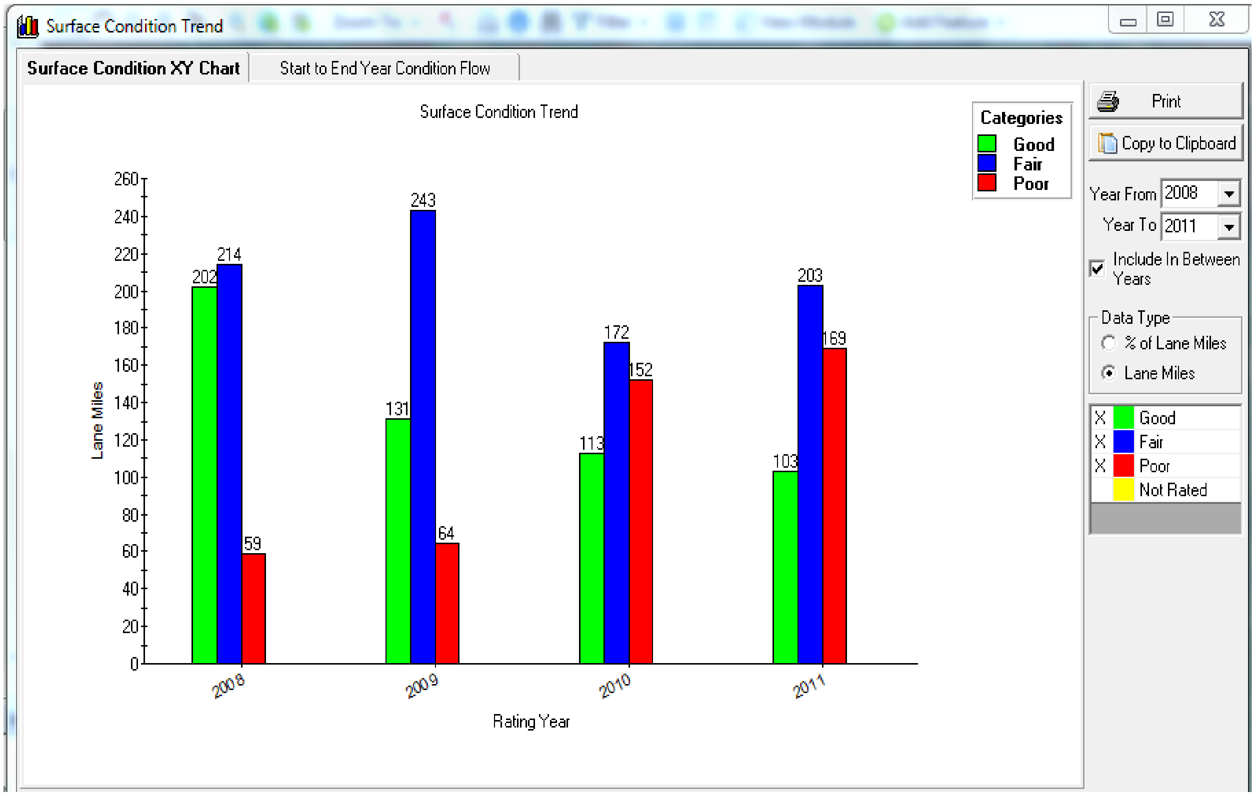


Figure 6: Network condition report

8) Assign Samples to Represent Network

The URCI method samples distress and inventory information to represent a larger network of roads. This functionality will be present in the DSS so that users can assign specific sampling locations to represent the larger road network. ***Figure 7*** illustrates how a sampling location (shown with the red highlighted segment) can be assigned to a larger road network (shown by the yellow highlighted road segments). *Technical Manual No. 5-626: Unsurfaced Road Maintenance Management* (Department of the Army, 1995) describes the process of dividing road networks for representation by samples.

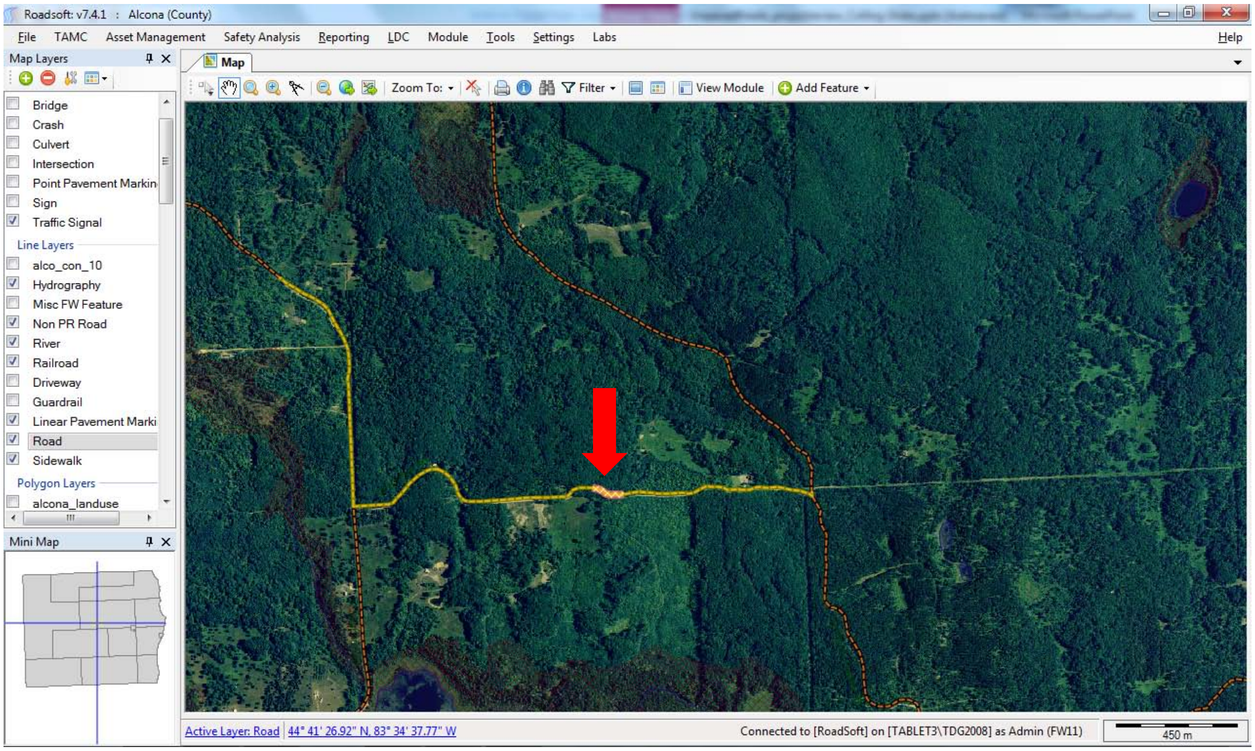


Figure 7: Assigning road sampling locations to a network of representative roads in the DSS

9) DSS Analysis of Data

The URCI method provides set of decision support criteria that guide a road manager to a specific course of action based on an observed road distress or condition. An example of decision support criteria is shown in ***Figure 8***. These criteria were designed specifically for U.S. military facilities to standardize decision making given the resources and criticality of the transportation systems they were intended for. However, they may not necessarily be the best practice or provide suitable guidance for public road managers with large unpaved road systems. The DSS developed for use in this project will allow individual road agencies to customize the applicable decision-making criteria based on their individual agency goals, resources and practice.

TM 5-626

Table 4-1. Maintenance alternatives

Distress	*Severity code*	*cost code*[1]	*Description*
81-Improper cross section	L	B	Grade only.
	M	B/C	Grade only/grade and add material (water or aggregate or both), and compact. Bank curve. Adjust transitions.
	H	C	Cut to base, add aggregate, shape, water, and compact.
82-Improper roadside drainage	L	B	Clear ditches every 1-2 years.
	M	A	Clean out culverts.
		B	Reshape, construct, compact or flare out ditch.
	H	C	Install underdrain, larger culvert, ditch dam, rip rap, or geotextiles.
83-Corrugations	L	B	Grade only.
	M	B/C	Grade only/grade and add material (water or aggregate or both), and compact.
	H	C	Cut to base, add aggregate, shape, water, and compact.
84-Dust stabilization	L	C	Add water.
	M	C	Add stabilizer.
	H	C	Increase stabilizer use. Cut to base, add stabilizer, water, and compact. Cut to base, add aggregate and stabilizer, shape, water, and compact.
85-Potholes	L	B	Grade only.
	M	B/C	Grade only/grade and add material (water, aggregate, or 50/50 mix of calcium chloride and crushed gravel), and compact.
	H	C	Cut to base, add aggregate, shape, water, and compact.
86-Ruts	L	B	Grade only.
	M	B/C	Grade only/grade, add material, and compact.
	H	C	Cut to base, add aggregate, shape, water, and compact.
87-Loose aggregate	L	B	Grade only.
	M	B/C	Grade only/grade, add material, and compact.
	H	C	Cut to base, add aggregate, shape, water, and compact.

[1]Cost code guide: A = labor, overhead; B = labor, equipment, overhead, C = labor, equipment, materials, overhead.

Figure 8: Decision support criteria based on observed distresses from TM 5-626 (Department of the Army, 1995)

The DSS functionality will be created for this project will allow road segments to be ranked as candidates for rehabilitation or maintenance treatments based on their historical distress ratings and inventory information. The ranking system will allow users to use any number of features to filter and sort candidates for ranking. For example a user would be able to filter out just unsurfaced roads of a specific functional class, in a specific region or political jurisdiction (township for example), due to funding constraints. The user could then rank potential road projects considering which road segments have the worst condition and highest traffic volume. Project ranking criteria will be available in a number of reports and tables in the DSS. The DSS will be capable of visually displaying candidate projects meeting specific criteria visually on a base map. ***Figure 9*** provides an example of project ranking tools.

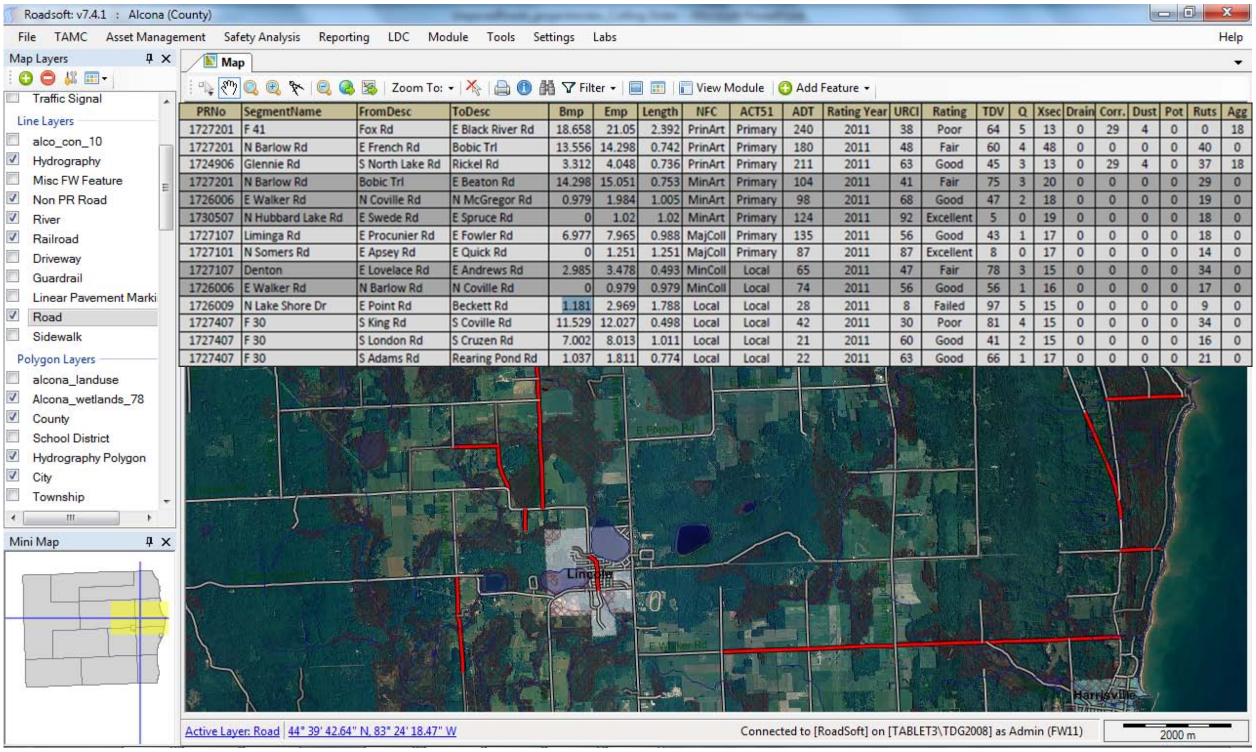


Figure 9: Example unpaved road project candidate ranking matrix based on condition and inventory

10) Selection of Candidates and Scheduling

The DSS will allow users to set up and schedule projects for all or part of a road segment or group of road segments. The scheduling tool allows users to define specific information about each planned project including project cost, project type, project location, job number and notes. Scheduled projects will be available for display in the DSS base map, as well as in a planned project report. ***Figure 10*** provides an example of a scheduling tool dialogue box. Planned project information can be used for construction advisories and communication with internal agency staff, and can also act as a historical record.

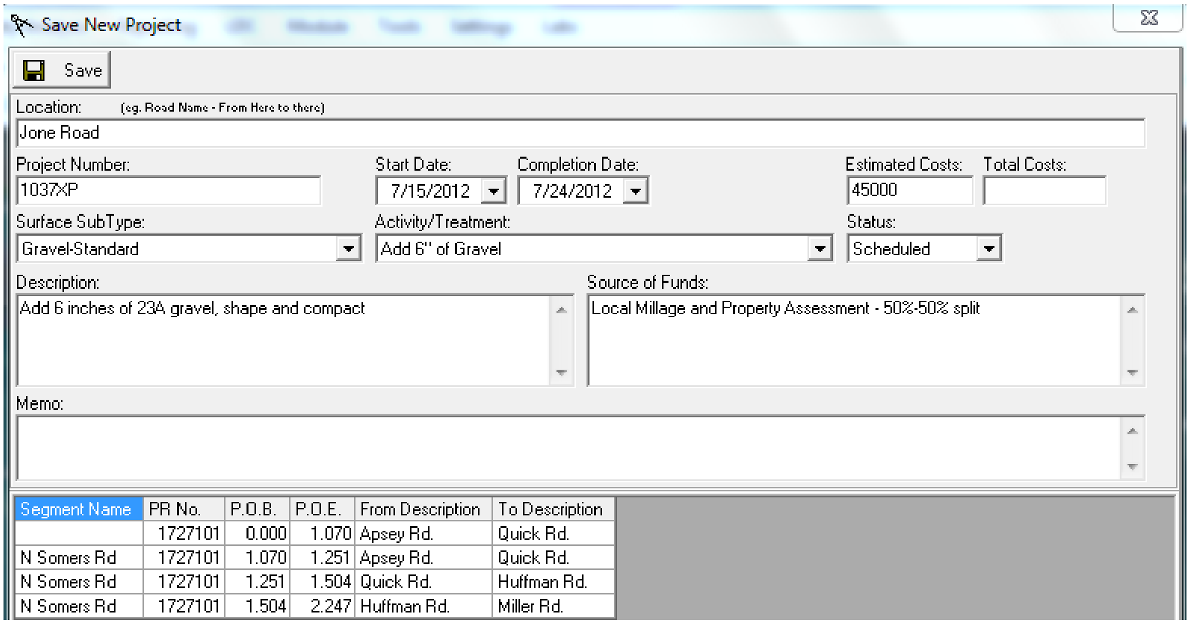


Figure 10: Road project scheduling tool

11) Record Competed Work

As road maintenance projects are completed, field reports can be used to update the DSS database by changing the status of projects from "planned" to "completed. Completed construction and maintenance project will show up in road segment history reports along with historical rating activities. Completed projects will be will also be available in reports showing historical construction activity. ***Figure 11*** shows an example of a historical rating and activity screen for a specific road sampling location. ***Figure 12*** shows a report that summarizes historical project activity.

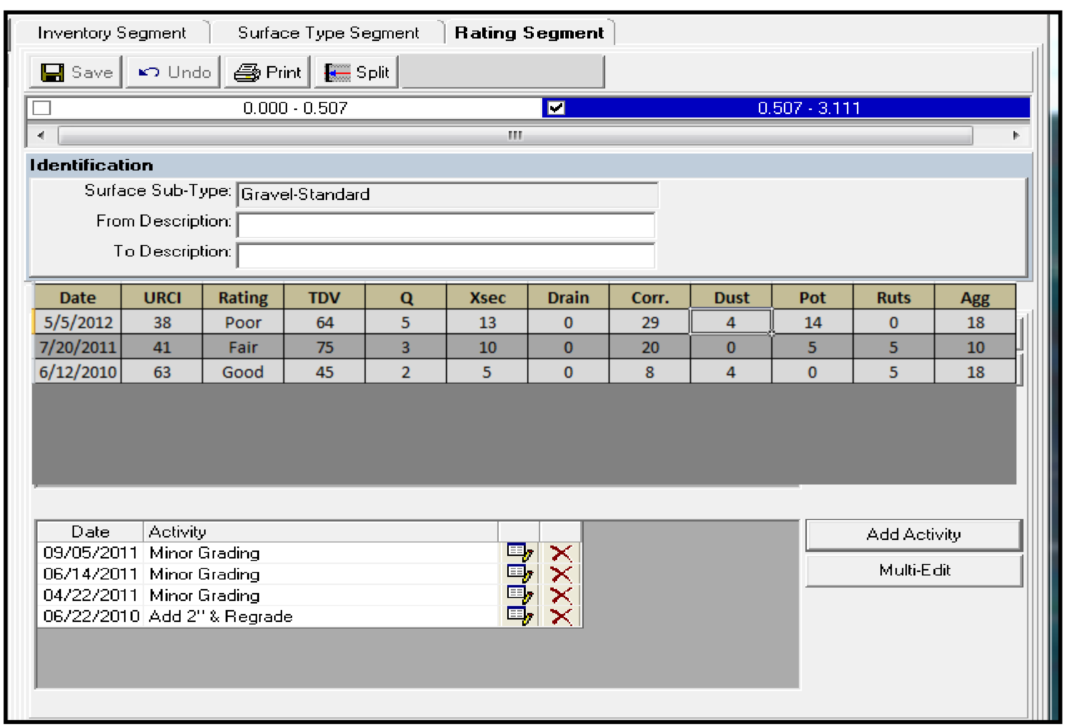


Figure 11: Road sample location form illustrating project construction history and historical rating activity

Annual Project Report

Alcona

Report Module: Road Surface Management Analysis

Today's Date: 6/15/2012

Date Range: 1968 - 2011

Report Filter

Field Name	Operator	Value
Surface Type	=	Gravel,Earth
Construction Activity	=	Gravel-Standard: Minor Grading,Gravel-Standard: Add 3" of Gravel,Gravel-Standard: Add 4" of gravel,Gravel-Standard: Add 2" & Regrade,Gravel-Standard: Add 4" Gravel in spots,Gravel-Standard: Add 4" R.A.P.,Gravel-Standard: Add 6" of Gravel,Gravel-Standard: Reconstruction

ProjYear	PRNumbe	BMP	EMP	Jurisdiction	Improvement	Length	Lanes	RoadName
2011	1729913	0	0.082	Haynes Twp	Add 4" of gravel	0.082	2	N Cedar Dr
2011	1729923	0	0.022	Haynes Twp	Add 4" of gravel	0.022	2	N Cedar Dr
2011	1728407	0	0.189	Harrisville Twp	Add 3" of Gravel	0.189	2	E Clark Rd
2011	3010050	1.942	2.483	Harrisville Twp	Add 3" of Gravel	0.541	2	N Coville Rd
2011	3010050	2.483	3.203	Harrisville Twp	Add 3" of Gravel	0.72	2	N Coville Rd
2011	1725906	0.505	1.014	Harrisville Twp	Add 3" of Gravel	0.509	2	E Dean Rd
2011	1725906	1.504	1.787	Harrisville Twp	Add 3" of Gravel	0.283	2	E Dean Rd
2011	3010014	0	0.351	Haynes Twp	Add 4" of gravel	0.351	1	E Elm St
2011	3010084	1.579	1.958	Harrisville Twp	Add 3" of Gravel	0.379	2	S Everett Rd
2011	3010040	0	0.196	Millen Twp	Add 4" Gravel in spots	0.196	2	N Front Rd
2011	1729809	0	0.089	Haynes Twp	Add 4" of gravel	0.089	2	E Harbor Dr
2011	1727703	0	0.18	Harrisville Twp	Add 3" of Gravel	0.18	2	E Holmes Rd
2011	1730212	0	0.099	Alcona Twp	Add 4" of gravel	0.099	2	N Lake St
2011	1730222	0	0.122	Alcona Twp	Add 4" of gravel	0.122	2	N Lake St
2011	1887711	0	0.106	Millen Twp	Add 6" of Gravel	0.106	2	N Louis Dr

Figure 12: Annual project report illustrating historical treatment information

12) Determine Data Needs and Repeat Cycle

At the end of the unpaved road analysis user agencies will need to determine their data needs prior to restarting the data cycle. Agencies may repeat the data cycle several times per year or as little as once per year depending on how they intend to use the DSS and the level of budget that they have available for data collection activity. Less frequent data cycles will limit the type of DSS analysis that is possible with the distress and inventory information. For example, a single annual data collection event may not provide enough distress data to determine monthly schedules for routine grading, but it may provide sufficient information for determining where reconstruction or heavy rehabilitation activities need to take place, as well as provide an overall network metric for the analysis of a maintenance program on an annual basis.

Data Transfer Format

The raw data requirements that the remote sensing system must be capable of meeting are outlined in the report *Deliverable 1-A: Requirements for Remote Sensing Assessments of Unpaved Road Conditions* (Brooks, Colling, & Roussi, 2011) which can be found at http://www.mtri.org/unpaved/ . This report defines the overall requirements for data collection; however it does not discuss the exact format and type of data that will be passed from the remote sensing systems to the DSS. This report will further define the data format that will be used to transfer data from the remote sensing systems to the DSS. It is anticipated that *Deliverable 1-A* will be a starting point to describe data transfer format. As the development of the remote sensing systems and the DSS interface progress (both of which are not scheduled for completion until several months after the date of this report), this document (Deliverable 6B) will be updated to reflect changes necessary during development.

A proposed data format is described in the appendices of this document. Appendix A provides sample XML field descriptions that could be sent to the DSS from the eCognition system, while Appendix B provides sample XML code that would accomplish this. Appendices C and D provide the same information as Appendices A and B respectively, except do so in regard to the RSPS rather than the eCognition system. Appendix E is a data comprehensive listing of all XML fields and tags used in Appendices A-D.

References

Brooks, C., Colling, T., & Roussi, C. (2011). *Deliverable 1-A: Requirements for Remote Sensing Assessments of Unpaved Road Conditions.*

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Scorseth, K., & Selim, A. (2000). *Gravel Roads Maintenance and Design Manual.* Washington D.C.: USDOT.

Appendix A: XML Field Descriptions in the DSS from the eCognition System

Field	Type	Size	Description	Comments
AerialDate	D	8	Aerial photo date	Date the aerial photo used was taken
Unpaved	C	3	Indicator of unpaved road	Yes indicates the road segment is unpaved
FrameworkVersion	C	3	Michigan Geographic Framework Version	Framework version used to specify the PR and mile points of the sample unit
PR	I	7	Physical Road ID Number	This value is derived from the Framework database
BMP	N	10,3	Beginning PR segment mile point of the sample unit	This value is derived from the Framework database and may not match the GIS length
EMP	N	10,3	Ending PR segment mile point of the sample unit	This value is derived from the Framework database and may not match the GIS length
BMPLat	F	8	Latitude of the BMP location	Coordinate value for latitude of BMP
BMPLong	F	8	Longitude of the MP location	Coordinate value for longitude of BMP
EMPLat	F	8	Latitude of the EMP location	Coordinate value for latitude of EMP
EMPLong	F	8	Longitude of the EMP location	Coordinate value for longitude of EMP
LRS_Link	C	23	Linear referencing segment ID	Used for summarizing the % of the road we were classifying as unpaved

Type:
- I – Integer
- C – Character
- N – Numeric
- D – Date (YYYYMMDD)
- B – Binary
- F – Floating

Appendix B: Sample Road Data Imported into the DSS from the eCognition System

<?xml version>1.0</xml version>
<AerialDate>20120612</AerialDate>
<Unpaved>Yes </Unpaved>
<FrameworkVersion>11a</FrameworkVersion>
<LRSNumber>14</LRSNumber>

<location>
<PR>1234</PR>
<bmp>1.000</bmp>
<emp>2.500</emp>
<BMPLat>38.898556</BMPLat>
<BMPLong>-77.037852</BMPLong>

<EMPLat>38.934562</EMPLat>
<EMPLong>-77.136294</EMPLong>
</location>

Appendix C: XML Field Descriptions in the DSS from the RSPS

Field	Type	Size	Description	Comments
InspectionDate	D	8	Inspection Date	Date the inspection was conducted
Inspector	C	255	Inspector Name	The name of the inspector – Repeating field?
Remarks				
FrameworkVersion	C	3	Michigan Geographic Framework Version	The Framework version used to specify the PR and mile points of the sample unit
Width	I	3	Sample Width	The average width in feet of the sample unit.
Area	I	5	Sample Area	The square footage of the sample unit (length x width)
Length	I	4	Sample Length	The length in feet of the sample unit
PR	I	7	Physical Road ID Number	This value is derived from the Framework database
BMP	N	10,3	Beginning PR segment mile point of the sample unit	This value is derived from the Framework database and may not match the GIS length
EMP	N	10,3	Ending PR segment mile point of the sample unit	This value is derived from the Framework database and may not match the GIS length
BMPLat	F		Latitude of the BMP location	Coordinate value for latitude of BMP
BMPLong	F		Longitude of the BMP location	Coordinate value for longitude of BMP
EMPLat	F		Latitude of the EMP location	Coordinate value for latitude of EMP
EMPLong	F		Longitude of the EMP location	Coordinate value for longitude of EMP
Type	I	2	Indicates the type of distress present: 81 - Improper cross section 82 - Inadequate roadside drainage 83 - Corrugations 84 - Dust 85 - Potholes 86 - Ruts 87 - Loose aggregate	The distress types define the types of distresses observed on the sample unit. Type is used in conjunction with Severity and Quantity to enumerate the types of distresses present on the sample
Severity	C	1	Indicates the severity of the distress: L - Low M - Medium H - High	Severity is used in conjunction with Type and Quantity to enumerate the types of distresses present on the sample unit
Quantity	I	5	Indicates the amount of distress present	Quantity is used in conjunction with Type and Severity to enumerate the types of distresses present on the sample unit

Type: I – Integer; C – Character; N – Numeric; D – Date (YYYYMMDD); B – Binary; F – Floating

Appendix D: Sample Road Data Imported into the DSS from the RSPS


```
<?xml version="1.0"?>
<inspections>
    <inspection inspectionDate="20120612">
        <inspector>R. Smith</inspector>
        <remarks>Erosion into road</remarks>
        <FrameworkVersion>11a</ FrameworkVersion>
        <width>14</width>
        <area>1400</area>
        <length>100</length>
    <location>
            <PR> =1234</PR>
            <bmp>1.000</bmp>
            <emp>2.500</emp>
            <BMPLat>38.898556</BMPLat>
            <BMPLong>-77.037852</BMPLong>
            <EMPLat>38.934562</EMPLat>
<EMPLong>-77.136294</EMPLong>            </location>
        <DistressTypes>
            <Type Distress=”81”>
                <Quantity>100</Quantity>
                <Severity>M”>
            </Type>
            <Type Distress=”82”>
                <Quantity>200</Quantity>
                <Severity>H</Severity>
            </Type>
            <Type Distress=”86”>
                <Quantity>490</Quantity>
                <Severity>M</Severity>
            <Type Distress=”86”>
                <Quantity>910</Quantity>
                <Severity>H</Severity>
            </Type>
            <Type Distress=”84”> Note this is dust, no quantity
                <Severity>L</Severity>
            </Type>
        </DistressTypes>
 </inspection> </inspections>
```

Appendix E: Glossary of XML fields

AerialDate – Indicates the date that the aerial photo was taken.

Unpaved – Indicates that the road is an unpaved road

Inspections – Indicates that this is a collection of individual inspections (XML tag)

Inspection – Indicates the start of an inspection at a sample location (XML tag)

InspectionDate – The date of the inspection

Inspector – Names of inspectors, can be repeated as necessary?

Remarks – Notes about anything unusual about the sample unit

FrameworkVersion – Framework version of the linear referencing system used to locate the sample

Width – the width in feet of the sample unit

Area - the square footage of the sample unit (length x width)

Length- the length in feet of the sample unit

Location – Describes the location of the sample unit using PR and mile points from the Framework version specified in FrameworkVersion. This section can be repeated as necessary if the sample unit spans more than a single PR. (XML tag)

> **PR –** Is the Physical Road ID Number for the sample unit
>
> **BMP -** Beginning Mile Point is the beginning PR segment mile point of the sample unit
>
> **EMP-** Ending Mile Point is the ending PR segment mile point of the sample unit
>
> **BMPLat –** Describes the bmp location of the sample unit using raw GPS data
>
> **BMPLong -** Describes the bmp location of the sample unit using raw GPS data
>
> **EMPLat –** Describes the emp location of the sample unit using raw GPS data
>
> **EMPLong -** Describes the emp location of the sample unit using raw GPS data

DistressTypes – There are seven distress types for unpaved roads. This section is used to enumerate the distress types that are present along with the quantity and severity of the distress. (XML tag)
Type – Each distress type present in the sample is specified by its Type, Quantity, and Severity level. There are seven distress types. The types are referenced by number as follows:

> **Type** – **81** (Improper cross section)
>
> > **Severity** – L, M, and H (Low, Medium, and High). Different severity levels may exist within the sample unit
> > **Quantity** – Linear feet per sample unit. The maximum length form all severity levels would be equal to the length of the sample unit
>
> **Type - 82** (Inadequate roadside drainage)

Severity – L, M, and H (Low, Medium, and High). Different severity levels may exist within the sample unit

Quantity – Linear feet per sample unit parallel to the centerline. The maximum length is two times the length of the sample unit (two ditches for the total length of the sample unit)

Type - 83 (Corrugations)

Severity – L, M, and H (Low, Medium, and High). Different severity levels may exist within the sample unit

Quantity – Measure in square feet of surface area per sample unit parallel to the centerline. Each severity level is recorded separately. The amount cannot exceed the total area of the sample unit

Type - 84 (Dust)

Severity – L, M, or H (Low, Medium, or High). Only one severity level is selected for the sample unit

Quantity –No quantity is specified for dust. Dust is measured as low, medium, or high severity for the sample unit

Type - 85 (Potholes)

Severity – L, M, and H (Low, Medium, and High). Different severity levels may exist within the sample unit

Quantity – The number of potholes of the specified severity level

Type - 86 (Ruts)

Severity – L, M, and H (Low, Medium, and High). Different severity levels may exist within the sample unit and are recorded separately

Quantity – The square feet of surface area per sample unit. Each severity level is recorded separately

Type - 87 (Loose aggregate)

Severity – L, M, and H (Low, Medium, and High). Different severity levels may exist within the sample unit and are recorded separately

Quantity – Linear feet parallel to the centerline in a sample unit. Each severity level is recorded separately

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Characterization of Unpaved Road Condition Through the Use of Remote Sensing

Deliverable 6-C: Software and Algorithms to Support Unpaved Road Assessment by Remote Sensing

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Purpose of this Document

This report is focused on summarizing the software acquired or developed during this project including the Decision Support System (DSS), image analysis components, and the road surface type data being used as an input for mission planning. It includes an update on progress on integrating distress data into the commercially available RoadSoft GIS tool being used as a demonstration of DSS capabilities for unpaved road management for this project. Also included is a detailed description of the software tools and algorithms being used to process remote sensing data of road condition into usable information. Finally, an update on progress in developing and applying a robust unpaved roads mapping algorithm using readily available color-infrared aerial photography is included.

Motivation

One of the main goals outlined for the *Characterization of Unpaved Roads by Remote Sensing* project was to show that data collected through remote sensing can be effectively used in a decision support system for managing unpaved roads. Management of unpaved roads has historically been challenged by the lack of a method or system that provides decision support and enables cost-effective data collection. Systems providing decision support or basic distress identification for unpaved roads have been developed, but data collection costs and quality have limited their effectiveness and adoption by unpaved road managers. It is the goal of this project to overcome these limitations by providing an example of how data can be collected cost-effectively from remote sensing systems using a standard road assessment and inventory technique[1] and how this data can be integrated into a DSS. The DSS makes use of a variety of data, including asset inventory data, condition (distress) data, and project history data to allow users to more quickly make informed asset management decisions, and to see the impacts of these decisions on the long term health of their road network.

[1]Department of the Army. (1995). *Unsurfaced Road Maintenance Management Technical Manual No. 5-626.* Washington DC: United States Department of The Army.

Part 1: Demonstration of DSS Software and Functions

The DSS provides an interface for storing, organizing and analyzing large quantities of data that assists users in determining a course of action. The DSS that was used for this project is the commercially available product called RoadSoft which uses a geographic information system (GIS) interface to spatially locate and display data related to transportation assets. More information on the DSS can be found at the RoadSoft web site (www.roadsoft.org) as was first reviewed for this project in Deliverable 6-B.

The DSS received data from two specific remote sensing and analysis processes. The road type Trimble eCognition-based process produces the unpaved road inventory information that the DSS used to identify the unpaved road network (see the second half of Deliverable 6-A, *A Demonstration Mission Planning System for use in Remote Sensing the Phenomena of Unpaved Road Conditions*[2] and the third section of this report. The remote sensing platform system (RSPS) (sensor plus platforms) produces road distress data and inventory feature data that the DSS uses to determine asset conditions. A detailed explanation of how the DSS, road type mapping, and RSPS systems work together and the data cycle associated with them was first presented in project Deliverable *6-B: A Demonstration Decision Support System for Managing Unpaved Roads in RoadSoft*[3].

Identify Unpaved Road Network

The DSS uses unpaved road inventory data from the aerial imagery analysis to update its existing pavement surface inventory from historical data if any exists. Road segments in the DSS that are identified as being unpaved in the aerial imagery analysis, but that do not have a pavement type assigned in the DSS, are set as “pavement type=gravel”. Road segments in the DSS that had an existing pavement surface type will only be assigned “pavement type=gravel” when most current surface type information in the DSS is older than the aerial image date used for the analysis. This logic ensures that the newest data will be used to determine pavement types from a combination of historical and new data. ***Figure 1*** provides an example of an updated road inventory in the DSS.

[2] Roussi, C., C. Brooks, A. Vander Woude. (2012). *Deliverable 6-A: A Demonstration Mission Planning System for use in Remote Sensing the Phenomena of Unpaved Road Conditions*. 16 pgs. Available at http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del6A_MissionPlanningSystemReport.pdf

[3] Colling, T., & Schlaff, G. (2012). *Deliverable 6-B: A Demonstration of Unpaved Road Condition Through the Use of Remote Sensing.* 31 pgs.

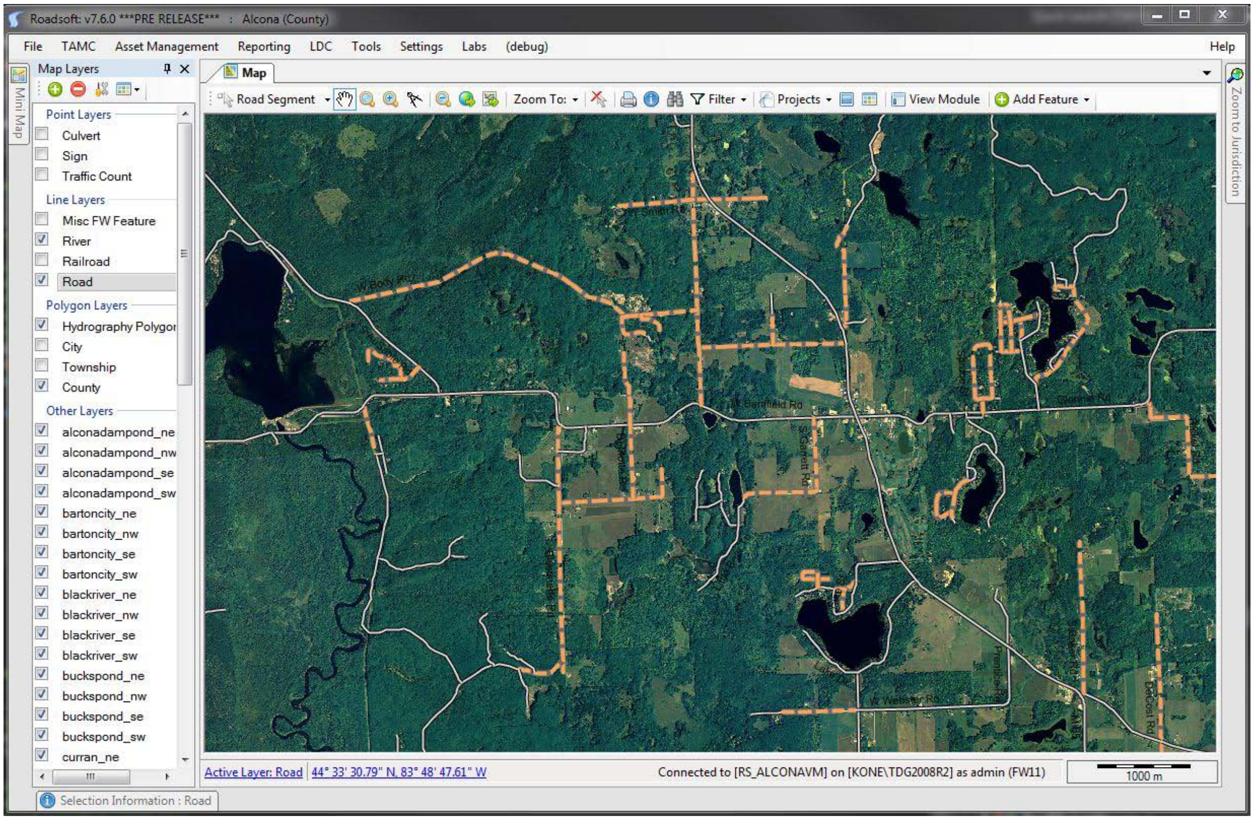


Figure 1: Example of an updated unpaved road inventory in the DSS (RoadSoft). Unpaved roads shown as orange dashes.

URCI Distress Type, Quantity, Severity Data and Density Calculation

Raw data collected by the remote sensing platform system (RSPS) during field collects to acquire distress data require post processing to convert the raw data to URCI categories prior to export to the DSS. Information on quantity and severity of the five distresses defined by the URCI (Unsurfaced Road Condition Index) method[4] are collected by the RSPS and are available for import into the DSS.

These distresses include:

- loss of road cross section,
- improper drainage (where possible)
- potholes
- ruts
- corrugations (washboarding)
- loose aggregate berms

[4] Brooks, C., T. Colling, M. Kueber, C. Roussi, K.A. Endsley. (2011). *Deliverable 2-A: State of the Practice of Unpaved Road Condition Assessment*. 50 pgs. Available at http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del2-A_State_of_the_Practice_for_Unpaved_Roads_MichiganTech.pdf

The URCI method also has a distress measure for dust but that distress was determined to be infeasible to be collected by remote sensing. The DSS can accept manually collected distress data for dust measurements, or any of the other URCI distresses.

The URCI method classifies distress severity into three severity bins of low, medium, or high severity. The criteria to sort specific distress into these bins are defined by the URCI method itself where there is a quantitative measurement associated with the severity level. Several distresses, such as improper cross section and loss of drainage do not contain a quantitative measure for determining their severity bin. Quantitative measures for each of these more qualitative distresses are proposed in *6-B*[5] (Colling & Schlaff, 2012).

The URCI method uses measurements of the quantity of each distress to calculate a parameter termed “density” of the distress. URCI parameter for distress density is calculated slightly different for each distress. Distress density is calculated separately for each distress severity of each distress type.

*Equation 1: URCI Density = distress measurement /total area of sample in sqft. *100*

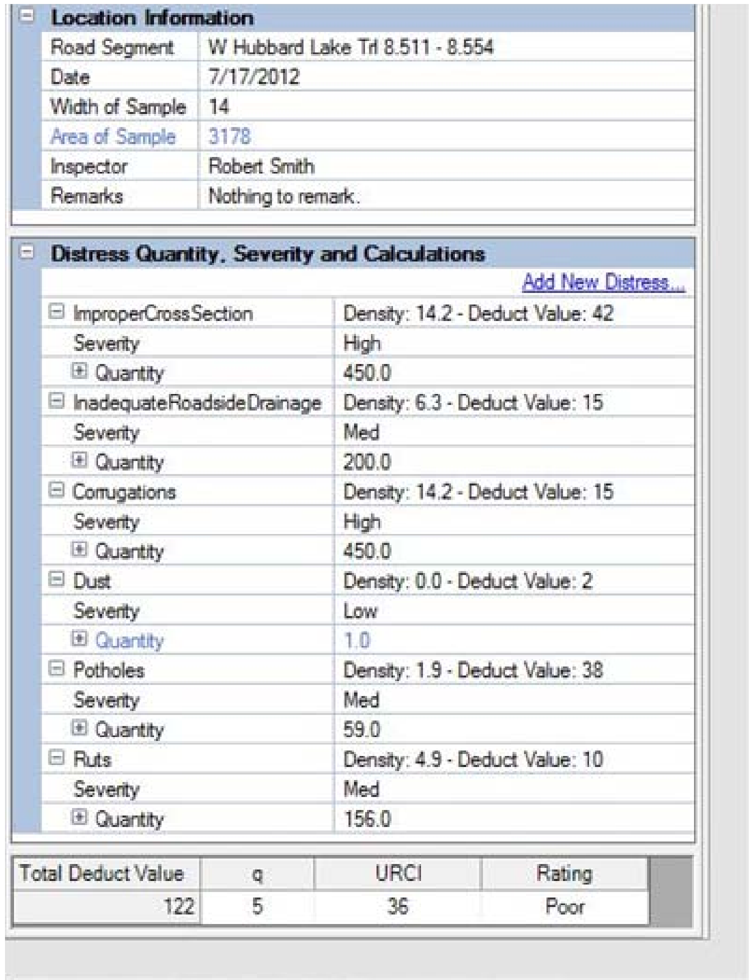
where the distress measurement for each distress type is shown in ***Table 1***.

Table 1: Road distresses assessed for determination of density parameter[6]**.**

Distress ID	**Road Characteristics and Distresses**	**Distress Measurement**
81	Improper Cross Section	Linear feet
82	Drainage	Linear feet
83	Corrugations	Square feet
84	Dust	NA
85	Potholes	Number
86	Ruts	Square feet
87	Loose Aggregate	Linear feet

[5] Colling, T., & Schlaff, G. (2012). *Deliverable 6-B: A Demonstration of Unpaved Road Condition Through the Use of Remote Sensing.* 31 pgs.

[6] Department of the Army. (1995). *Unsurfaced Road Maintenance Management Technical Manual No. 5-626.* Washington DC: United States Department of The Army.



Location Information	
Road Segment	W Hubbard Lake Trl 8.511 - 8.554
Date	7/17/2012
Width of Sample	14
Area of Sample	3178
Inspector	Robert Smith
Remarks	Nothing to remark.

Distress Quantity, Severity and Calculations

Add New Distress...

ImproperCrossSection	Density: 14.2 - Deduct Value: 42
Severity	High
Quantity	450.0
InadequateRoadsideDrainage	Density: 6.3 - Deduct Value: 15
Severity	Med
Quantity	200.0
Corrugations	Density: 14.2 - Deduct Value: 15
Severity	High
Quantity	450.0
Dust	Density: 0.0 - Deduct Value: 2
Severity	Low
Quantity	1.0
Potholes	Density: 1.9 - Deduct Value: 38
Severity	Med
Quantity	59.0
Ruts	Density: 4.9 - Deduct Value: 10
Severity	Med
Quantity	156.0

Total Deduct Value	q	URCI	Rating
122	5	36	Poor

Figure 2: DSS data form showing distress quantity for each distress severity and type.

The DSS has been developed to store and display URCI data relating to a segment of road, as shown in ***Figure 2***. The quantity and extent of each URCI distress can either be received from the RSPS or user-entered from manual collection activities.

URCI Distress Deduct Value Calculation

The URCI method uses unique plots of distress density and severity to calculate URCI deduct point values for each distress. Distresses higher in severity and density accumulated more deduct values[7].

An example of a deduct value curve for the improper cross section factor is shown in ***Figure 3*** below. The deduct curves for the remainder of the distresses are shown in Appendix A.

[7] Department of the Army. (1995). *Unsurfaced Road Maintenance Management Technical Manual No. 5-626.* Washington DC: United States Department of The Army.

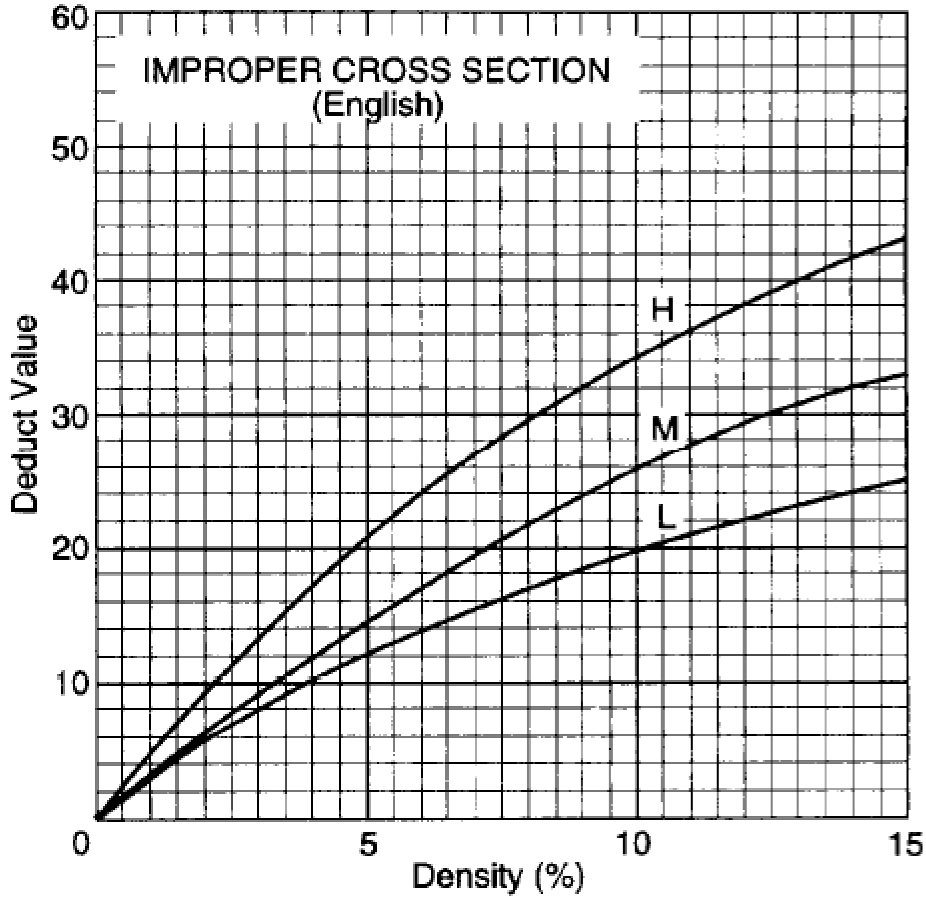


Figure 3: Improper cross section factor deduct value curves[8].

Curve formulas for each of the combinations for severity and density for each distress were generated using a software product called *Curve Expert 1.4*[9] and programmed into the DSS. Data points were chosen by visual inspection of the deduct value curves found in the manual, *Unsurfaced Road Maintenance Management Technical Manual No. 5-626*[8]. The points were then plotted into *CurveExpert* to create a curve that visually matched the manual. *CurveExpert* contains a tool called *CurveFinder* that generates the best fit curve formula for the entered data points. This process was performed for each distress (corrugations, potholes, ruts, etc.) and severity (low, medium, high), along with the URCI curves that will determine the URCI rating of the sample. High, medium, and low curves for improper cross section are shown in ***Figure 4***, ***Figure 5***, and ***Figure 6***.

[8] Department of the Army. (1995). *Unsurfaced Road Maintenance Management Technical Manual No. 5-626.* Washington DC: United States Department of The Army.
[9] Hyams, D. (2012). *CurveExpert Software.* http://www.curveexpert.net.

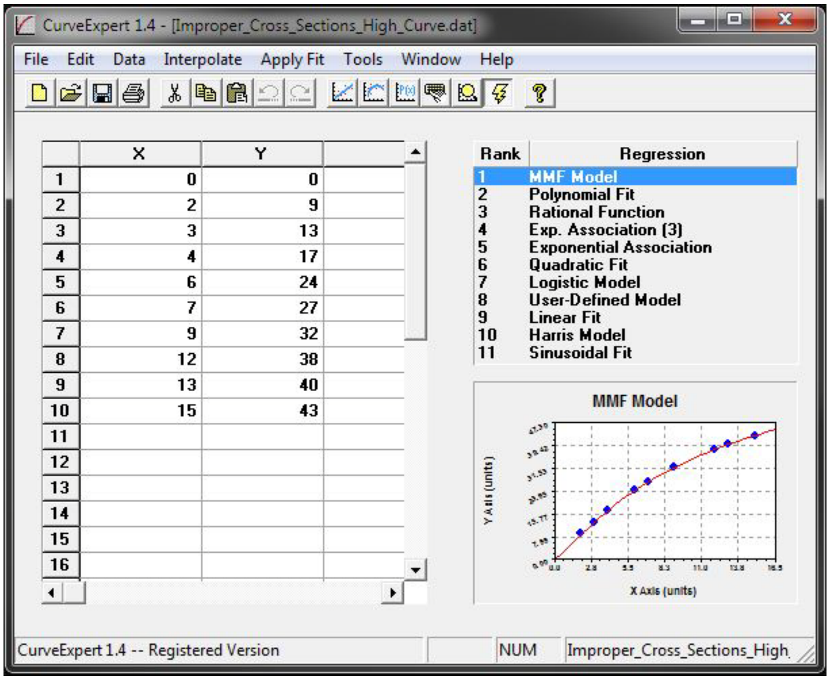


Figure 4: Improper cross section, high severity curve.

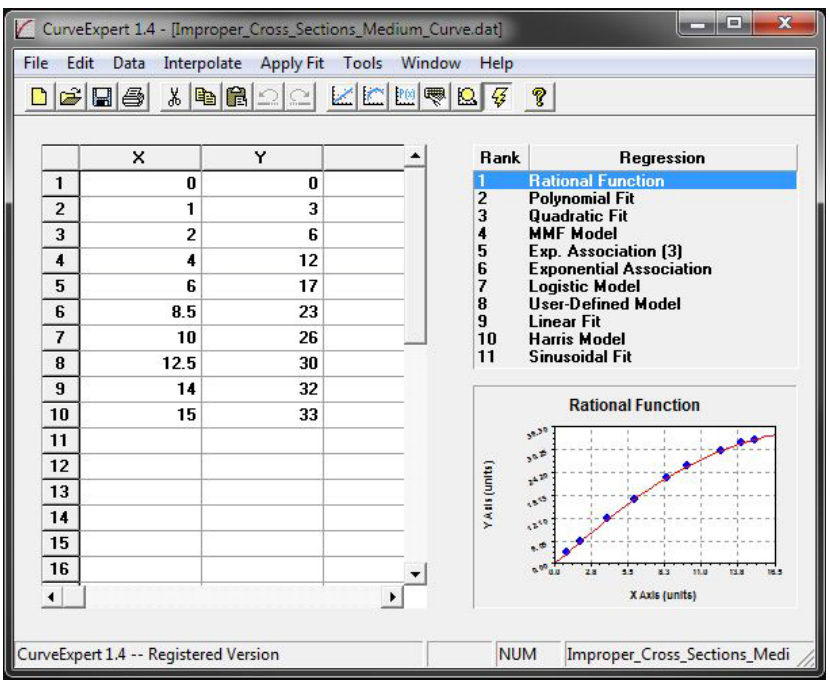


Figure 5: Improper cross section, medium severity curve.

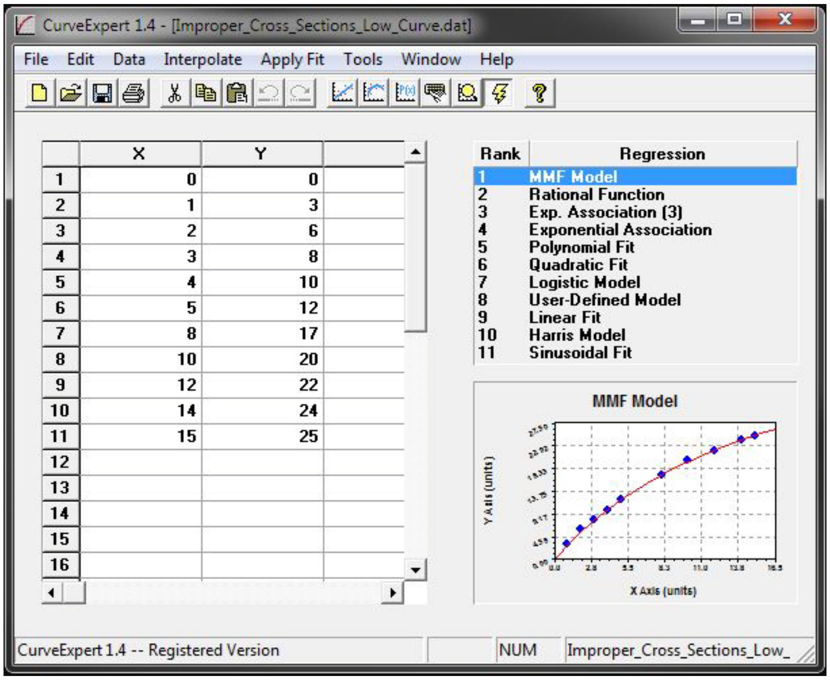


Figure 6: Improper cross section, low severity curve.

The DSS curve formulas for improper cross section are shown in ***Table 2***. The remainder of the deduct curve formulas are included in Appendix A. The DSS will automatically calculate a deduct value based on a combination of distress quantity and severity (***Figure 2)***.

Table 2: Improper cross section curve formulas.

Severity	Algorithm
Low	Deduct Value = (0.0213781589694 * 17.6038875585 + 56.6449253924 * density^0.972223138332) / (17.6038875585 + density^0.972223138332)
Medium	Deduct Value = (-0.014565276145 + 3.0534364876 * density) / (1 + 0.00128303716868 * density + 0.00162998582341 * density * density)
High	Deduct Value = (0.0113024064979 * 16.6711811904 + 76.047792454 * density^1.13553088175) / (16.6711811904 + density^1.13553088175)

Distress Index Calculation

The URCI method creates a combined index (URCI Rating) that is an overall measure of a road segment's condition. The URCI rating is calculated by totaling all of the individual distress deduct values to Total Deduct Value. Additionally, a parameter termed the "q value" is used in combination with the Total Deduct Value to determine the road segment's URCI rating. The q value is the number of deduct values greater than 5. ***Figure 7*** contains the curves used for converting the Total Deduct Value and the corresponding q value to a URCI rating. Curve formulas for each combination of q and Total Deduct Value were generated and programmed into the DSS as shown in ***Table 3***. The seven curves for the q value are included in Appendix A.

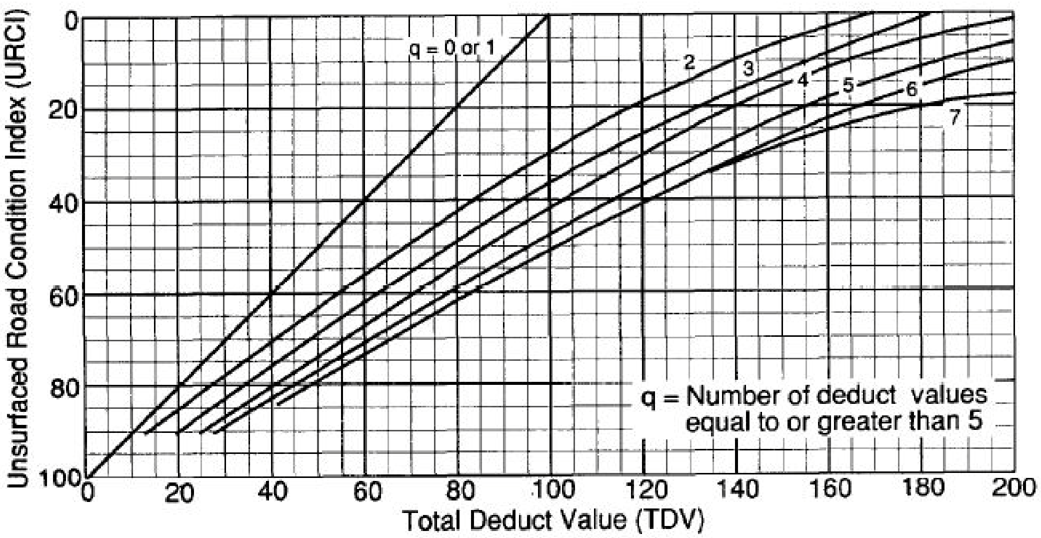


Figure 7: Total deduct value[10].

Table 3: Total deduct value curve formulas.

Severity	Algorithm
q = 1	urci = 100 - totalDeductValue
q = 2	urci = 99.442556802 + -0.702281190257 * totalDeductValue + -0.000908764111217 * totalDeductValue^2 + 0.00000945743530741 * totalDeductValue^3
q = 3	urci = 106.628343108 + -0.834213315131 * totalDeductValue + 0.00138080609451 * totalDeductValue^2
q = 4	urci = 105.042340814 + -0.582137674653 * totalDeductValue + -0.00131723014292 * totalDeductValue^2 + 0.00000826614167894 * totalDeductValue^3
q = 5	urci = 106.118811703 + -0.543444824815 * totalDeductValue + -0.00110649065181 * totalDeductValue^2 + 0.00000669423111377 * totalDeductValue^3
q = 6	urci = 108.216181713 + -0.57663504313 * totalDeductValue + -0.000309192757172 * totalDeductValue^2 + 0.00000368307683483 * totalDeductValue^3
q = 7	urci = 106.158373529 + -0.486152049414 * totalDeductValue + -0.00152237178229 * totalDeductValue^2 + 0.00000868306923091 * totalDeductValue^3

Information from the RSPS can be augmented with other distress or inventory data from manual field inspections as users deem necessary. Data for the dust distress measurements would be required to be manually collected and entered since it is infeasible to reliably measure this distress with remote sensing to the extent necessary to make the data usable, at least within the context of this project.

Use of URCI Data in the DSS

A user interface was developed for the DSS to allow inspection of each of the road sample segments and the respective distress data. ***Figure 8*** shows an example of the user interface in the DSS showing recently collected URCI distress data for a given sample segment.

[10] Department of the Army. (1995). *Unsurfaced Road Maintenance Management Technical Manual No. 5-626.* Washington DC: United States Department of The Army.

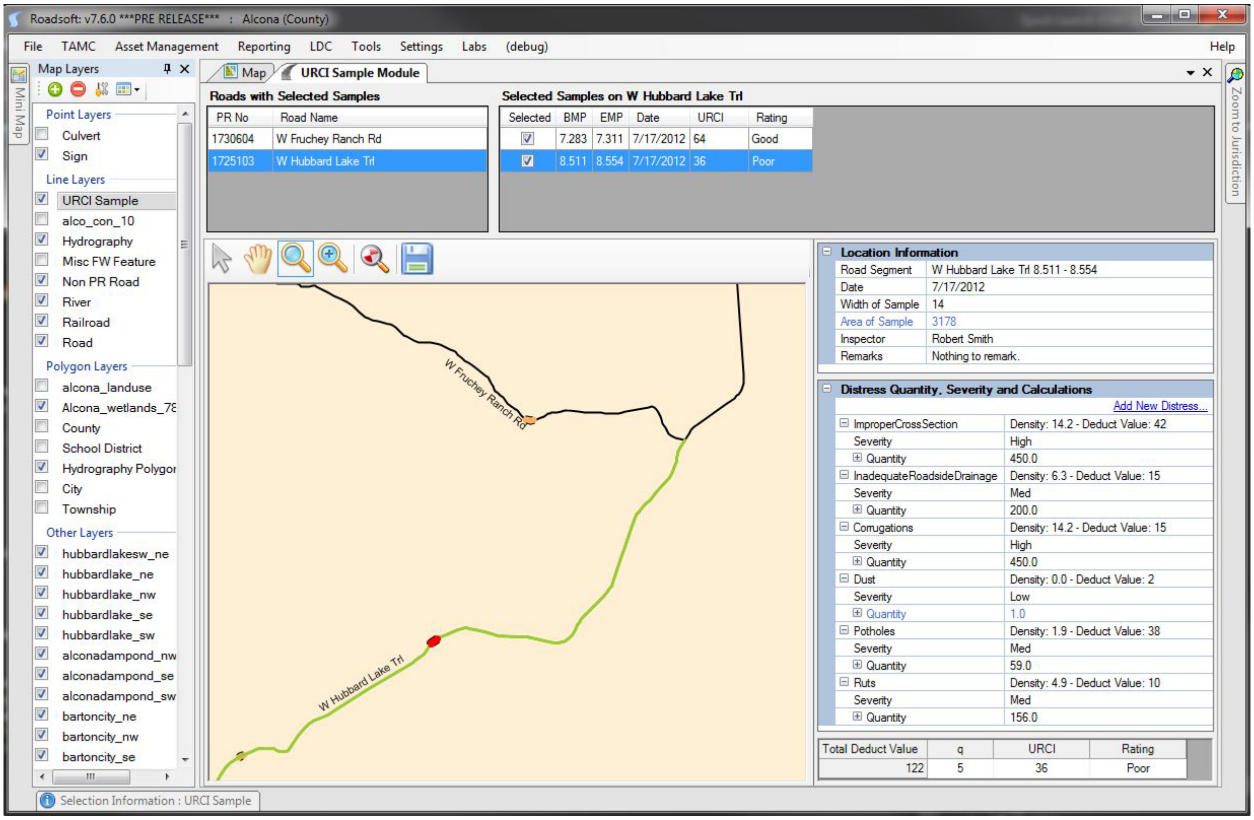


Figure 8: Example URCI distress form for a road sample segment

The URCI method samples distress and inventory information to represent a larger network of roads. This functionality is present in the DSS and users can assign specific sampling locations to represent the larger road network. ***Figure 9*** illustrates how a sampling location (shown with the red highlighted segment) was assigned to a larger road network (shown by the yellow highlighted road segments). *Technical Manual No. 5-626: Unsurfaced Road Maintenance Management*[11] describes the process of dividing road networks for representation by samples.

[11] Department of the Army. (1995). *Unsurfaced Road Maintenance Management Technical Manual No. 5-626.* Washington DC: United States Department of The Army.

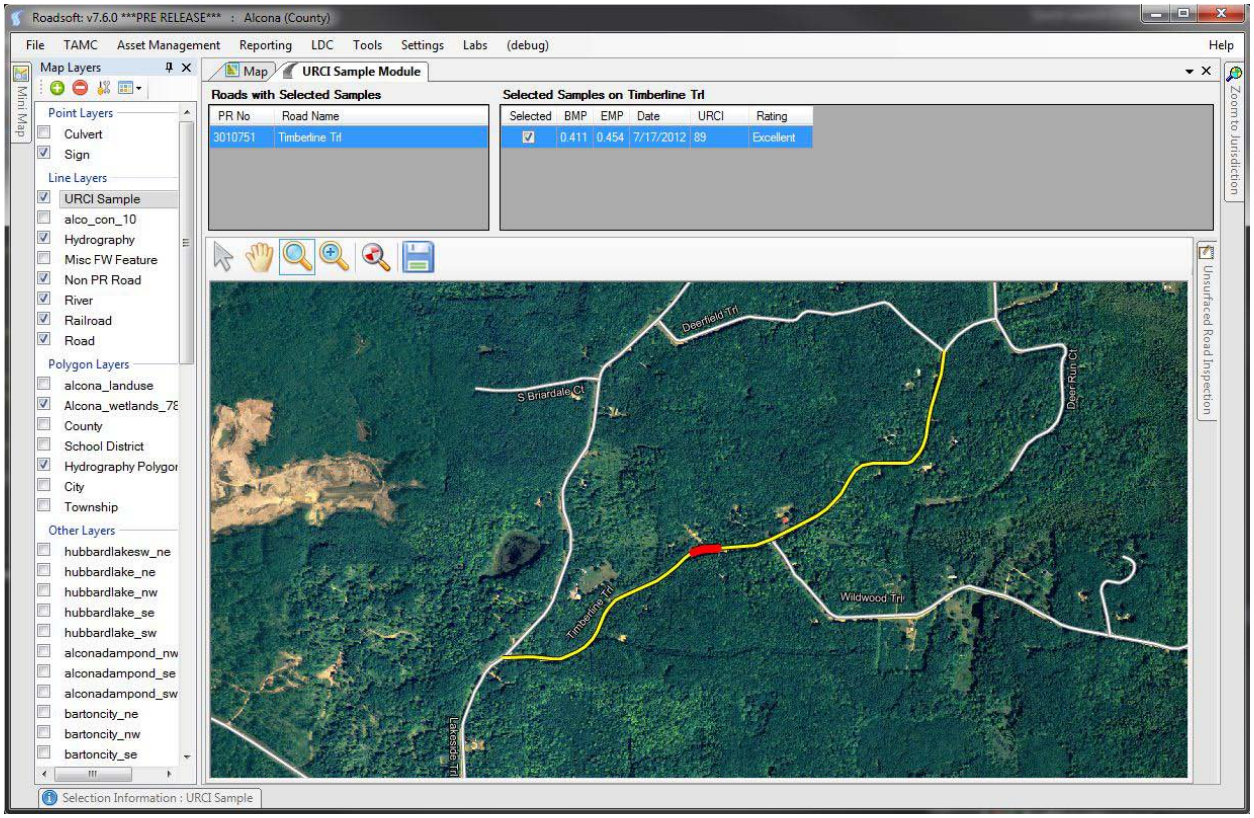


Figure 9: Assigning road sampling locations to a network of representative roads in the DSS.

The URCI method provides a set of decision support criteria that guides a road manager to a specific course of action based on an observed road distress or condition. An example of decision support criteria is shown in ***Figure 10***. These criteria were designed specifically for U.S. military facilities to standardize decision making given the resources and criticality of the transportation systems they were intended for. However, they may not necessarily be the best practice or provide suitable guidance for public road managers with large unpaved road systems. The DSS developed for use in this project allows individual road agencies to customize the applicable decision-making criteria based on their individual agency goals, resources and practice.

TM 5-626

Table 4-1. Maintenance alternatives

Distress	Severity code	cost code[1]	Description
81-Improper cross section	L	B	Grade only.
	M	B/C	Grade only/grade and add material (water or aggregate or both), and compact. Bank curve. Adjust transitions.
	H	C	Cut to base, add aggregate, shape, water, and compact.
82-Improper roadside drainage	L	B	Clear ditches every 1-2 years.
	M	A B	Clean out culverts. Reshape, construct, compact or flare out ditch.
	H	C	Install underdrain, larger culvert, ditch dam, rip rap, or geotextiles.
83-Corrugations	L	B	Grade only.
	M	B/C	Grade only/grade and add material (water or aggregate or both), and compact.
	H	C	Cut to base, add aggregate, shape, water, and compact.
84-Dust stabilization	L	C	Add water.
	M	C	Add stabilizer.
	H	C	Increase stabilizer use. Cut to base, add stabilizer, water, and compact. Cut to base, add aggregate and stabilizer, shape, water, and compact.
85-Potholes	L	B	Grade only.
	M	B/C	Grade only/grade and add material (water, aggregate, or 50/50 mix of calcium chloride and crushed gravel), and compact.
	H	C	Cut to base, add aggregate, shape, water, and compact.
86-Ruts	L	B	Grade only.
	M	B/C	Grade only/grade, add material, and compact.
	H	C	Cut to base, add aggregate, shape, water, and compact.
87-Loose aggregate	L	B	Grade only.
	M	B/C	Grade only/grade, add material, and compact.
	H	C	Cut to base, add aggregate, shape, water, and compact.

[1]Cost code guide: A = labor, overhead; B = labor, equipment, overhead, C = labor, equipment, materials, overhead.

Figure 10: Decision support criteria based on observed distresses from TM 5-626[12].

The DSS was designed to allow road segments to be ranked as candidates for rehabilitation or maintenance treatments based on their historical distress ratings and inventory information. The ranking system allows users to use any number of features to filter and sort candidates for ranking. For example a user can filter out just unsurfaced roads of a specific functional class, in a specific region or political jurisdiction (township for example), due to funding constraints. The user can then rank potential road projects considering which road segments have specific distress levels, while also considering other attributes like traffic volumes. Project ranking criteria is available in a number of reports and tables in the DSS. The DSS is capable of visually displaying candidate projects meeting specific criteria by highlighting them on a base map. ***Figure 11*** provides an example of the project ranking tools.

[12] Department of the Army. (1995). *Unsurfaced Road Maintenance Management Technical Manual No. 5-626.* Washington DC: United States Department of The Army.

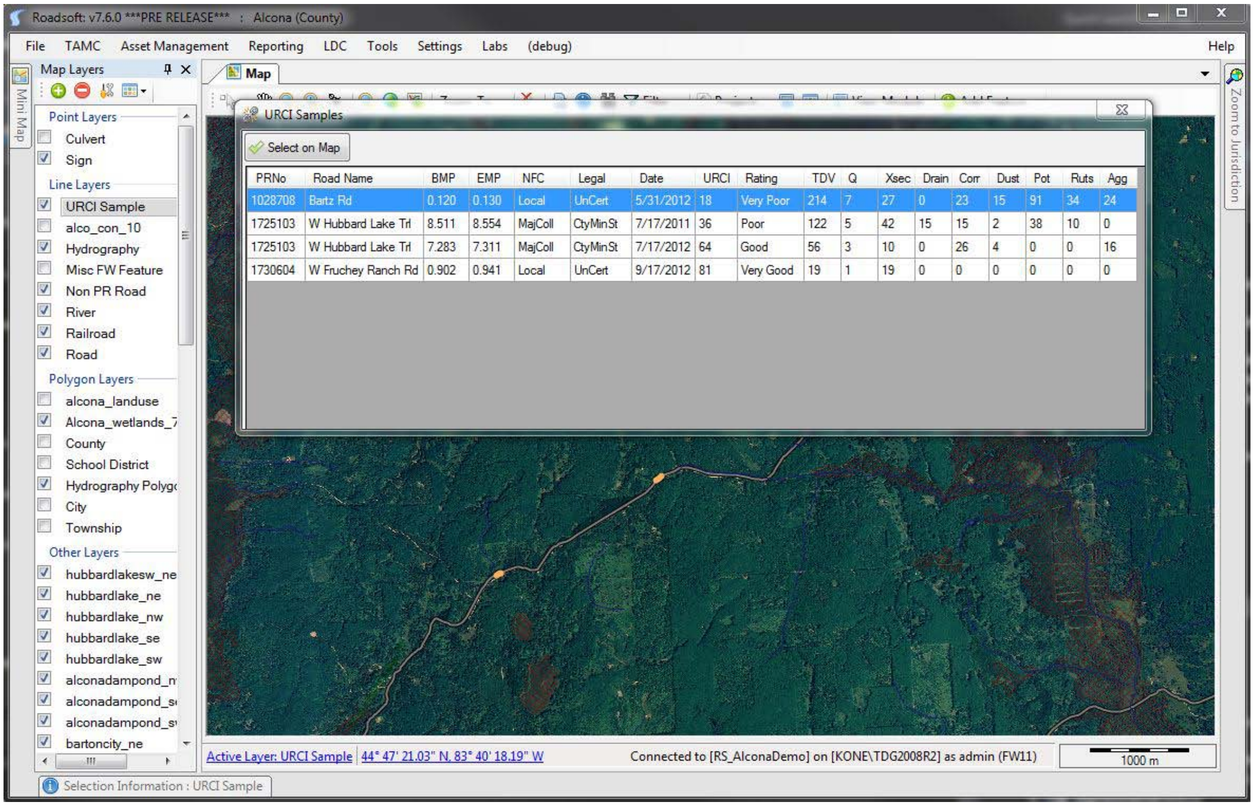


Figure 11: Example unpaved road project candidate ranking matrix based on condition and inventory.

The DSS allows users to set up and schedule projects for all or part of a road segment or group of road segments. The scheduling tool allows users to define specific information about each planned project including project cost, type, location, job number and notes. Scheduled projects can be displayed in the DSS base map, as well as in a planned project report. ***Figure 12*** provides an example of a scheduling tool dialogue box. Planned project information can be used for construction advisories and communication with internal agency staff, and can also act as a historical record.

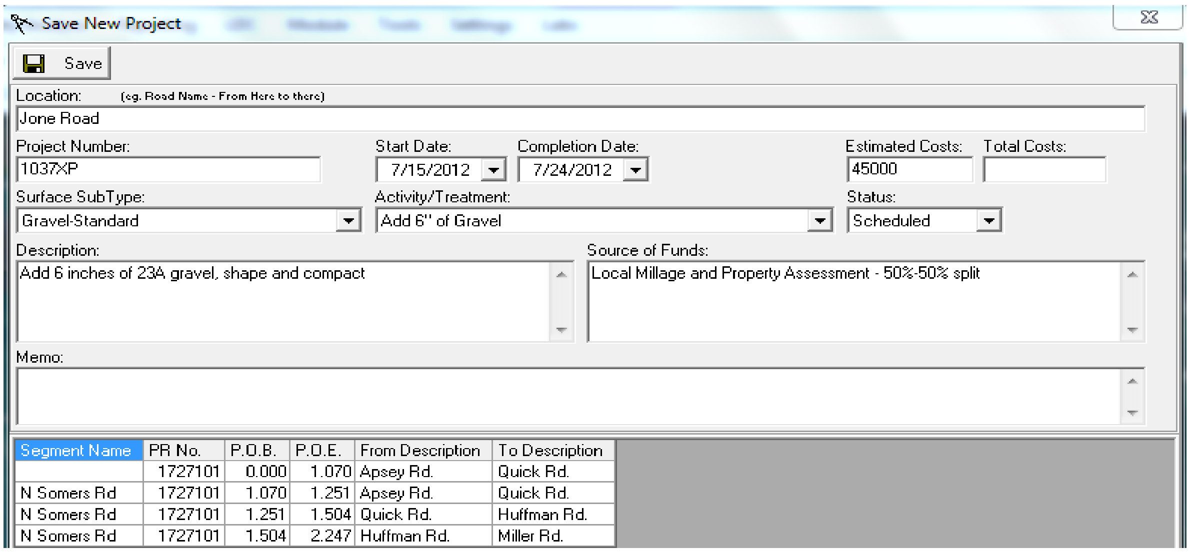


Figure 12: Road project scheduling tool.

DSS Continued Development

As test data becomes available from field sorties, the DSS will be continually refined to make use of the collected data. User testing will begin when data sets become available.

Part 2: Software and Algorithms Developed and Applied for Analysis of Unpaved Road Condition Imagery.

Software Development

It requires sophisticated software to process aerial images in order to extract unpaved-road distresses, characterize them, and report them to a decision support system. The current software development effort has, as its basic goal, to construct a system that can perform these functions efficiently. The choice of a software architecture influences directly this development effort.

Software Architecture Philosophy

Before choosing a software architecture, it was clear that the project, as funded, could not support the development of exclusively new software, nor was it clear that this was needed. Much of the functionality needed had already been shown to be useful in other domains. Underlying all our decisions in the choice of software and its containing architecture was the basic requirement that we conserve time and funds. Guided by this, we determined that these were our goals:

1. Whenever possible, make use of existing code, algorithms, and packages. This has the advantage of reducing both development time and cost.
2. Be portable to at least Linux and Windows environments. While Linux is often the preferred development environment, a large base of systems (and users) exists that use Windows only, and this base cannot be ignored.

3. Modularity. This allows various functional blocks to be "swapped out" as needed, to try different algorithms, without impacting the overall software system (again, reducing development time and costs).
4. Whenever possible, use tools that are license-free, or do not incur excessive recurring costs. This would exclude, for example, an implementation in MatLab.
5. Use the most up-to-date techniques possible. This ensures that the system does not become functionally obsolete before it can be distributed, and makes the best use of current knowledge in signal analysis and processing.

Based on these goals, we elected to use certain tools, packages, and computer languages, as described below. Because the packages to be incorporated in the system were written in a variety of languages, we were driven to use a generic environment, with custom-written interfaces between the existing software packages.

Software Toolbox

Rather than a system developed in a single environment (e.g. a tool written using ENVI only), we have pulled together a variety of environments and tools (a "toolbox", with many drawers). This was done by choosing a most basic control structure, which is based on a command-line shell ("bash") and packages interpreted by that shell. This forms the "glue" which binds together the various components of the system. It does not contribute to the functions needed to meet the system requirements, but exists solely to interconnect components.

The Bash Shell

The program that starts processes, interprets commands, and handles user inputs is called a "command shell", or just "shell". The one we use is named "bash". It was released in 1989 as part of the Unix operating system, and as a replacement for the Bourne Shell ("sh"). It has since been deployed across Linux, MacOS, Windows, Android, and even Novell Netware. This command interpreter forms the basis for the control of our software system.

The bash syntax is sufficiently complex that it can be considered a computer programming language in its own right. However, it was intended primarily for job-control (at which it excels), and something else is needed for inter-process communication and numerical manipulation.

The Python Interpreter

Like bash, Python is an interpreted language, and is often used as a scripting language. Like bash, it was released in 1989. Unlike bash, it is a general-purpose, high-level, object-oriented programming language, with a large number of supporting packages that perform functions ranging from scientific analysis (sciPy, numpy, etc.) to interprocess communications. Python runs on Linux, Windows, MacOS, and has been ported to Java and the .NET virtual machines. And there is precedent for using Python in environmental processing; ESRI recommends using Python to develop ArcGIS scripts[13].

Much of the code that we have developed is either written in, controlled by, or accesses native libraries of, Python. Although Python is invoked by bash, in many cases it performs many of the control functions of bash, in a sense replacing it once it starts running.

[13] http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=About_getting_started_with_writing_geoprocessing_scripts

The Processing Scheme

There are also functions that are performed by third-party or custom (when necessary) packages, such as image and signal processing. However, the distinction between Python and these other packages is blurred at times, since Python has the ability to perform many image and signal analysis functions. The relationship between Python, bash, and the processing tools is not strictly hierarchical; it is a complicated interplay of all of them, depicted in Figure 13.

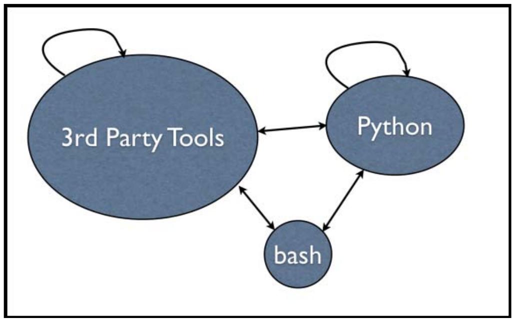


Figure 13: Relationship of processing tools

The diagram in Figure 13 is meant to show not only how the parts depend on each other, but also how they interact. For example, the bash-shell may invoke Python, which itself may invoke some 3rd party tool, and this tool might then invoke Python again, or bash, or even another tool. Once the process begins, it is entirely flexible, allowing great and detailed control over the processing of the results.

Third-Party Tools

As mentioned, software reuse has been a major focus of this effort. To that end, we have been using a number of already-written tools, presented in Table 4.

Table 4: summary of third-party tools used for image processing

Name	Source	Description
Bundler	Univ. of Washington, open source	A structure-from-motion tool for unstructured collections of images, written in C and C++. It is used to find a collection of 3D points and camera views that represent the scene.
PMVS (patch-based multi-view stereo)	Univ. of Washington, open source	Takes the output of Bundler and densifies the 3D point cloud. Written in C and C++.
Meshlab	Univ. of Pisa, and open source	portable, and extensible system for the processing and editing of unstructured 3D triangular meshes. Written in C and C++.
OpenCV	Willow Garage, open source	A package of computer vision tools written in optimized C/C++
SciPy	SciPy.org, open source	open-source software for mathematics, science, and engineering.
VLFeat	VLFeat.org, open source	A package of computer vision tools written in C.

Most of these tools are generally not useful in a stand-alone fashion; we have had to write drivers and "glue-code" in order to make use of these tools. All are free to use, and may be redistributed freely, with certain provisions.[14,15]

Processing Functional Flow

The processing consists of a series of steps, depicted in Figure 14.

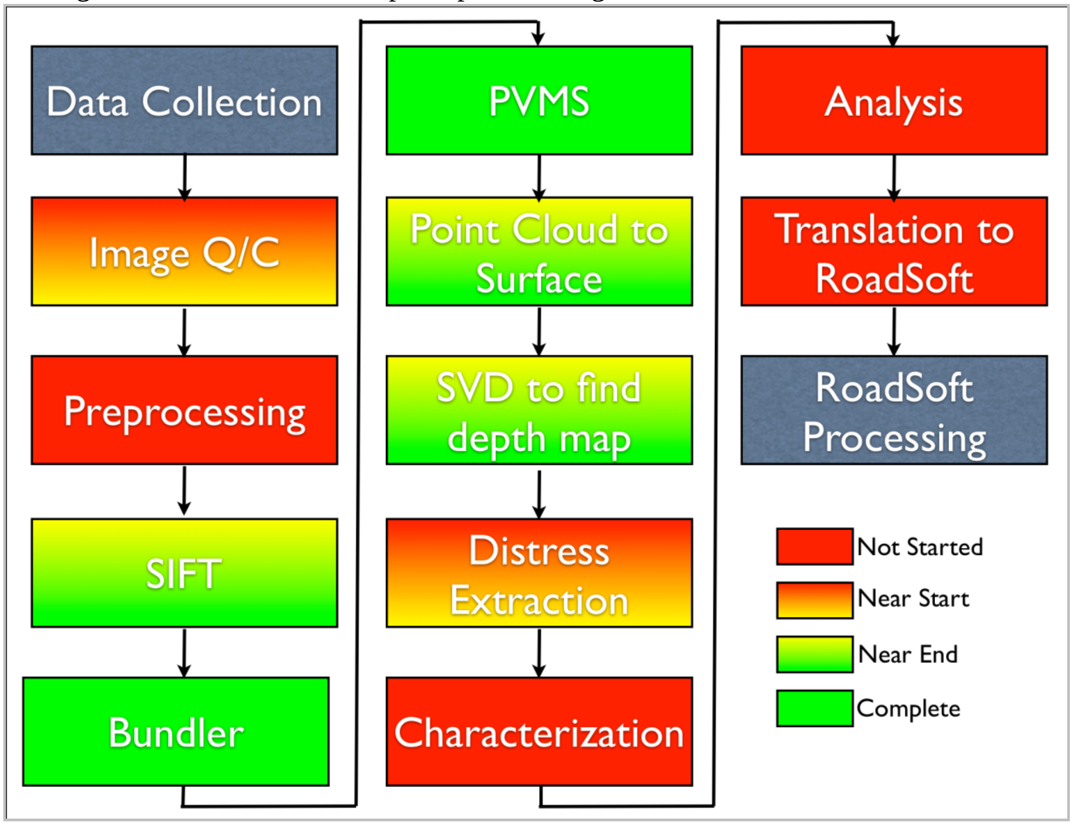


Figure 14 - Processing functional flow

The data collection and RoadSoft processing are external to the image analysis process, and are considered elsewhere, in Deliverable 6-B and the first section of this report. The other steps are color-coded to indicate the state of completion at the time of this writing.

We began our software development with what we considered the more difficult problem of extracting the 3D information needed from a series of 2D images. This is largely completed, and we have begun filling in the details of the less-complicated, or more well-understood, parts of the process.

Image Quality Check

A typical data collection will produce thousands of high resolution photos. It is time-consuming (and not particularly useful) to look at all of these. A software program is being developed to "inspect" the images to make sure that they are suitable for processing. At this time, this only includes a process to check for clarity, but it may include other, more sophisticated checks later.

[14] http://www.gnu.org/licenses/old-licenses/gpl-2.0.html
[15] http://www.linfo.org/bsdlicense.html

Preprocessing

This step prepares an image for processing by the downstream software. It may include resampling the image (if it is too high a resolution, for example, we may want to make it smaller to improve throughput), sharpening the image, or other simple steps to make the image more likely to be useful to subsequent programs.

Scale-invariant Feature Transform

Objects in an image exhibit "interesting points" (e.g. corners) that can be extracted as features of that object. For reliable recognition, those features (called "keypoints") should be detected even if the scale of the image changes (the object is larger or smaller), there is noise in the image (like other objects nearby), or the illumination changes between images. Also, the relative positions between the features should not change from one image to another. Being able to identify the same feature in two different images, possibly taken from different locations, is important to the process of 3D reconstruction to follow.

An algorithm to perform this function, first published in 1999, is available. Called SIFT[16], it finds so-called "keypoints" of objects in an image, and stores them in a database of such features. Then, in another image, "keypoints" are found, and the Euclidean distance between those features and the stored features is found. If the features are in substantial agreement in terms of scale, location, and orientation, then they are listed as "good" matches, and "bad" matches are discarded. If there are 3 or more such features that match, they are subjected to a more detailed verification, and the probability of the presence of an object is computed (based on the accuracy of the match, and the number of the probably false matches). These matches are passed to the Bundler process.

Bundler

This takes a set of images, and the image features and matches (from SIFT), and produces a 3D reconstruction of camera positions and a sparse scene geometry as output. The scene is reconstructed incrementally, a few images at-a-time, based on the sparse-bundle adjustment package of Lourakis and Argyros[17]. In other words, it produces sparse point-clouds in 3D representing objects in the image. These point-clouds can be useful, but for our purposes, we need a denser representation (more points in the cloud). For this, we need the next algorithm.

Patch-based Multi-view Stereo

This package, provided by Yasutaka Furukawa[18], takes a set of images and camera parameters, and reconstructs the 3D structure of an object or a scene. It ignores non-rigid objects, and outputs a set of points that represent the rigid scene (not a mesh model) containing both the 3D coordinates and the surface normal at each point.

Depth Map

The process of generating a depth map from the dense point cloud takes multiple steps, outlined below:

1. Form a surface from the points. This can be done quickly using a Poisson reconstruction[19], or more slowly (but more accurately) by a ball-pivoting operation[20].

[16] D. G. Lowe, "Distinctive image features from scale-invariant keypoints", *International Journal of Computer Vision*, 60, 2, (2004), pp 91-110

[17] http://www.ics.forth.gr/~lourakis/sba/

[18] Y. Furukawa, J. Ponce, "Accurate, Dense, and Robust Multi-View Stereopsis", *IEEE Trans. on Pattern Analysis and Machine Intelligence*, 2010, vol. 32, no. 8, pp. 1362-1376

[19] M. Kazhdan, M. Bolitho, H. Hoppe, "Poisson Surface Reconstruction", Proc. of Eurographics Symposium on Geometry Processing, 2006.

2. Smooth the surface, to remove reconstruction outliers. An example algorithm is Taubin smoothing[21].
3. Find the transformation that maps the plane of the road into the X-Y plane. When this is done, the Z-axis is the height field. This can be most conveniently performed using Singular Value Decomposition[22] (SVD).

Once we have the depth map, a variety of operations may be performed to evaluate the nature of the surface, including finding distresses.

Distress Extraction

The first problem becomes locating those areas of the surface to characterize. The distresses that we are finding include:

1. Potholes. These are detected, and their locations and sizes determined, using a modified circular Hough-Transform[23].
2. Ruts. These are detected using a Gabor filter[24] formulation.
3. Corrugations. These, too, are found using a Gabor filter.
4. Crown. This feature is found by taking a cut through the surface orthogonal to the road direction in the image.
5. Loose aggregate. Detected as berms on the road surface not associated with ruts.

The various quantities are measured, and passed on to the characterization stage.

Distress Characterization

In this stage, the various requirements on ranking damages are applied. For example, potholes are sorted into bins based on their diameter, depth, etc. The number of potholes in each bin is what is used in analysis and reporting.

Analysis

The abstracted distress information can then be summarized, statistics found, and reported for use in Decision Support Tools such as RoadSoft.

Feature Translation

The RoadSoft program is expecting the data to be presented at its interface in some form, in a tabular format with fields that match those described in Appendix A: "XML Field Descriptions in the DSS from the eCognition System" as described on page 26 in Deliverable 6-B. A program will be written, based on the interface description, which will translate the numbers we measure into numbers acceptable to RoadSoft. In some cases, this may be as simple a unit conversion. In other cases, it may be somewhat more difficult; we are in the process of creating the interface control document (ICD) which will define the process of translation for us.

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[20] F. Bernardi, J. Mittleman, H. Rushmeier, C. Silva, G. Taubin, “The Ball-Pivoting Algorithm for Surface Reconstruction”, IEEE Trans. on Visualization and Computer Graphics, 1999, vol. 5, pp. 349-359.

[21] G. Taubin. “A signal processing approach to fair surface design”. *Proceedings of ACM SIGGRAPH 95*, pages 351–358, 1995.

[22] G. Golub, W. Kahan,"Calculating the singular values and pseudo-inverse of a matrix". *Journal of the Society for Industrial and Applied Mathematics: Series B, Numerical Analysis, 1965*, **2** (2): 205–224

[23] M. Rizon, H. Yazid, P. Saad, A. Shakaff, A. R. Saad, M. Sugisaka, S. Yaacob, M. R. Mamat, and M. Karthigayan, “Object detection using circular hough transform”, American Journal of Applied Sciences 2 (12), 2005.

[24] S. Grigorescu, N. Petkov, P. Kruizinga, “Comparison of Texture Features Based on Gabor Filters”, IEEE Trans. on Image Processing, vol. 11, no. 10, 2002.

Example Case

The following example shows results from data collected on a small (30m) section of Petersburg Rd, in Milan Michigan. The data were collected from an altitude of 20m, with the UAS moving forward at 2m/s, and a camera frame-rate of 2 frames/sec.

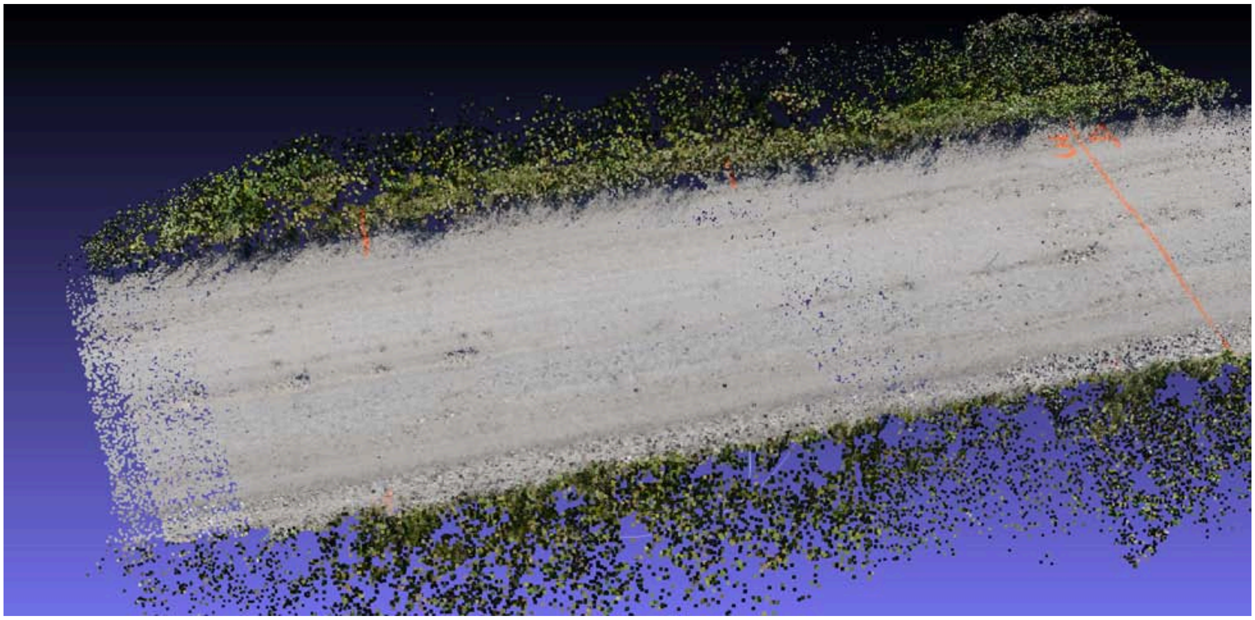


Figure 15: 3D Point cloud generated from 28 images input to Blender

The point cloud which Blender generated for these images is shown in Figure 15. While it appears dense in this view, it is not dense enough to meet the system requirements of being able to detect the smallest changes in the surface needed, as described in Deliverable 1-A, the Requirements Definition Report. After running PMVS on the cloud, though, it is much denser, and can support the measurement we need. This is shown in Figure 16.

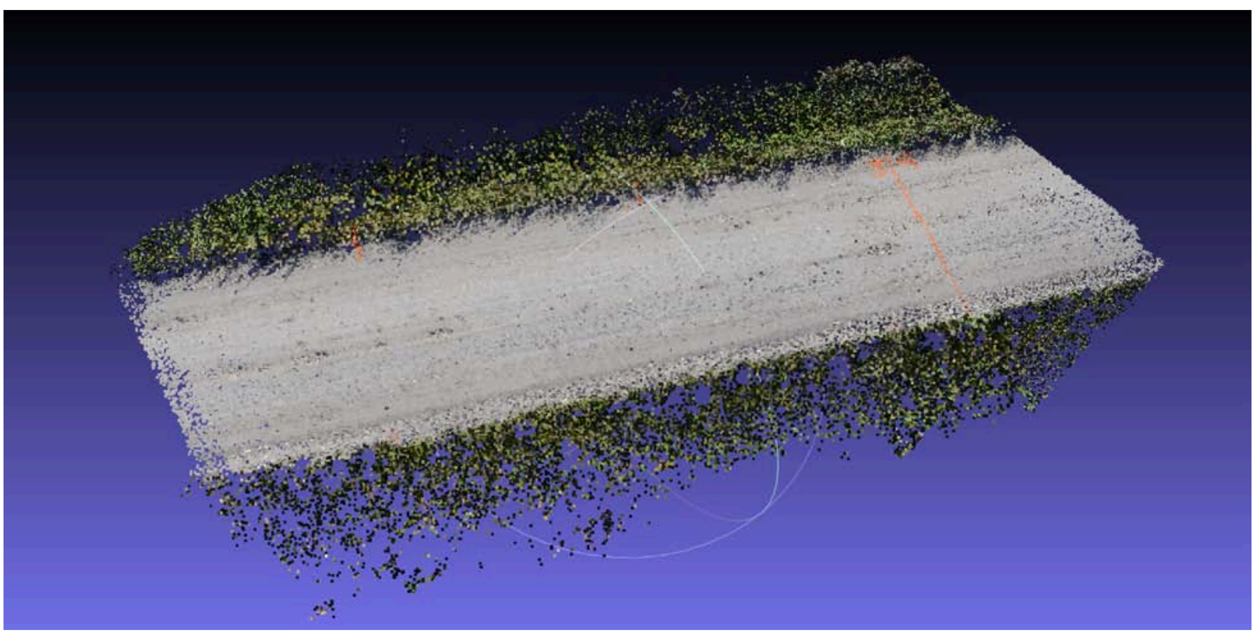


Figure 16: Densified point cloud from PMVS

Several other views in Figure 17 show more details of the 3D structure of the reconstructed damages. Figure 18 shows the same area as taken by the Remote Sensing Platform System, in this case the Bergen Tazer 800 UAV helicopter mounted with the Nikon D800 sensor being used so far in this project. Figure 19 shows the UAV helicopter on its first field deployment in October, 2012 as it returns from collecting road condition imagery.

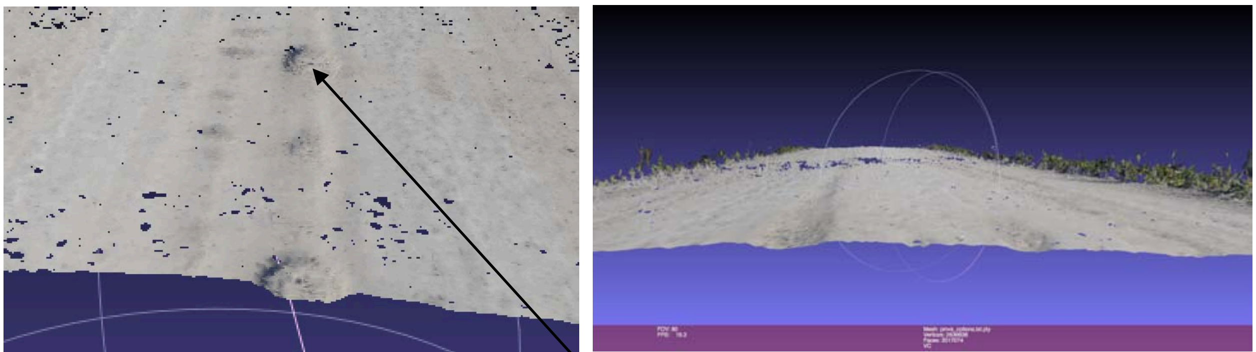


Figure 17: Cuts through the 3D surface showing height changes in potholes and ruts.

Figure 18: The same area shown in Figure 17, as taken by the UAV helicopter during a recent field test deployment.

Figure 19: The project's UAV helicopter mounted with the Nikon D800 sensor system collecting data for unpaved road condition assessment. *A video of one of the initial field test data collects is currently available at* http://www.youtube.com/watch?v=KBNQzM7xGQo

The result of finding the depth map is shown in Figures 20 and 21. In this case, the scale is relative to some arbitrary height above the road, and is in cm. Red coloration is higher than blue. Note that it is clear that there is a good crown of about 10cm, and that the various potholes are clearly seen. The two large potholes near the center of the road on the left are seen to range in depth from about 4cm to 7cm. This is consistent with the measurements made on the ground during the collect.

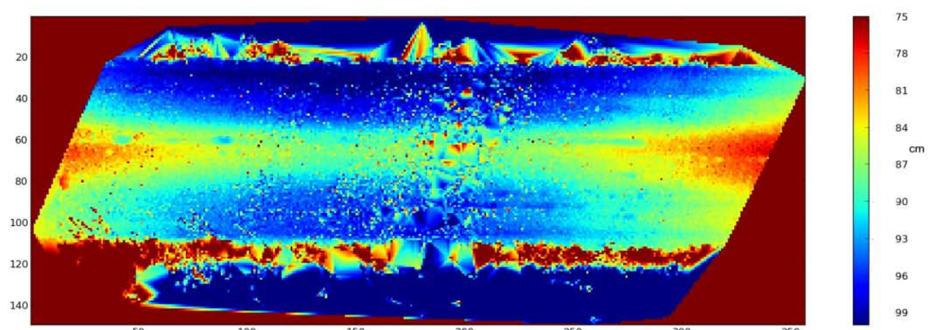


Figure 20: Depth Map showing relative deviation in surface height. Scale is in cm.

Figure 21 shows a close-up of the left edge of the segment, with median filtering applied to the height field to remove single-voxel noise. This process will make the resulting measurement somewhat less spatially accurate, but reduces the reported variance of the measurements to more realistic values.

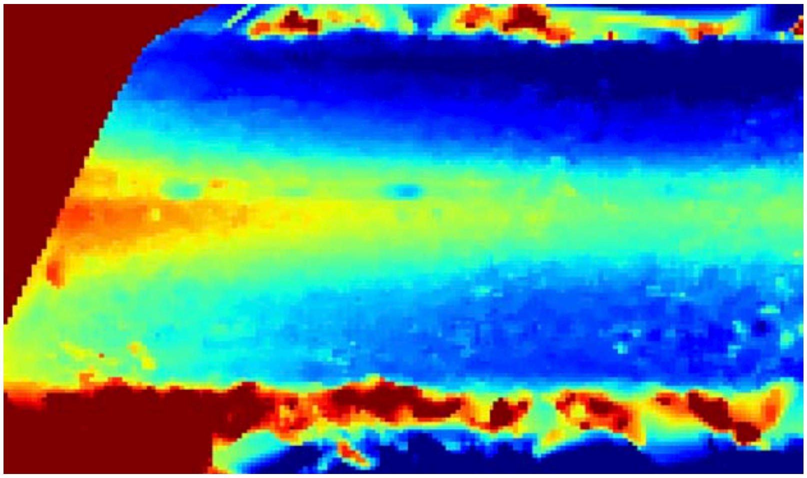


Figure 21: Depth Map after median filtering, to remove single-point noise artifacts.

At the time of this writing, the data are being run through the rest of the processing chain, to extract quantitative values for the various distresses. Also, data from other sites are being processed, which contain other distresses not present in the data shown above. Tuning of the software will continue as the project develops further and more field data are collected for processing.

Summary

All components of the signal processing chain, from data collection to reporting to the Decision Support System, have been identified. The software consists of a combination of existing code, third-party tools, and some custom-written code and scripts. Work is proceeding to integrate the individual components into an automated framework of glue-code and custom scripts, so that data can be processed in an entirely automated fashion. Some example data have been processed, and preliminary results indicate that the resolution of the collected data, and processed output, will support the requirements identified for each of the distresses.

Part 3: Unpaved Road Identification and Classification.

As the next area of Southeast Michigan for identifying the location and type of roads for use in mission planning, Monroe County was selected to evaluate the performance of the algorithm and procedures first developed and applied to Oakland County, also in SE Michigan (see Deliverable 6-A: Roussi, Brooks, A. Vander Woude, 2012 for the initial Oakland County-based methods). Monroe County differs from Oakland County in a number of respects – not least of which is a road network that is much less extensive, lower population, extensive agricultural activity, and fewer segments of the road network shaded by trees. All of these factors lead to improved visibility of road surface in aerial photography and improved performance of the classification algorithm. This Monroe County scenario was intended as one more similar to deployment in more treeless areas such as the Dakotas and as a likely place for early field test deployments. Monroe County roads were processed using the methodology described in Deliverable 6-A: *A Demonstration Mission Planning System for use in Remote Sensing the Phenomena of Unpaved Road Conditions*.

Image mosaics approximately 10,000 feet square were created from the Southeast Michigan Council of Governments (SEMCOG) four-band (R,G,B,IR) orthoimagery provided as project cost-share by SEMCOG. Three Principal Component images were created in ERDAS Imagine, a commercial image processing software tool. The SEMCOG aerial imagery, principal components and a shapefile defining a 30 foot roads buffer all are added to a Trimble eCognition project, where a segmentation and classification ruleset is applied. The 30 foot road buffer was applied to the Michigan Framework Roads Network to exclude areas that were not near roads from processing. This change allowed us to increase the accuracy by tuning the threshold values for the unpaved roads classification and provided significant reductions in e-Cognition image processing time.

The segments that were classified as unpaved in eCognition were exported as GIS shapefiles and imported into ESRI Desktop ArcGIS, the leading commercial GIS software. The unpaved polygons from eCognition were intersected with the Michigan Framework Road Network centerline shapefile in ArcGIS. The output of the intersect process is a shapefile containing road segments that are classified as unpaved. To label a complete road segment as unpaved, the length of the segment that was classified as unpaved by eCognition and the overall length of the road are compared. If the length of the unpaved part of the road is greater than a certain amount (such as 21 percent, which the team found produced road mapping data that closely matched ground results) of the overall length of the road, the entire road is considered to be unpaved. The results of this unpaved road mapping effort for northern Monroe County can be seen in Figure 22 and 23. The amount of roads mapped as unpaved so far is 372 miles (599 km) out of the 658 miles (1060 km) processed, or 56% of the evaluated Monroe County road network appears unpaved.

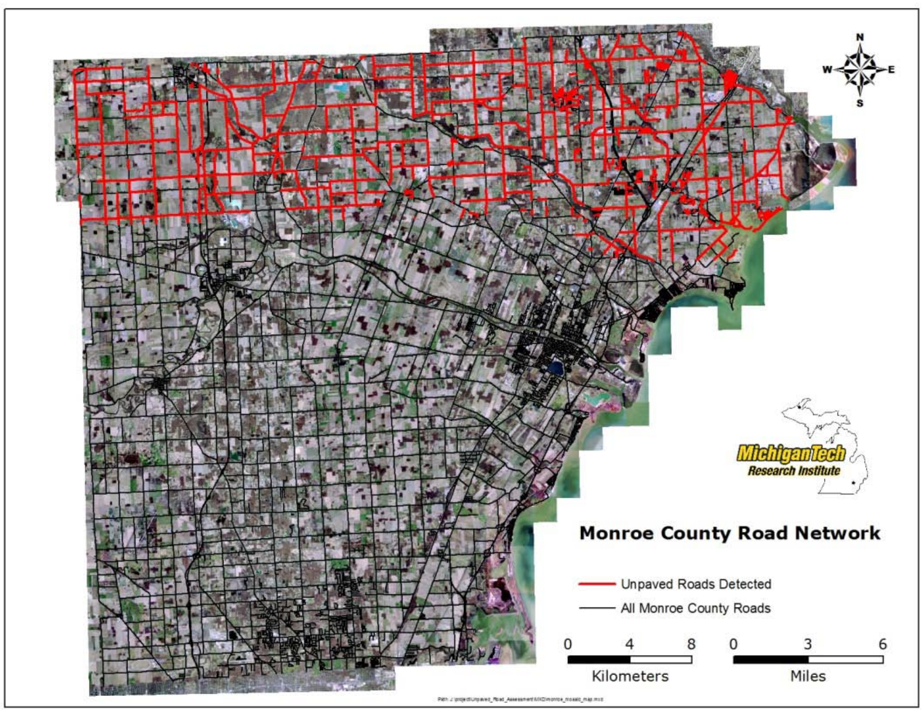


Figure 22: Monroe County road network including areas mapped as unpaved. *Roads that have been run through the eCognition ruleset and have been classified as unpaved are identified by the red lines. Approximately 40 percent (75 of 188 10,000 foot square tiles) of the northern section (red road network) of the county has been processed using the eCognition ruleset so far.*

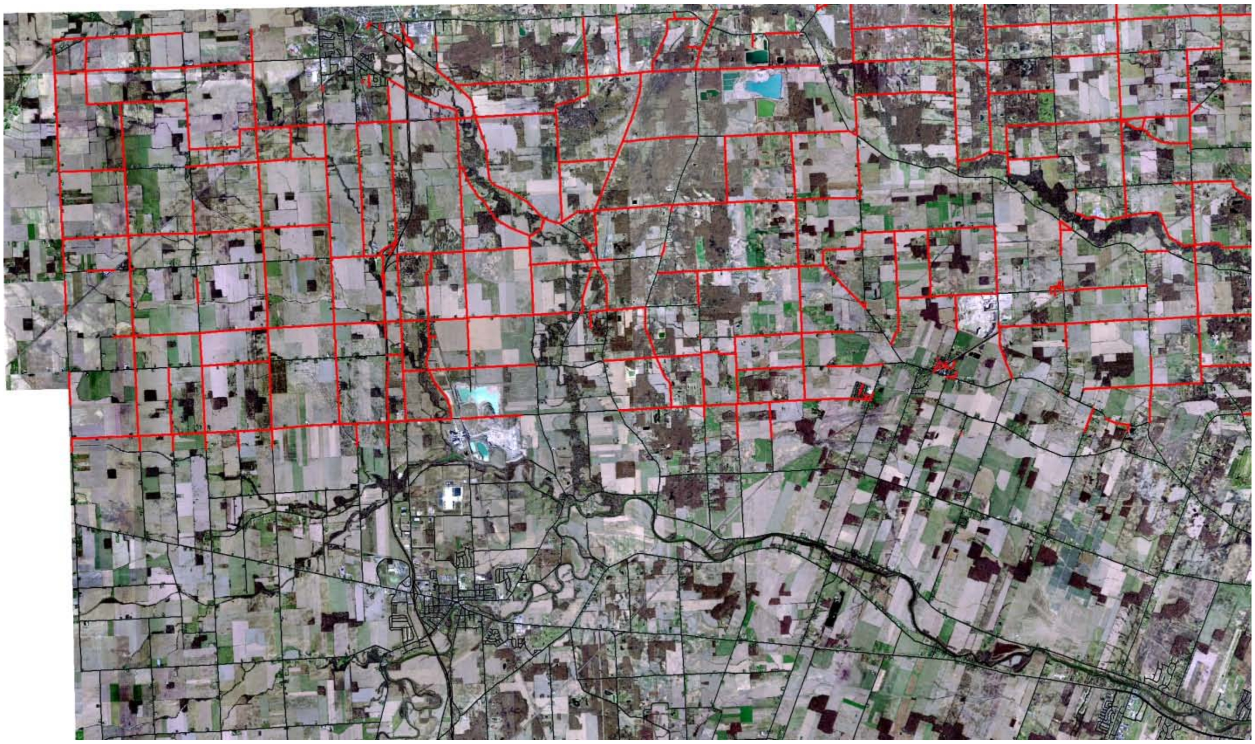


Figure 23: The northwest corner of Monroe County with the Michigan Framework Road Network (black lines) and areas mapped as unpaved (red lines) over SEMCOG orthorectified imagery. *The northern half of this map has been processed through the eCognition algorithm, the red road segments have been classified as unpaved by the algorithm.*

A Receiver Operating Characteristic (ROC) curve was plotted to compare the probability of detection and the probability of a false detection based upon how well the algorithm is classified unpaved roads[25]. The ROC curves help tune the road detection by finding the best segmentation settings as well as aiding in the classification rule sets in eCognition, to improve the accuracy of threshold values for pulling out the full extent of the unpaved roads.

A preliminary receiver operating characteristic (ROC) curve was calculated for a subset of Northern Oakland County (Figure 24). This curve plots the probability of detection against the probability of false alarm (ρ_d and ρ_{fa} , respectively) of an unpaved road. These probabilities were based upon a polygon that was hand-digitized for areas known as unpaved road can be seen visually as an unpaved road. This hand-digitized polygon was then compared to the polygon output from eCognition that took only the road area into consideration. It was found through investigating the parameters used to map road type that the infrared (IR) band minus the green band (IR-Green) had the largest effect on whether the road would be classified as unpaved. In our analysis we found that the optimal threshold value for IR-Green should be set at a value of 6.0 to maintain a high probability of detection while keeping the probability of false detection as low as possible; this can be seen in Figure 24 below. Also seen in Figure x is that the probability of false detection is quite high. This is an artifact of the selection of the ground truth (what is "really" road). Due to a very aggressive approach in selecting only "perfect" road pixels, the algorithm is,

[25] Hand, D and R. Till. (2001). *A Simple Generalisation of the Area Under the ROC Curve for Multiple Class Classification Problems*. Volume 45, Number 2 (2001), 171-186. DOI: 10.1023/A:1010920819831

in fact, finding them, but we are counting them as false positives. In future work, we will take this into consideration, choosing a road polygon that is less precise; this should improve false alarm rejection. This type of analysis gives us a tool to test our classification algorithm's performance with various input parameters and see which of these parameters performs the best.

$$\rho_{\mathrm{d}} = \frac{TP}{TP + FN}$$

$$\rho_{fa} = \frac{FP}{FP + TN}$$

TP = Road pixel detected as road
FN = Road pixel detected as not road
FP = Not road pixel detected as road
TN = Not road pixel detected as not road

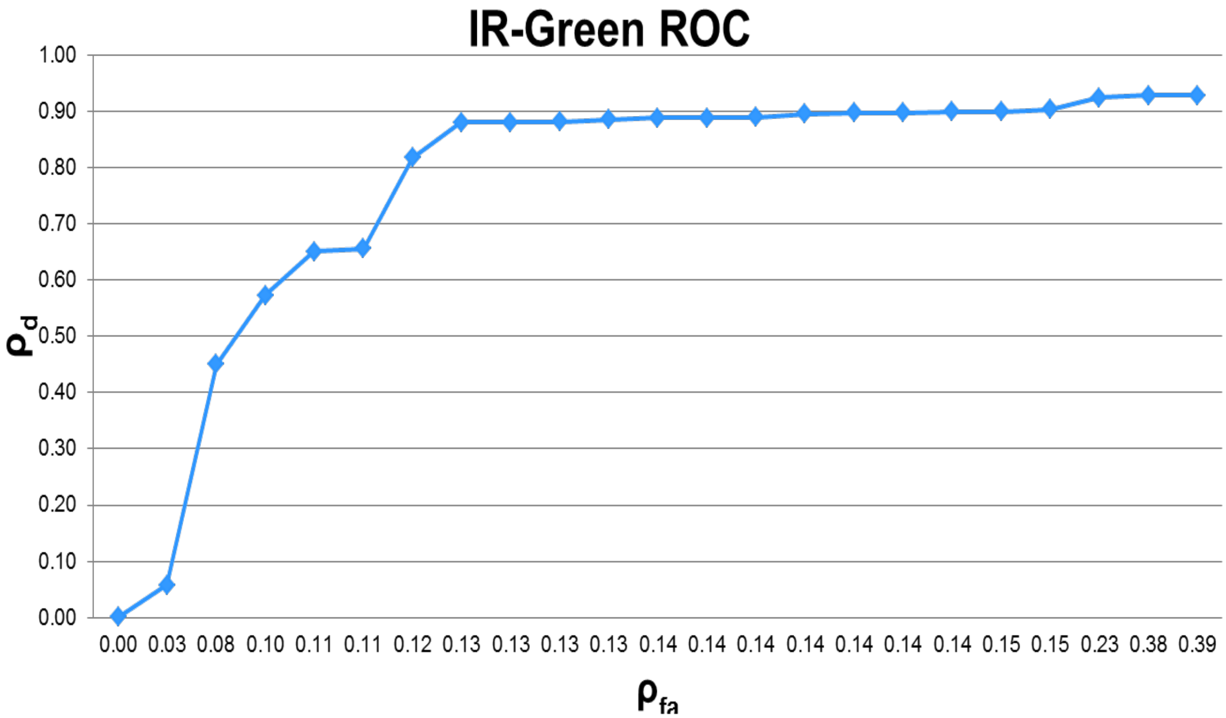


Figure 24: A Receiver Operating Characteristic (ROC) curve that was used to find the optimal threshold for the greatest contribution to the detection of unpaved roads, the IR-Green parameter. *The ROC curve shows the fraction of true positives (ρ_d) out of the total positives plotted against the fraction of false positives out of the negatives (ρ_{fa}). This allows us to find the best value for IR-Green by selecting a value that maximizes the fraction of true positives and minimizes the proportion of false positives.*

About 40% of Monroe County (75 of 188 tiles) has been processed through eCognition and ArcGIS using the same methodology and values as were used in Oakland County. Monroe County classification results appear to be similar to Oakland County although quantitative results are still being processed.

Figure 25 below is a sample of the eCognition output after the segmentation and classification process. The inputs to the process are the SEMCOG 30 cm 4 band (R, G, B, IR) aerial orthophotos, Principal Components 1-3, and a shapefile that defines a 30 foot buffer around the Michigan Framework Road network. The eCognition ruleset evaluates only the area within the buffer which reduces the amount of image processing and improves the results by excluding areas we are not interested in. The red polygons within the buffer are classified as unpaved, darker green polygons are vegetation, lighter green polygons are bare earth, gray represents paved roads and cyan polygons are classified as shadows (figure 25 below; figure 26 shows the same area but with the eCognition segmentation polygon borders drawn).

Figure 25: eCognition segmentation and classification results over Monroe County SEMCOG orthoimagery.

Figure 26: Segmentation and classification output from eCognition with segments outlined to highlight the potential complexity of the segmentation/classification output. *The eCognition ruleset exports the segments classified as unpaved (red polygons) as ESRI shapefiles, which are used to help determine whether a road segment is unpaved.*

The polygons classified as unpaved are exported from eCognition as shapefiles and imported into ArcGIS. The Michigan Framework Roads network is overlaid on the polygons then the ArcMap Intersect tool is run. The result is a shapefile that contains road segments that the eCognition segmentation and classification process found to be unpaved. The length of the road segments classified as unpaved is compared to the overall road segment length, if the percentage of the road segment that is classified as unpaved exceeds a best estimated value, in this case 21 percent, the entire segment is considered to be unpaved. Figure 27 shows the results displayed in Figures 25 and 26 but with the Michigan Framework Roads centerline layer (version 11) displayed as blue lines.

Figure 27: A segment of a classified road network processed in displayed in ArcMap with the Michigan Framework roads layer displayed as blue lines. *The red polygons (unpaved roads) are eCognition output; the Michigan Framework Roads Network was intersected with the polygons which resulted in roads that are considered unpaved (blue lines). The north-south road at right is classified as paved (and in fact is a paved road), the rest of the roads in the image are unpaved and are classified as such.*

Image processing results were used to select candidate unpaved road segments for the first flight of the MTRI UAV over distressed roads. This classification methodology works best when the road network centerlines have been correctly drawn and actually run down the centerline of the road in the imagery that is used to classify the road segments. Road segments that are not in the center of the road in the aerial imagery can easily be misclassified as they make contact with polygons that are not roads. Fields and road shoulders often are spectrally similar to unpaved roads and can be classified as unpaved. The classification of non-road pixels as road is generally not problematic if road centerlines are correctly aligned with roads in imagery or the road is unpaved. However, when road centerlines do not correctly align with roads in imagery, misclassification can (and often will) occur. We have found this to be a common cause of misclassification of road segments. The problem can be minimized by using the best available centerline file. E-911 (enhanced 911 – used for routing emergency responders such as police, EMS and fire crews) road centerline files offer the good quality centerline data and should be used if available to minimize off-center errors. Figure 28 shows such an example where off-center roads have led to some classification errors that can be corrected with better road centerline data.

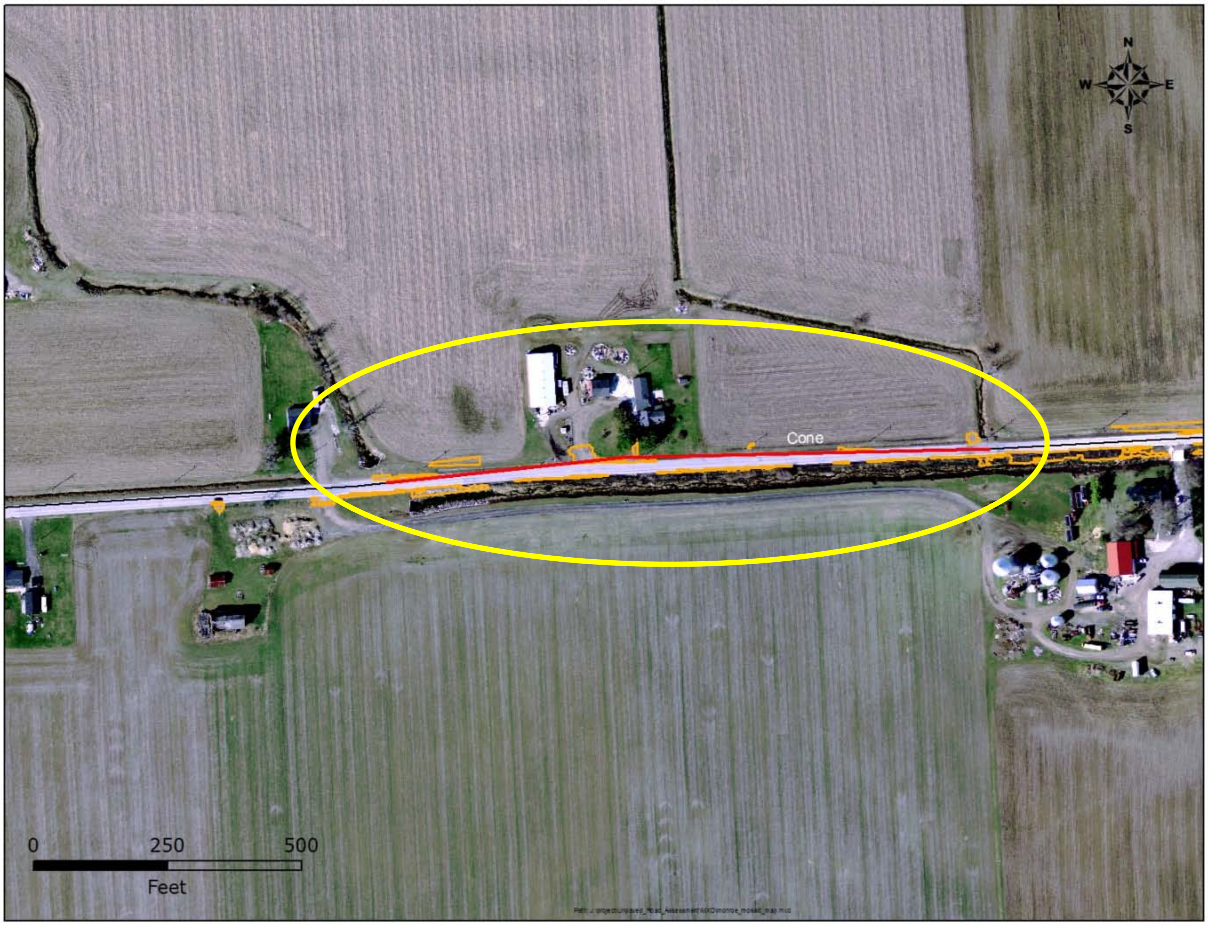


Fig 28: An example of poor road centerline alignment causing misclassification that could be fixed with better roads data. *In this case, a segment of the road centerline wanders off center and intersects polygons that represent the 'Unpaved' class even though the road is paved. Enough of the centerline intersected the polygons to meet the criteria for the entire line to be incorrectly classified as unpaved.*

Another cause of misclassification of roads is the spectral similarity of roads both paved and unpaved to adjacent non road features. Unpaved roads comprised of natural aggregate appear spectrally very similar to bare earth resulting in road segments improperly classified as bare earth. A similar phenomenon occurs when unpaved roads made of crushed limestone are classified as paved road as a result of similar spectral response. This phenomenon is being evaluated and adjustments to the eCognition classification/segmentation algorithms will be made as warranted.

Concluding Comments

Currently (as of 10/31/2012), ongoing work includes completing processing of Monroe County imagery to obtain road type through the eCognition and ArcGIS processing methods along with a formal accuracy assessment. Field data flights with the Bergen Tazer 800 UAV helicopter have been completed in October 2012 and are likely to continue with good field conditions to demonstrate and test UAV utility. Plans are under development to deploy the imaging sensor in a manned fixed wing aircraft as well.

Imagery taken during these flights is being processed into usable unpaved road condition indicators and will be integrated into RoadSoft DSS demonstrations of unpaved road management.

Appendix A: Deduct Value Curves

Deduct value curves for inadequate roadside drainage are shown below in ***Figure F-1***. Curve formulas generated from the deduct value curves used in the DSS are shown in ***Table F-1***. Low, medium, and high curves for inadequate roadside drainage are shown in ***Figure F-2***, ***Figure F-3***, and ***Figure F-4***.

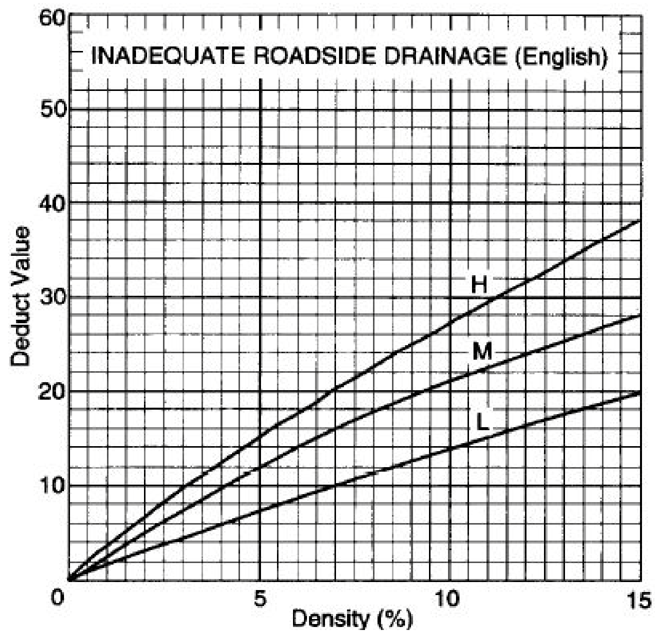


Figure F-1: Deduct value curves for inadequate roadside drainage[26].

[26] Department of the Army. (1995). *Unsurfaced Road Maintenance Management Technical Manual No. 5-626.* Washington DC: United States Department of The Army.

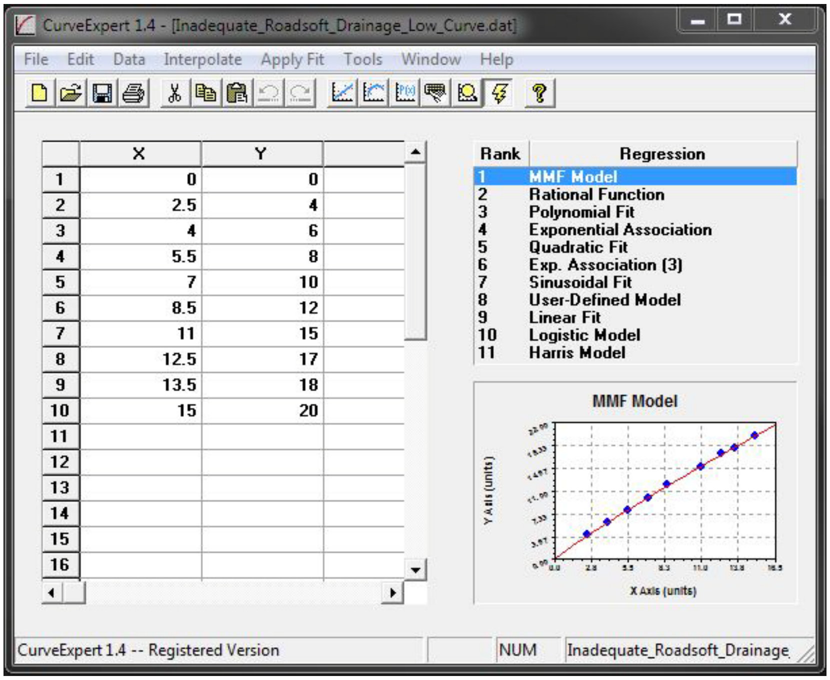


Figure F-2: *Inadequate roadside drainage, low severity curve.*

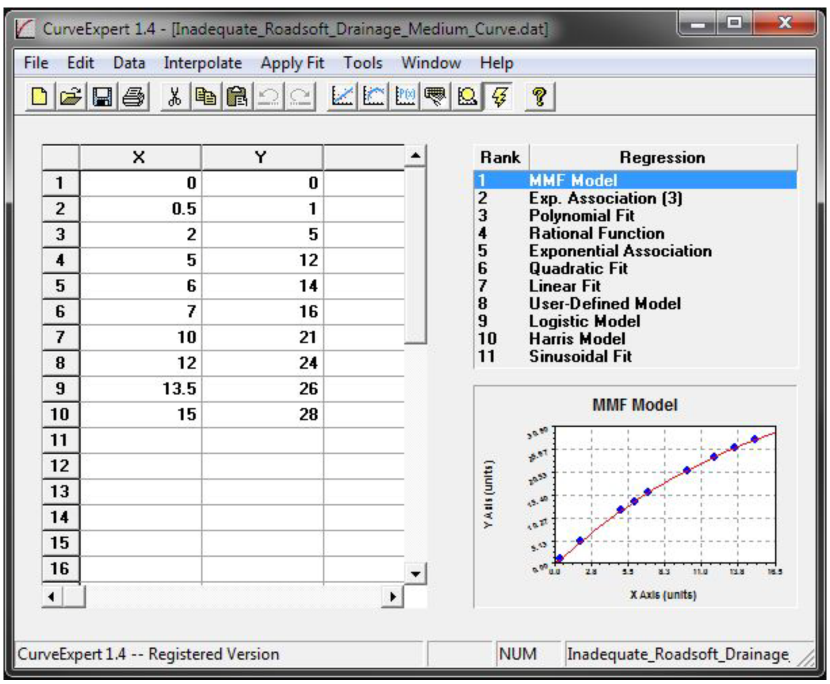


Figure F-3: Inadequate roadside drainage, medium severity curve.

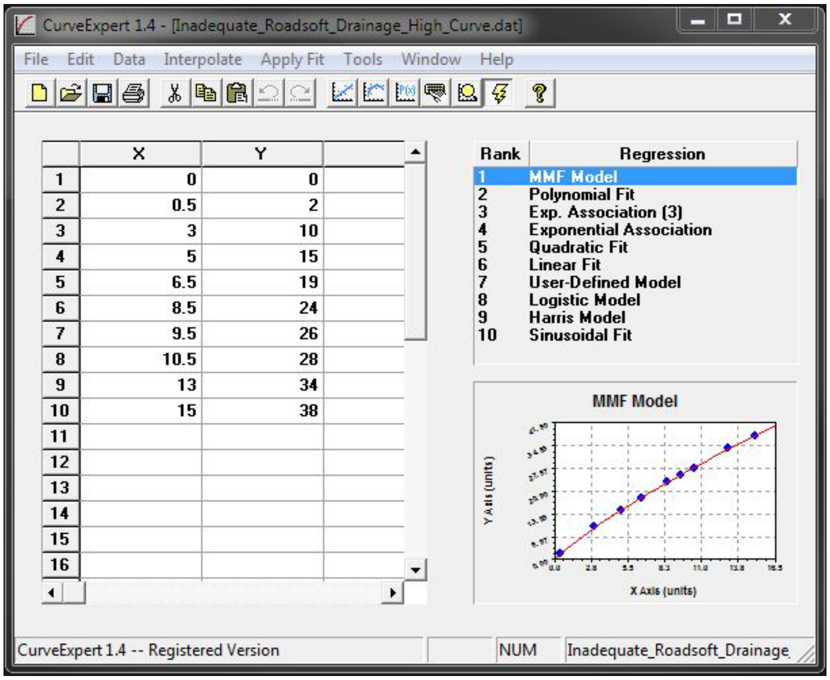


Figure F-4: Inadequate roadside drainage, high severity curve.

Table F-1: Curve formulas for inadequate roadside drainage.

Severity	Algorithm
Low	Deduct Value = (0.010769564038 * 23151673.5868 + 39717193.3208 * density^0.90564729865) / (23151673.5868 + density^0.90564729865)
Medium	Deduct Value = (-0.0875497215303 * 26.3284371647 + 68.578360111 * density^1.06966141769) / (26.3284371647 + density^1.06966141769)
High	Deduct Value = (-0.0180371576449 * 158.667828534 + 609.321296367 * density^0.870481679574) / (158.667828534 + density^0.870481679574)

Deduct value curves for corrugations are shown ***Figure F-5*** below. Curve formulas generated from the deduct value curves used in the DSS are shown in ***Table F-2***. Low, medium, and high curves for corrugations are shown in ***Figure F-6***, ***Figure F-7***, and ***Figure F-8***.

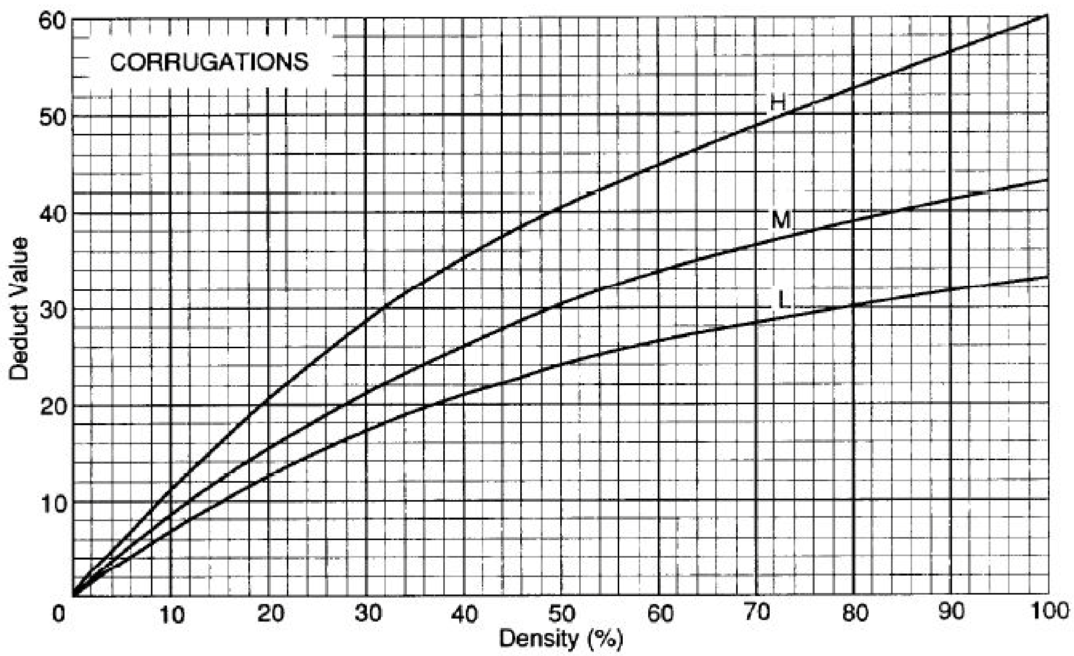


Figure C-3. Distress 83-corrugations deduct values (English or metric units)

Figure F-5: Deduct value curves for corrugations[27].

[27] Department of the Army. (1995). *Unsurfaced Road Maintenance Management Technical Manual No. 5-626.* Washington DC: United States Department of The Army.

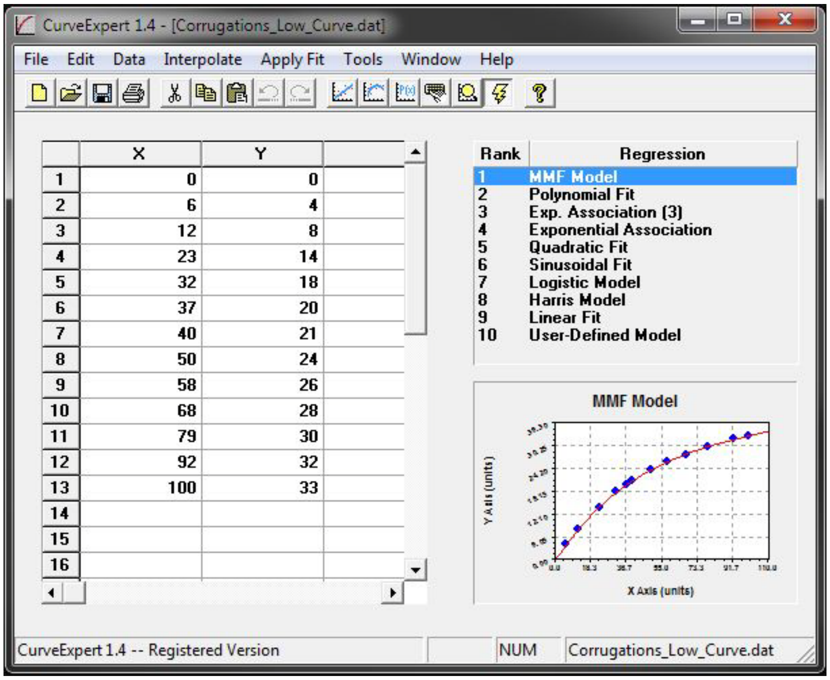


***Figure F-6**: Corrugations, low severity curve.*

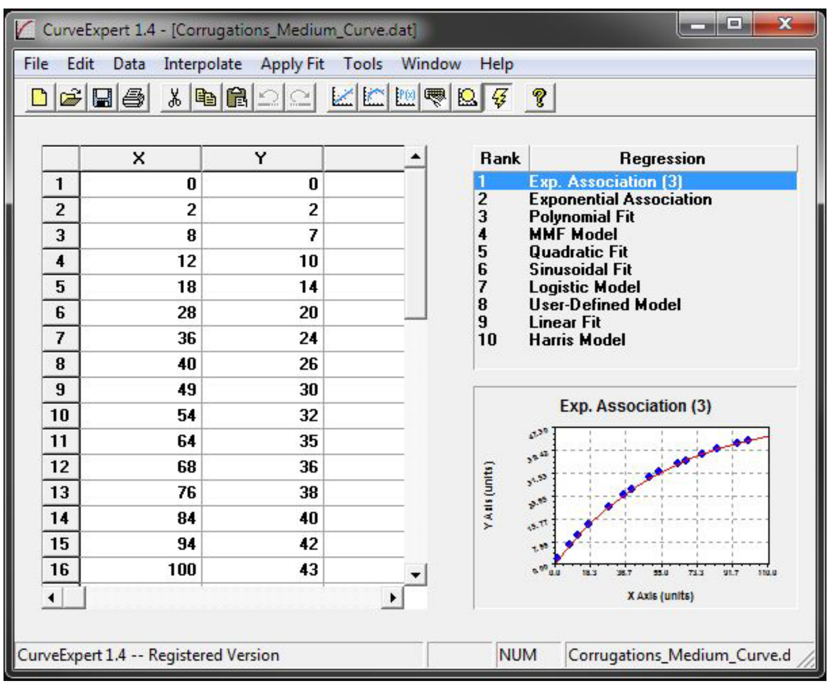


***Figure F-7**: Corrugations, medium severity curve.*

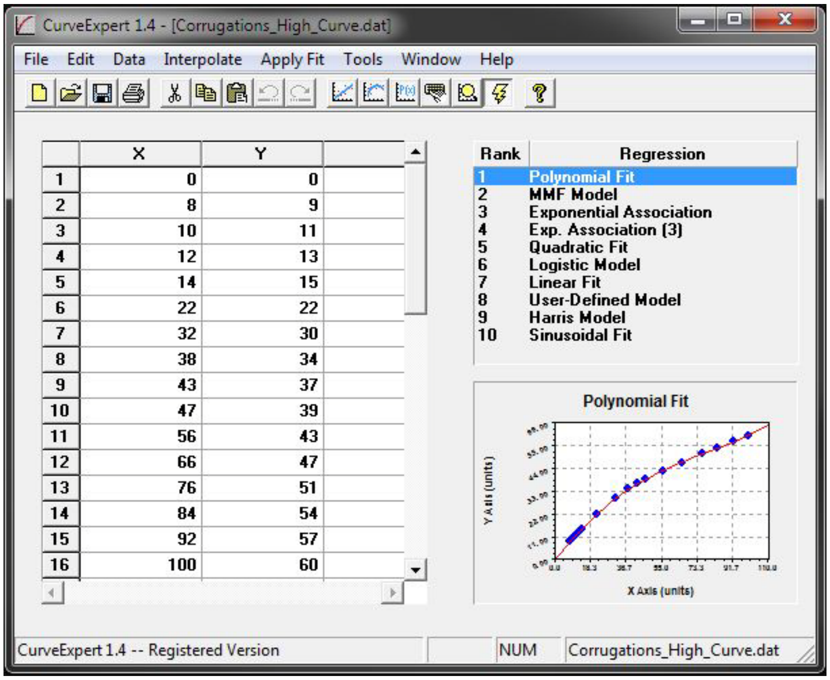


Figure F-8*: *Corrugations, high severity curve.

Table F-2: Curve formulas for corrugations.

Severity	**Algorithm**
Low	Deduct Value = (-0.00379839591404 * 82.818228481 + 48.3105152512 * density^1.12504439308) / (82.818228481 + density^1.12504439308)
Medium	Deduct Value = 52.1682629313 * (1.00321941571 - Exp(-0.017172240501 * density))
High	Deduct Value = -0.273624745718 + 1.24345950507 * density + -0.0108403199493 * density^2 + 0.0000443361980078 * density^3

Deduct values for dust are shown ***Figure F-9:*** below. Since curves for dust were not provided, the deduct values used in the DSS were the same as provided as shown in ***Table F-3***.

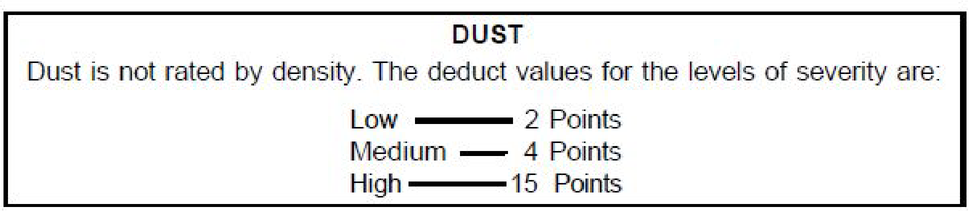


Figure F-9 Deduct values for dust[28].

[28] Department of the Army. (1995). *Unsurfaced Road Maintenance Management Technical Manual No. 5-626.* Washington DC: United States Department of The Army.

Table F-3: Deduct values for dust.

Severity	Algorithm
Low	Deduct Value = 2
Medium	Deduct Value = 4
High	Deduct Value = 15

Deduct value curves for potholes are shown ***Figure F-10*** below. Curve formulas generated from the deduct value curves used in the DSS are shown in ***Table F-4***. Low, medium, and high curves for potholes are shown in ***Figure F-11***, ***Figure F-12***, and ***Figure F-13***.

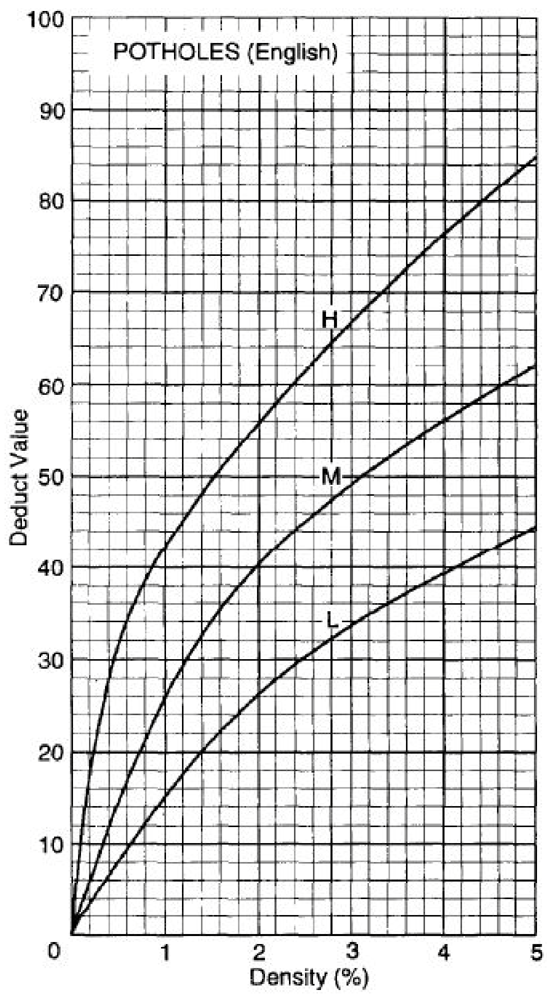


Figure F-10: Deduct value curves for potholes[29].

[29] Department of the Army. (1995). *Unsurfaced Road Maintenance Management Technical Manual No. 5-626.* Washington DC: United States Department of The Army.

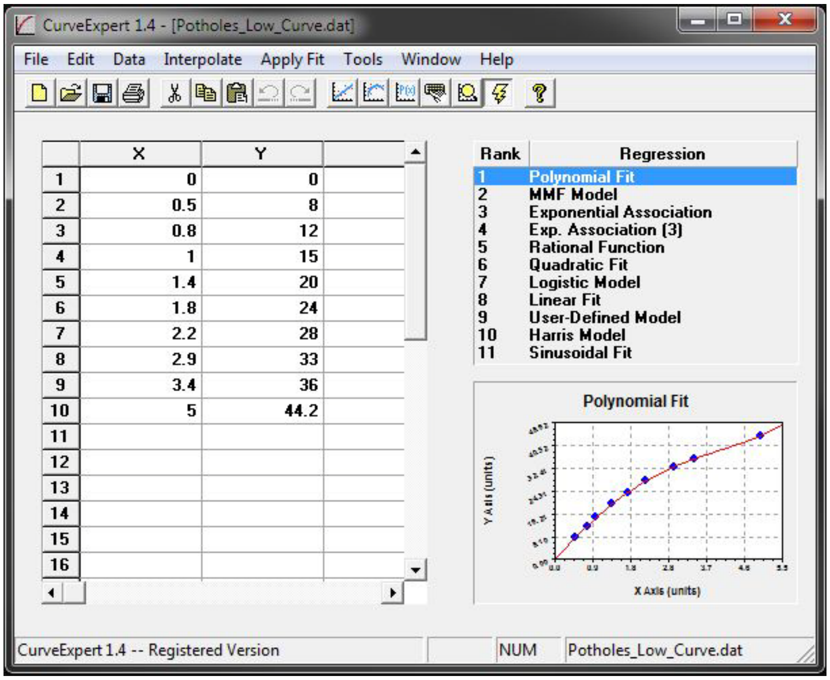


Figure F-11*: *Potholes, low severity curve.

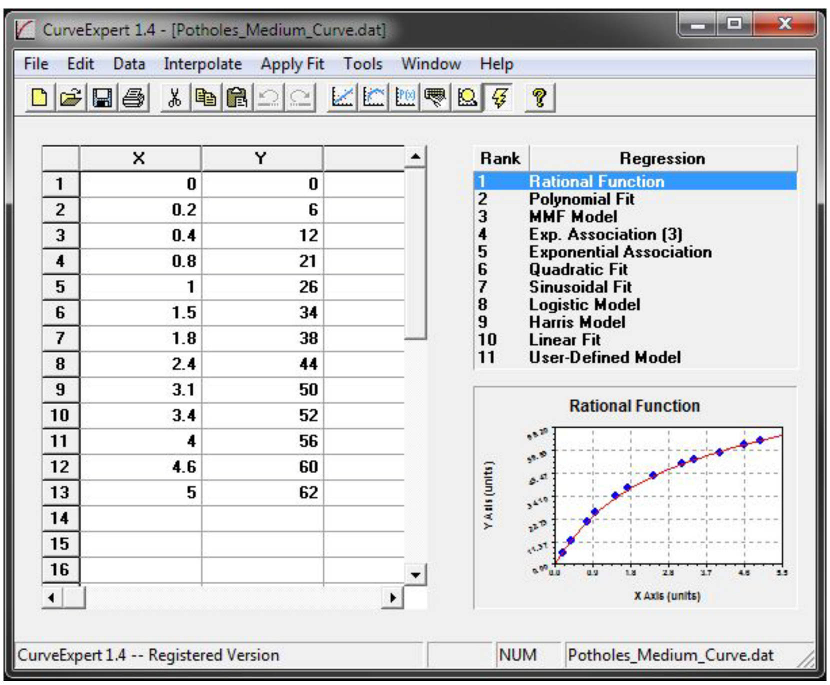


Figure F-12*: *Potholes, medium severity curve.

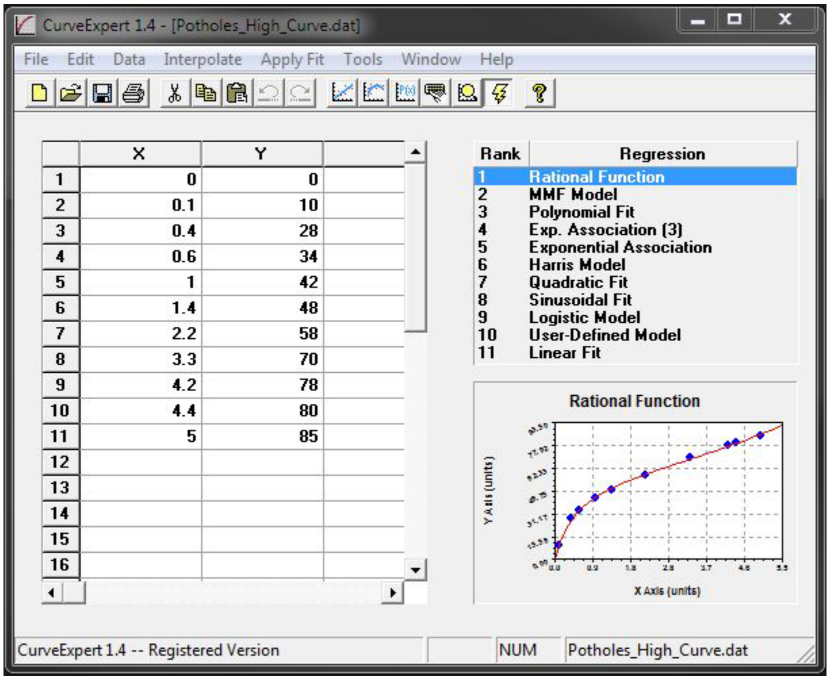


***Figure F-13*: Potholes, high severity curve.**

Table F-4: Curve formulas for potholes.

Severity	Algorithm
Low	Deduct Value = -0.145203405025 + 17.6452174132 * density + -2.66757581779 * density^2 + 0.182186773967 * density^3
Medium	Deduct Value = (-0.421500600708 + 36.8259996065 * density) / (1 + 0.433331765546 * density + -0.00782769159002 * density^2)
High	Deduct Value = (0.262257127407 + 114.154975711 * density) / (1 + 1.80453994682 * density + -0.13539521394 * density^2)

Deduct value curves for ruts are shown below ***Figure F- 14***. Curve formulas generated from the deduct value curves used in the DSS are shown in ***Table F-5***. Low, medium, and high curves for ruts are shown in ***Figure F-15***, ***Figure F-16***, and ***Figure F-17***.

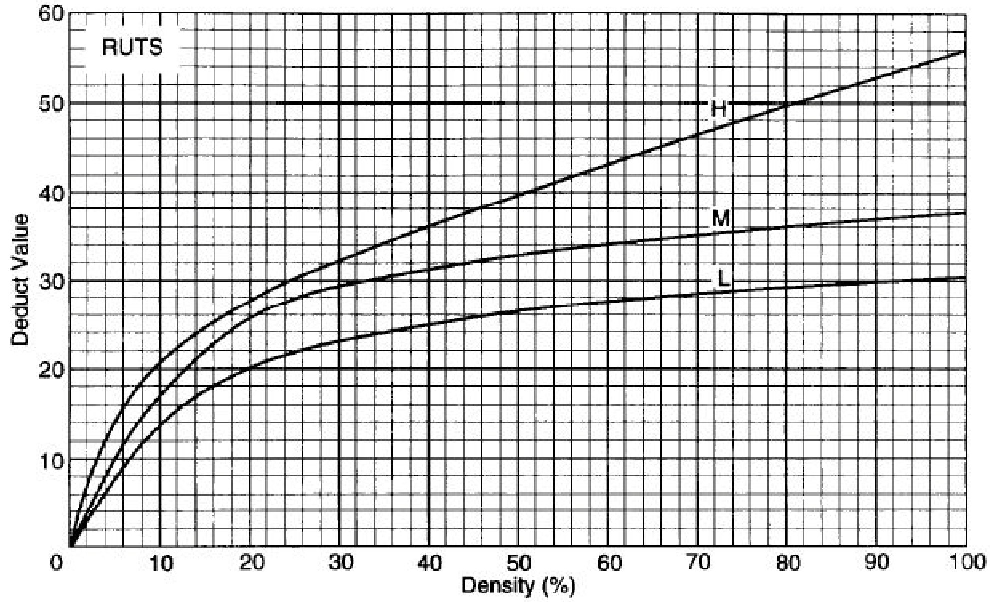


Figure F- 14: Deduct value curves for ruts[30].

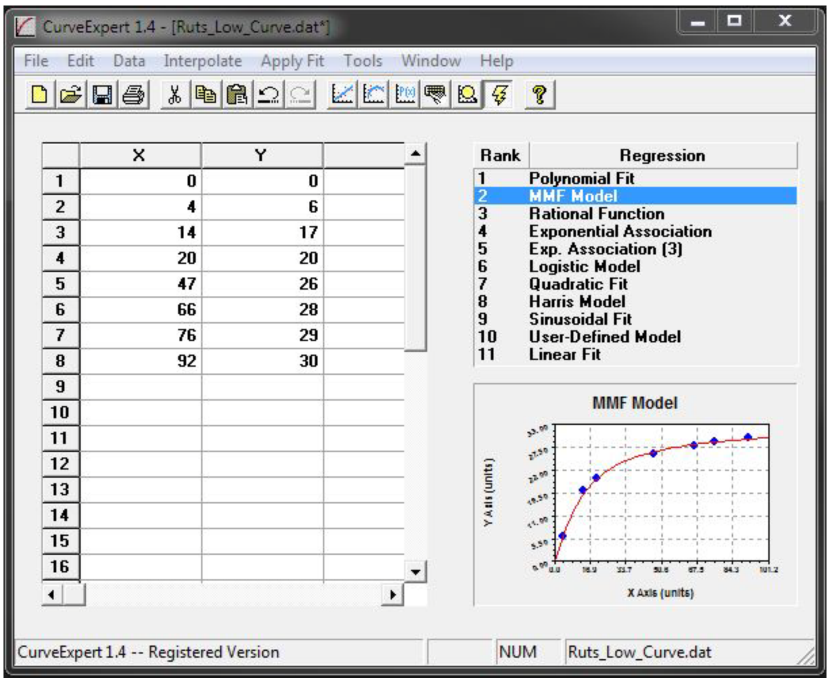
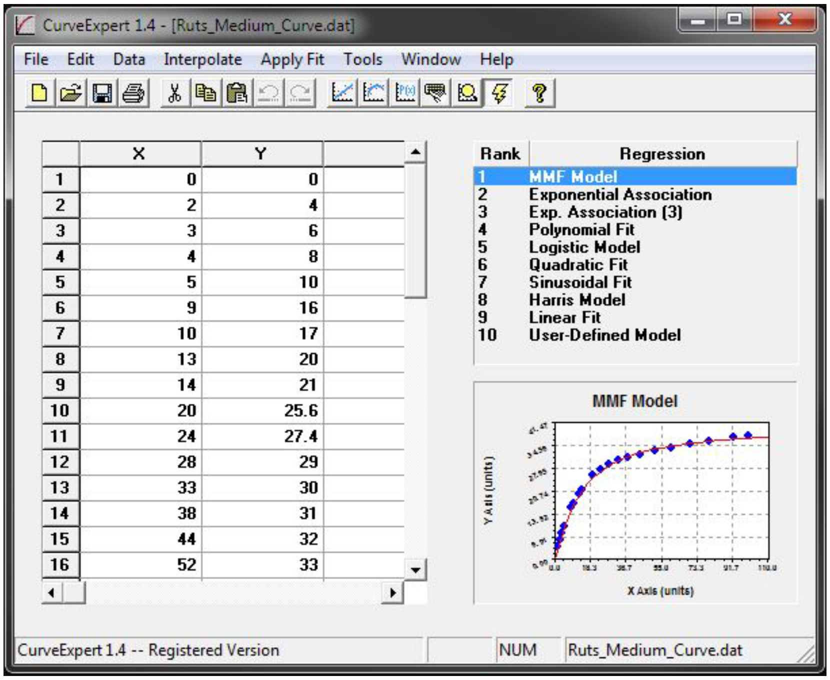


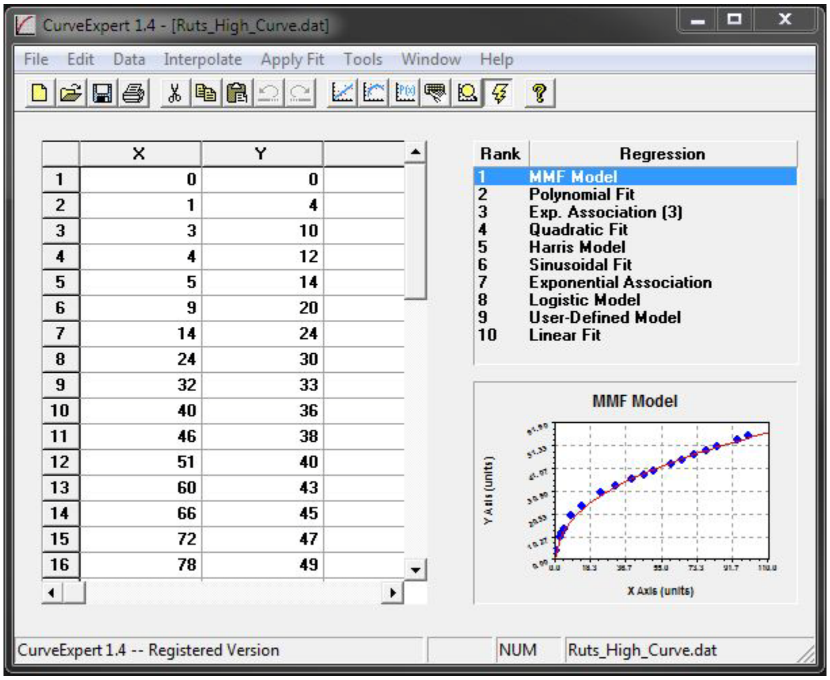
Figure F-15*: *Ruts, low severity curve.

[30] Department of the Army. (1995). *Unsurfaced Road Maintenance Management Technical Manual No. 5-626.* Washington DC: United States Department of The Army.



	X	Y
1	0	0
2	2	4
3	3	6
4	4	8
5	5	10
6	9	16
7	10	17
8	13	20
9	14	21
10	20	25.6
11	24	27.4
12	28	29
13	33	30
14	38	31
15	44	32
16	52	33

Figure F-16: ***Ruts, medium severity curve.***



	X	Y
1	0	0
2	1	4
3	3	10
4	4	12
5	5	14
6	9	20
7	14	24
8	24	30
9	32	33
10	40	36
11	46	38
12	51	40
13	60	43
14	66	45
15	72	47
16	78	49

Figure F-17: ***Ruts, high severity curve.***

Table F-6: Curve formulas for ruts.

Severity	Algorithm
Low	Deduct Value = ((-0.180079645328 * 17.1341777707) + (34.233052738 * density^1.04992408893)) / (17.1341777707 + density^1.04992408893)
Medium	Deduct Value = ((-0.0886072180049 * 19.4773810794) + (40.4131963046 * density^1.15633948131)) / (19.4773810794 + density^1.15633948131)
High	Deduct Value = ((-0.785806790035 * 86.5215401586) + (600.859004333 * density^0.472634159393)) / (86.5215401586 + density^0.472634159393)

Deduct value curves for loose aggregates are shown below ***Figure F-18***. Curve formulas generated from the deduct value curves used in the DSS are shown in ***Table F-6***. Low, medium, and high curves for loose aggregate are shown in ***Figure F-19***, ***Figure F-20***, and ***Figure F-21***.

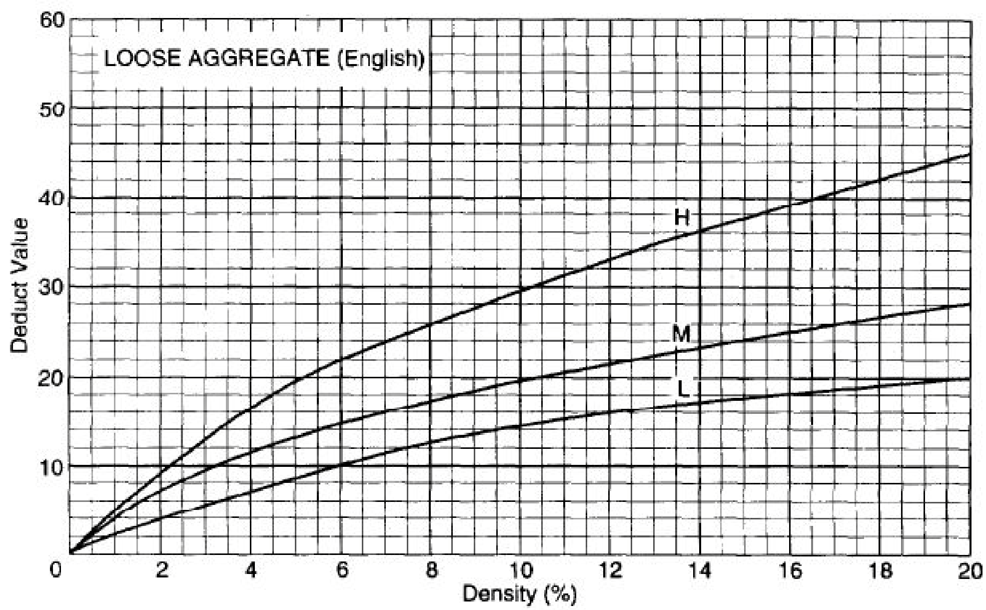


Figure F-18: Deduct value curves for loose aggregates[31].

[31] Department of the Army. (1995). *Unsurfaced Road Maintenance Management Technical Manual No. 5-626.* Washington DC: United States Department of The Army.

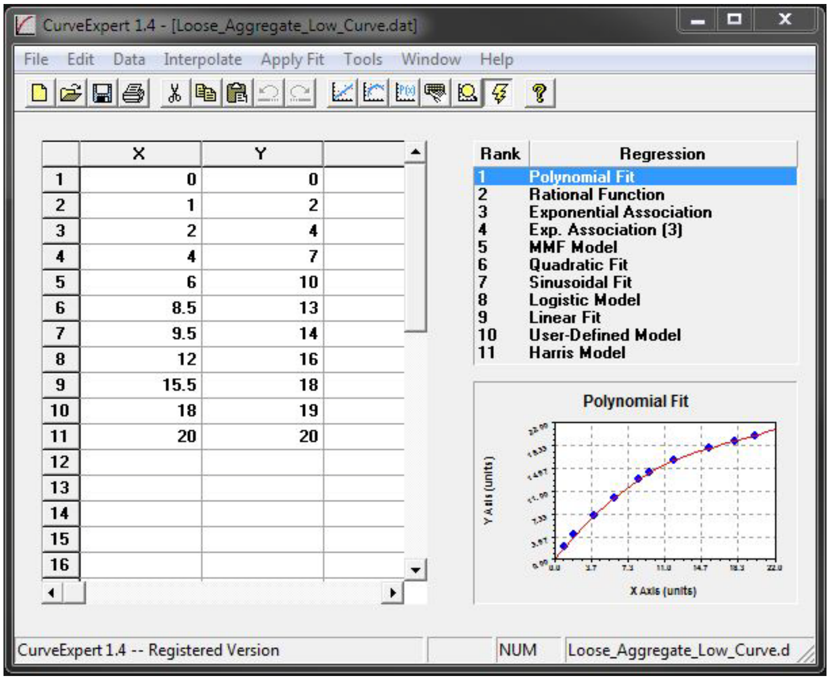


Figure F-19: *Loose aggregates, low severity curve.*

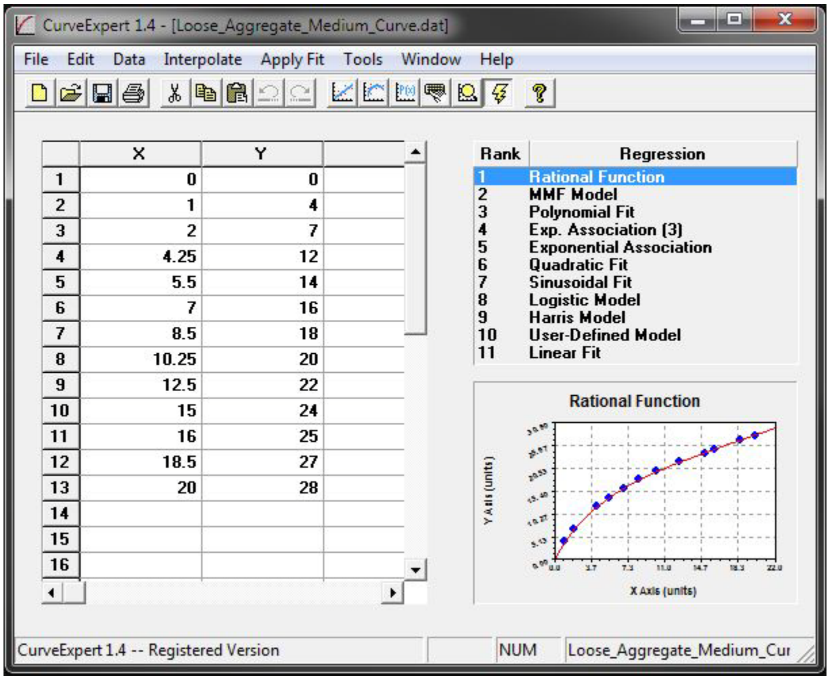


Figure F-20: *Loose aggregates, medium severity curve.*

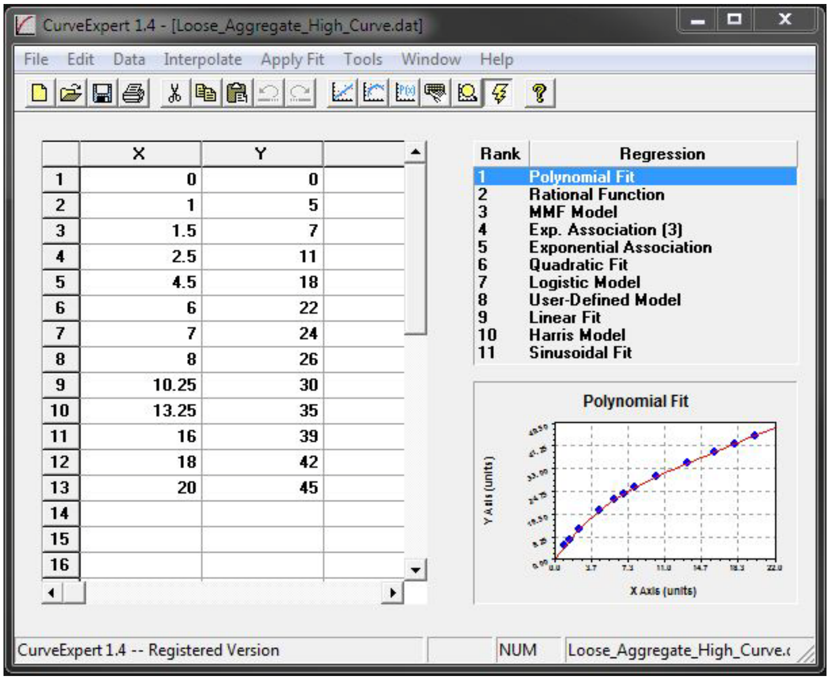


Figure F-21*: *Loose aggregate, high severity curve.

Table F-7: Curve formulas for loose aggregate.

Severity	**Algorithm**
Low	Deduct Value = -0.0221815218694 + 2.1071933272 * density + -0.0784469215412 * density^2 + 0.0011431910305 * density^3
Medium	Deduct Value = (0.044404207459 + 4.46393014104 * density) / (1 + 0.146860977646 * density + -0.00188919709574 * density^2)
High	Deduct Value = (-0.241473638904 + 5.83687100267 * density) / (1 + 0.11080476604 * density + -0.00154420883851 * density^2)

Curves for q values one through seven are shown in ***Figure F-22*** through ***Figure F-28***.

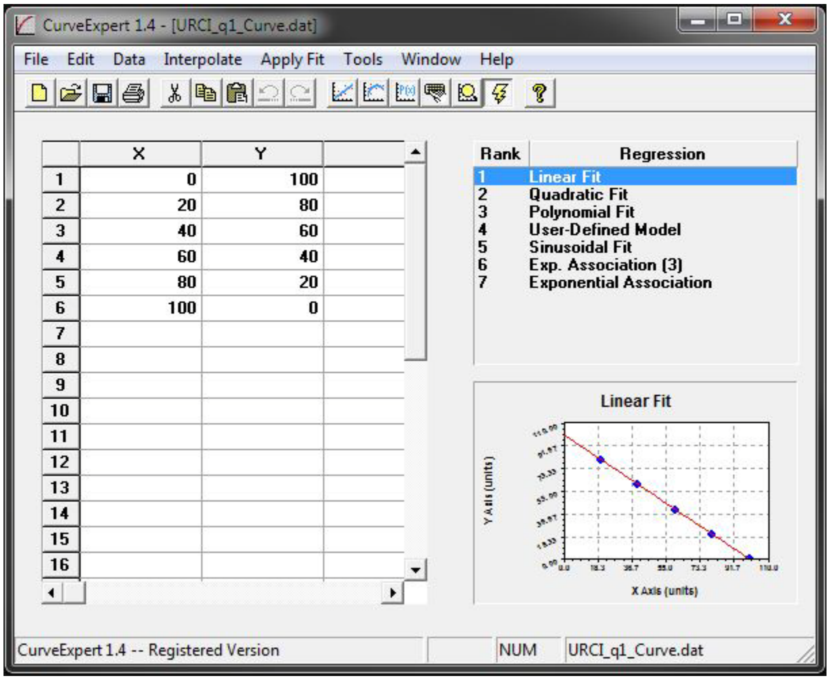


Figure F-22: *Q1 curve.*

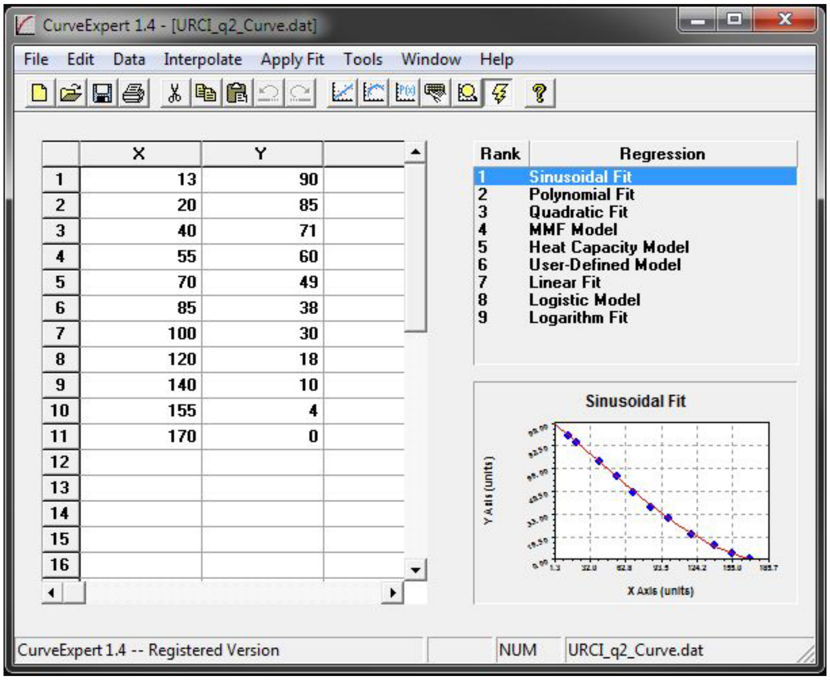


Figure F-23: *Q2 curve.*

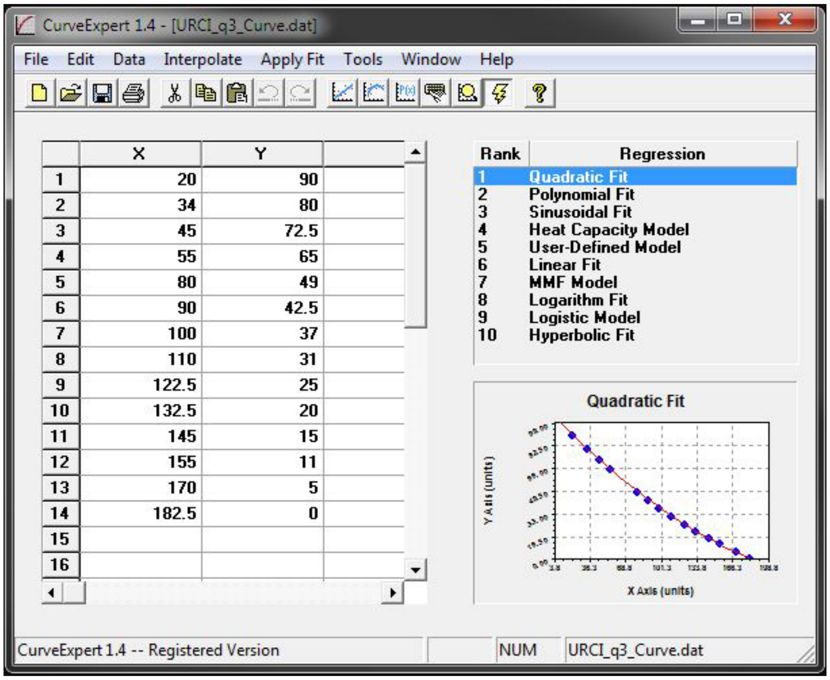


Figure F-24: *Q3 curve.*

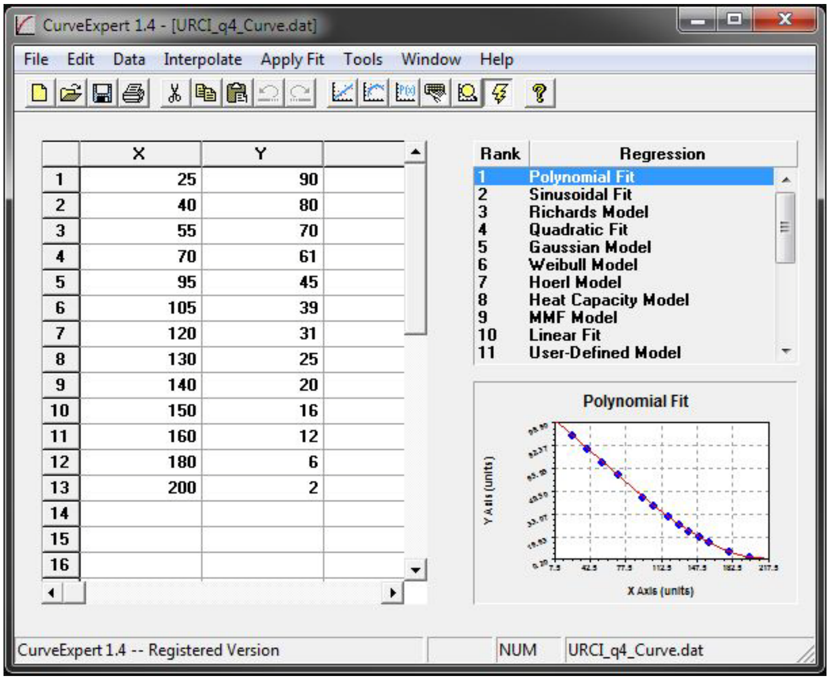


Figure F-25: *Q4 curve.*

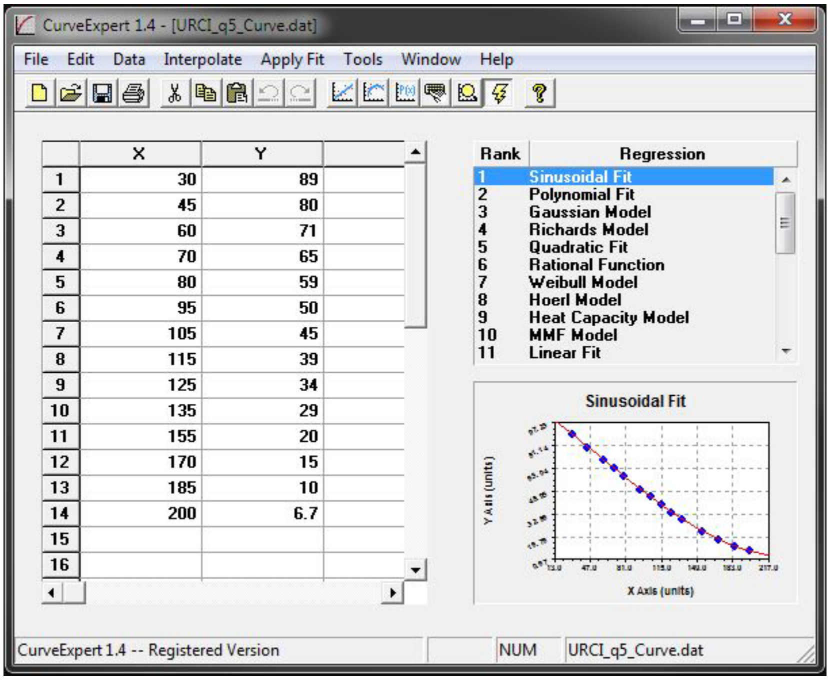


Figure F-26: *Q5 curve.*

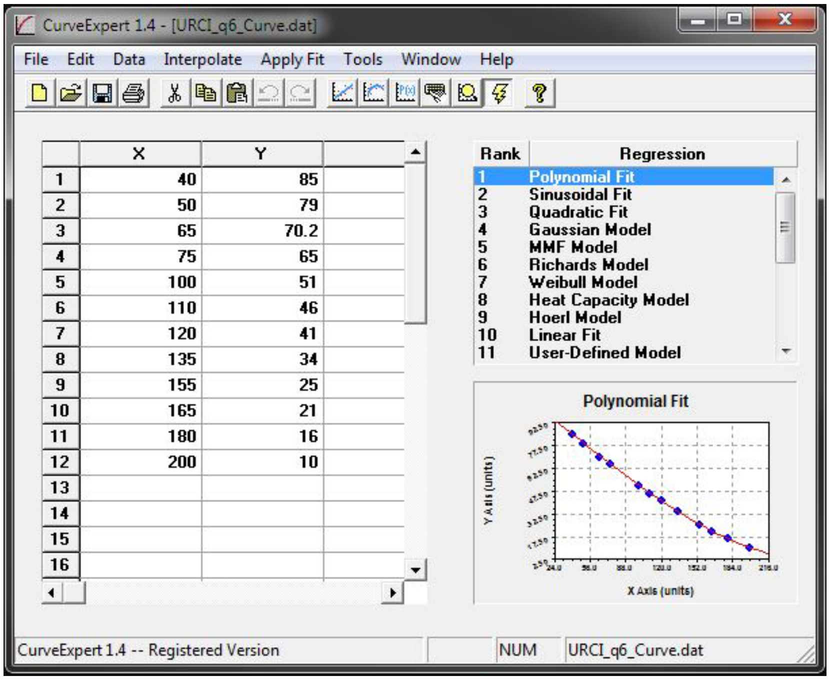


Figure F-27: *Q6 curve.*

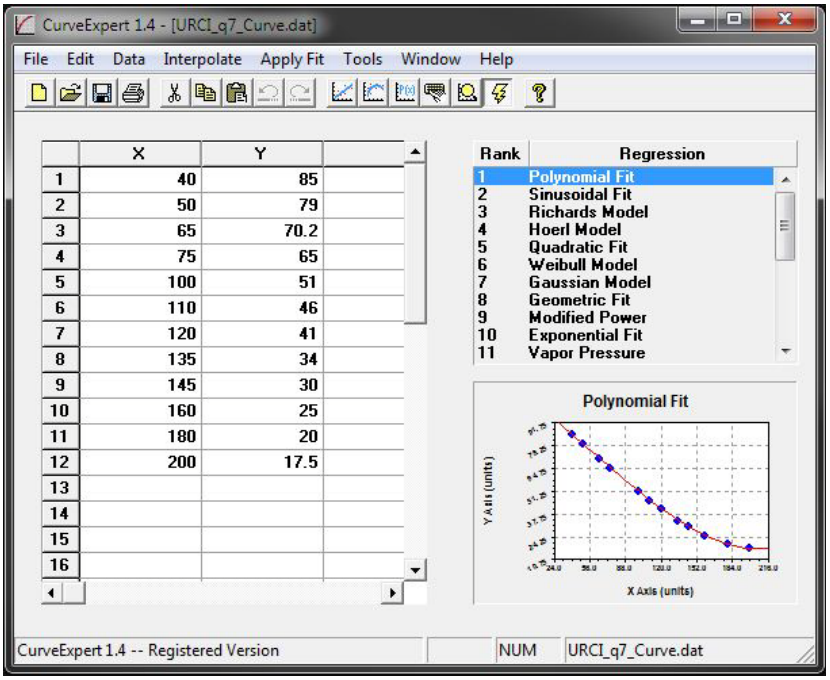


Figure F-28*: *Q7 curve.

Michigan Technological University

Characterization of Unpaved Road Condition Through the Use of Remote Sensing

Deliverable 7-A: *Plans for Field Deployment of Recommended System for Remote Sensing of Unpaved Road Conditions*

Submitted version of:
May 30, 2013

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http://www.mtri.org/unpaved/

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Prepared By:
Michigan Tech Research Institute
Michigan Tech Center for Technology & Training
Michigan Technological University

Deliverable 7-A: Plans for Field Deployment of Recommended System for Remote Sensing of Unpaved Road Conditions

Purpose of this Document

This document describes the plans for field deployment of the unpaved roads data collection platforms and sensor initially described in Deliverables 4-A (the Sensor Selection report) and 5-A (Recommended Remote Sensing Platforms report). Also included will be a new hexacopter platform that has become available since 5-A to provide a wider view of remote sensing platform capabilities. These deployments will provide the larger data set necessary for the next deliverable report, 7-B, "Performance Evaluation of Recommended System for Remote Sensing of Unpaved Road Conditions." Additional data, beyond the initial exploratory data collections from Fall 2012 will also provide an opportunity to further refine the distress detection algorithms and provide more data to demonstrate within the RoadSoft GIS Decision Support System. Procedures are described that help ensure that the necessary ground truth measurements are taken and that the requirements (Deliverable 1-A) are met to sufficiently assess unpaved road condition in a rapid and cost-effective manner. All Deliverables, 1-A through 6-C, have been posted to the project web page at http://www.mtri.org/unpaved/ (see under the "Tasks and Deliverables" sub-page) and directly at http://geodjango.mtri.org/unpaved/tasks/ (scroll to the bottom of the page, under "Deliverables").

Motivation

Data useful for evaluation of the condition of unpaved roads can be collected using aerial platforms and on the ground. Other documents submitted for this project have outlined the sensors and airframes that will be used to collect aerial imagery for processing with the purpose of extraction of unpaved road condition. This document discusses a systematic collection of aerial data using both manned and unmanned aerial platforms as well as the protocols used to collect the ground reference data necessary to verify the results of image processing work and prepare a formal performance evaluation.

Data Collection Campaign

The primary goal of the summer 2013 field deployment's data collection efforts is to obtain a larger set of example images from our airborne platforms of unpaved road surfaces, ranging from newly graded, to surfaces containing large numbers of ruts, corrugations, and potholes. These images will go through our analysis process (described in Part 2 of Deliverable 6-C), and the road segments will be scored automatically using the Unsurfaced Road Condition Index (URCI) rating system as selected in Deliverable 2-A with modifications to help fully assess unpaved road conditions such as improper cross section and drainage. In addition, these same segments will be carefully measured on the ground, manually, and rated. These results will be compared to our automated outputs for accuracy and performance.

Flight Systems

We will collect data using two UASs, the single rotary-wing platform first described in Deliverable 5-A and a 6-rotor system ("hexacopter") now available to the project team (see Figure 1), as well as a manned fixed-wing aircraft (a Cessna 152) with a camera mounted in a modified flight-approved door. Several of the sites will be collected with both a manned and unmanned system, to compare the performance of the systems, which will be documented in the Performance Evaluation report.

Figure 1: A Bergen hexacopter recently acquired by the project team as part of a demonstration of the capabilities of multi-rotor remote control helicopters. *The system is capable of deploying the same Nikon D800 digital camera as sensor as the Bergen Tazer 800 single-rotor platform but is significantly simpler and easier to fly.*

Road Segment Selection Criteria

We will identify a number of road segments with the following characteristics.

- These will be between 100 feet (30.5 m) and 600 feet (182.9 m) long (100 feet is the recommended segment length for assessment of representative segments for the Department of the Army's URCI).
- The set of road segments chosen will span all the distresses that we need to measure, as well as several segments without damage, for comparison. As described in Deliverable 2-

A, these distresses are improper cross section, drainage, corrugations / washboarding, potholes, ruts, and loose aggregate.

- The roads should be generally unobstructed from overhead, and have a minimum number of obstacles present (e.g. powerlines, stop-lights, etc.).
- At least two of the segments will be measured by both a UAS and manned aircraft, and those segments must be clear of overhanging trees.
- The segments shall be capable of being blocked-off during the duration of the collection.
- Each candidate road segment must be surveyed manually, and all distresses located and characterized.
- The road segments will be in relatively rural sparsely-populated or uninhabitated areas not close to airports (>3 miles / 4.8 km away).

Road Marking and Measurement

Once roads with distresses of interest to the team have been identified, a ground truth data collection team will travel to the selected road a day or so before the scheduled data collection to identify distresses and score the road using the methodology described in Deliverable 1-A. These identifications need to be completed as soon as possible before remote sensing flights to ensure the unpaved road segments have not changed significantly.

The ground truth team will divide the selected road into 100 foot segments. Members of the team will then identify the distresses present within the segment, measure and log the distresses on a score sheet and mark the road with marking paint to identify the distress and its measured extent. An extended score sheet is being developed to allow the ground team to detail the locations of the distresses along with their severity to allow a better correlation of distress location and severity with the output from the automated process. The pavement markings will allow a comparison between the distress area and severity values generated by the ground truth team and those output by the automated system to identify and understand the cause of any disagreement between the automated scoring process and the manual scoring process. Notes will also be made on unpaved road aggregate type – whether primarily made of crushed limestone, natural aggregate or a mix of both types of aggregate.

More specifically, the ground truth team will complete the following ground truth:

Road width will be measured and recorded at each end of the segment and every ten feet (3.05 meters) down the length of the road segment to a precision of +/- four inches.

Road Cross Section ("crown") will be measured and recorded at each end of the segment and every ten feet (3.05 meters) down the length of the road segment. Crown measurements will be made at the same locations as the road width measurements.

Potholes will be measured and classified by their diameter and depth. Potholes will be classified and placed in measurement bins based on depth and diameter according to the table below (from Deliverable 1-A, p. 8). The classification will be used to determine the severity of pothole distress within the measured road segment.

Table 1. Measurement bins for pothole classification (Department of the Army, 1995):

Max. Depth	**Average Pot Hole Diameter**			
	<1 ft (<0.30 m)	**1-2 ft (0.30 -0.61 m)**	**2-3 ft (0.61 - 0.91 m)**	**>3 ft (> 0.91 m)**
<2” (<5.1 cm)	Number of Occurrences	Number of Occurrences	Number of Occurrences	Number of Occurrences
2”-4” (5.1 cm - 10.2 cm)	Number of Occurrences	Number of Occurrences	Number of Occurrences	Number of Occurrences
>4” (>10.2 cm)	Number of Occurrences	Number of Occurrences	Number of Occurrences	Number of Occurrences

Rutted areas will be classified by the depth of the ruts in the measured area as measured from the bottom of the rut to the adjacent road surface. The rutted surface will be classified into three bins: up to 1 inch (2.5cm) deep, 1 to 3 inches (2.5 – 7.6cm) and greater than three inches deep (>7.6cm).

Corrugations (“washboarding”) area is measured in area where corrugation is determined to be present. Severity of washboarding will be determined by placing the depth values of the corrugations into three bins: up to 1 inch (2.5cm) deep, 1 to 3 inches (2.5 – 7.6cm) and greater than three inches deep (>7.6cm).

Roadside drainage (ditches) measurements will be made at the shoulder of the road and at the bottom of roadside drainage if possible. If water is present in the ditch, a measurement of water level must be made and its presence in the ditch noted. These measurements will be made every ten feet and measurements will be made at the same locations as the road width and crown measurements.

Loose (float) aggregate berms will be identified by their width, length, depth and location on the road. Presence or absence of float aggregate berms will be measured every ten feet and berms less than ten feet long will not be considered significant. Assessment for presence and measurement of float aggregate will be made at the same locations as the roadside drainage, road width and crown measurements.

Temporary road marking paint in different colors will be used to define the type of distress and mark it measured extent to facilitate identification of distresses measured on the ground and in aerial imagery. The ground truth data collection team will test/validate data collection protocols and make necessary adjustments to the procedures in advance of flight operations.

Equipment Needed

The primary equipment list that will be needed for the field deployment is:

Bergen Tazer 800, with:

Nikon D800
50mm prime lens
Camera Controller

Bergen Hexacopter, with:

Nikon D800
50mm prime lens
Camera Controller

Manned Fixed-winged flight by licensed pilot John Sullivan at the Ann Arbor airport, identified with help of Chuck Boyle, President of the Professional Aerial Photographers Association (PAPA):

Nikon D800
200mm zoom lens
Camera Controller

Ground Support Equipment:

Ground station computer and controls
Power inverter, 800W
Handheld radios
Safety gear/traffic cones (to control rural road traffic during actual flight time)
Spare batteries - various sizes

Sensor Package Configuration

The Nikon D800 digital camera sensor with the team's frame rate controller will be used for both the remote controlled helicopter and manned fixed winged aircraft collects. It has been important to our team to demonstrate how the same capable sensor can be used with both manned and unmanned platforms, as described in the project 's approved work statement. For the remote controlled helicopter collects, a 50mm prime lens will be used. This lens has proven to be sufficient for collecting the necessary data at that altitude (in the range of 25-30m (82.0 to 98.4 feet). This setup will be the same as in previous collects.

A 200mm zoom lens will be used for the manned fixed winged collects. This has changed from the 105mm prime lens originally used last year, since we were not able to collected imagery with an adequate resolution. The camera and lens will be mounted inside the door of a Cessna 152 where the lens points downward. Earlier collects were conducted with the camera being pointed out of the aircraft window at an angle at the road. The door mounted camera will offer a more stable platform and will take imagery closer to nadir.

Flight Coordination

Remote Control Helicopter:

Prior to a remote control helicopter mission, we inspect the flight path for potential obstructions. Weather conditions are important; >5km visibility, light (<19kph) winds, >2000ft ceiling, dry road-surface are needed. Waypoints are programmed into the autopilot to help the operator follow the centerline of the road segment under evaluation, at an altitude of 25m-30m. For manual flight control, a safety observer is placed at the farthest point from the launch site, to report observations to the pilot.

Fixed-Wing:

Standard flight operation protocols are followed. The pilot will fly at the minimum altitude permitted (generally 500 feet above ground level) at a slow but controllable airspeed and maintain contact with air traffic control as necessary for safe operation.

Flight and Collection Operations

A mission plan will be prepared for each road segment, identifying flight waypoints, altitudes, and speeds. For the helicopter, we will operate in GPS mode while collecting imagery, with a safety pilot in control at all times as the mission operator. The hexacopter will be flown in flight-assist mode, with the safety pilot guiding the aircraft along the flight-path, with auto-pilot attitude stabilization. The manned flights will have a ground-crew on-site to control traffic during the overflight.

For safety reasons, the unmanned helicopter systems will only be operated in uninhabited, or sparsely inhabited, areas, with no pedestrian traffic present. Similarly, the fixed-wing aircraft will only be operated along segments where a 500ft altitude can be maintained without danger to persons or property in case of an emergency landing, meeting standard FAA requirements.

There should be as little time as possible between the manual ground truth survey and the overflights, to ensure a consistent road condition. Ideally, this will be the same day, but it may be as many as three days on lightly-traveled roads assuming no weather events.

Data Formats

Data on road condition needs to be obtained in two distinct formats: the "manual assessment" data, consisting of measurements on the ground by trained personnel, and the "automated assessment" analyzed digital imagery outputs generated from the images taken by the sensor package. The manual measurements are considered the "ground truth", against which all the automated outputs are assessed. A standardized form for manual assessment has been created for this purpose.

Proposed Calendar of Events

Data collections will take place during the summer of 2013, depending on weather, safe operations, and conditions of available rural unpaved roads. The project team is currently considering four possible weeks in June, July, and August for data collections. These are currently intended for:

June 17-21
July 8-12
July 15-19
August 5-9

Concluding Comments

This Deliverable report has described the field deployments plans necessary to collect sufficient data for the project's upcoming Performance Evaluation report (Deliverable 7-B), to help complete any refinement of analysis algorithms, and to demonstrate the integration of additional analyzed data within RoadSoft GIS. Deliverable 7-B is now due by the end of month 26 of the project (end of September, 2013, as described in the project's recent no-cost time extension. These data and evaluation will also help with demonstrating the utility of the platforms and sensor as part of the extended outreach approved as part of the project extension.

Deliverable 7-B: Performance Evaluation of Recommended Remote Sensing Systems in Unpaved Road Type Condition Characterization

Michigan Technological University

Characterization of Unpaved Road Condition Through the Use of Remote Sensing Project

Submitted version of:
November 26, 2013

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Table of Contents

List of Tables and Figures

Section I: Introduction and Executive Summary

The ultimate goals of this program were to design, build, and test a prototype remote sensing-based unpaved road condition assessment system that can compete with manual methods, and to incorporate these measurements into a decision support system (DSS) to aid in managing unpaved road networks. A number of requirements were established for the performance of this system; previously established requirements are reviewed and the performance our assessment system are reported in this document. The criteria for such a system consists of a flight-worthy sensor for collecting data, a software suite to process these data to extract road distresses, and RoadSoft® GIS, a tool for road asset management decision support and data visualization. As described in our reports, Deliverables 1-A to 7-A, we have designed, built, and deployed such an integrated system, now named our Unsurfaced Road Condition Assessment System (URCAS). This report evaluates the performance of URCAS against the requirements established at the beginning of the project. Previous reports are available on our project website at www.mtri.org/unpaved under “Tasks and Deliverables.”

This deliverable report, the most detailed of all our project reports so far, provides a summary of the measurement and sensor requirements originally described in the project’s first report, Deliverable 1-A. Of the several requirements, the need to detect a 1” (2.5cm) elevation change in a 9’ (2.7m) distance from road center to edge to measure cross section, so that presence of sufficient crown can be assessed, ended up being one of the most critical in defining needed resolution in the 3D data we were capable of producing. As we developed our system, the need to measure road features to a 1”/2.5 cm resolution was a requirement we were always keeping in mind.

To start the main Performance Review section, we thoroughly review each of the eight main unpaved road sites assessed in 2012 to 2013 (one site was repeated from the first assessment summer to the second). These were all rural, unpaved roads located in southeastern Michigan with a wide variety of representative road distresses that could be readily accessed by a field crew using the UAV and, when it could be arranged, by a manned fixed-wing aircraft operating from the Ann Arbor, MI airport. In addition, we collected data at two sites in Iowa and one in Nebraska in 2013 when a coincident data collection opportunity presented itself. This opportunity enabled us to demonstrate that our Unsurfaced Road Condition Assessment System could characterize results for other states’ roads as well. For all these sites, we have been able to analyze data for 45 total road segments.

The Performance Review section then continues to describe the sensor system performance. The UAV-based system more than met the requirements to collect the type of overlapping imagery data needed to collect 1% crown measurement variations using readily available commercial hardware costing $9,000. However, even flying at the lowest safe elevation (about 500’ or 150m), using the same single camera from the UAV-based system in a manned fixed wing aircraft could not meet resolution requirements due a lack of needed angular diversity. Without sufficient angular diversity, creating the needed 1” / 2.5cm resolution data is not possible with a 36 mp camera flying above 400’ (120m). In the future, as technologies advance, a manned fixed-wing aircraft-based data collection system could eventually match the current capabilities of our UAV-based system.

The software suite used to extract road distresses from the measured data consists of a series of open-source packages focused on Structure from Motion (SfM) techniques, tied together with custom-written scripts. These were described in Deliverables 6-A and 6-C, but additional development would be needed to have a ready-to-install, simpler-to-operate commercial software suite. The Performance Review section continues with describing the performance of the URCAS analysis algorithms. The typical performance of the overall system in correctly estimating distresses is measured in two ways, by individual distresses, and by comparing Unpaved Road Condition Indices (URCIs). Overall, the analysis algorithms detected 93% of distresses measured manually, with the best performance for potholes. The overall false-alarm rate (detecting a distress when none was present) was 14%, reasonable in our opinion for maximizing detection of actual distresses. 95% of potholes were detected with a false alarm rate of only 4%. When compared to manual measurements, the requirement to measure crown with 2.5 cm (1”) accuracy was met. Rut detection was more challenging with a 67% of probability of detection. Short ruts, essentially elongated potholes, were missed most often. While 100% of corrugations were detected, there was a relatively high level of false alarm, with the corrugation algorithm often identifying areas with significant 3D data reconstruction noise as corrugation. Tuning of this algorithm is continuing.

This report’s final main section is a cost comparative analysis. There are a number of possible data-collection systems that can be fielded to perform necessary measurement functions; however the preferred system we tested is a heavy-lift multi-rotor UAV (we used a Bergen Hexacopter as our second-year platform), a high-resolution camera (Nikon D800 or equivalent), and good-quality lens (Nikkor 50mm f/1.4). This system, when operated 8 hours per day, 3 days per week, for a 21-week season to collect 300 road-miles of data segments, will cost $0.74/mile to operate to meet a representative set of unpaved road assessment needs (see the Comparative Cost Analysis section). This assumes a 3-year amortization of the initial hardware (aircraft and sensor). This preferred data-collection system satisfies all outlined performance requirements.

This preferred system was not suitable for manned, fixed-wing, collections without modifications that were beyond the scope of this effort, particularly affordability. However, it is possible that a system, built with current technology, could be fielded, with significantly more complicated processing required. Such a system, used to collect a similar amount of road data as described above, includes the following estimates: the plane costs $160/hr to fly, a one hour flight can cover up to 5 miles of roads needing assessment (because there are target areas for collection; not every mile of road in a flight path needs assessment), 300 road-miles need to be assessed over a season, and there is a 21-week data collection season. As described in the Comparative Cost Analysis section, this will cost $16,340 per season. For a system consisting of 3 cameras ($10k amortized over 3 years), this comes to $10.26/mile.

Section II: Requirements Review

Deliverable Report 1-A (Brooks et al. 2011a) provided a thorough description of the requirements that would need to be met to develop a remote sensing system capable of collecting inventory and distress data for unpaved roads that would be useful to road managers, with the goal of developing a working prototype of a commercially viable unpaved road data collection and asset management system. The "Requirements for Remote Sensing Assessments of Unpaved Roads Conditions Report" has been available on the project website (www.mtri.org/unpaved) since early in this project and can be found directly at http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del1-A_RequirementsDocument_MichiganTechUnpavedRoadsr1.pdf. In it, several critical indicators were defined for unpaved road condition assessment; these were the distresses that would be measured to indicate condition:

Critical leading indicator:

* Cross section (loss of crown)

Trailing indicators:

* Loose aggregate
* Corrugations
* Potholes
* Ruts

Desirable but optional:

* Road-side drainage
* Dust

The first table in Deliverable 1-A provided the most effective summary of measurement requirements, and is repeated here:

Table 1: Summary of requirements for a successful unpaved road data collection and asset management system as described in Deliverable 1-A.

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"

Number	Name	Type	Definition
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'
17	Field-of- View	Sensor	11 degrees
18	Resolution	Sensor	0.5", (4M pixels for this geometry)
19	Image Capture Speed	Sensor	2.25 frames per second

Deliverable 1-A also summarized as the sensor system as needing at least the following properties:

1. Flight altitude ~400ft (~122 m)
2. 11º FOV at that altitude -> 75mm lens
3. >4MP sensor
4. >2.25 fps imaging rate

The report also provided an initial description of the Unsurfaced Road Condition Index (URCI), (Department of the Army 1995; Eaton 1987) that was further detailed in Deliverable 2-A, the State of the Practice of Unpaved Road Condition Assessment (Brooks et al. 2011b; available at http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del2-A_State_of_the_Practice_for_Unpaved_Roads_MichiganTech.pdf). Selection of the URCI was based on its ability to integrate information on unpaved road distresses into management and cost information needed by road managers. Distress information on improper cross section, corrugation (washboarding), potholes, ruts, and loose aggregate (berms) are scored based on the density and severity and compiled for a 0-100 score based on deduct values from a look-up table. Table 2 shows an example of the URCI data being tied to cost codes and management options (from Eaton, 1987; Eaton 1987a; Department of the Army, 1995) for a collection of information necessary to make the severity assessments that helped shape the project requirements.

Table 2: Maintenance alternatives and corresponding distress categories, severity codes determined from UCRI, and cost codes adapted from the Unsurfaced Road Maintenance Management method.

Distress Number	Distress	Severity code	Cost code*	Description
81	Improper cross section	L	B	Grade only.
		M	B/C	Grade only/grade and add material (water or both), and compact. Bank curve. Adjust transitions.
		H	C	Cut to base, add aggregate, shape, water, and compact.
82	Improper roadside drainage	L	B	Clear ditches every 1-2 years.
		M	A	Clean out culverts.
			B	Reshape, construct, compact or flare out ditch.
		H	C	Install underdrain, larger culvert, ditch dam, rip rap, or geotextiles.
83	Corrugations	L	B	Grade only.
		M	B/C	Grade only/grade and add material (water or aggregate or both), and compact.
		H	C	Cut to base, add aggregate, shape, water, and compact.
84	Dust stabilization	L	C	Add water.
		M	C	Add stabilizer.
		H	C	Increase stabilizer use. Cut to base, add stabilizer, water, and compact. Cut to base, add aggregate and stabilizer, shape, water, and compact.
85	Potholes	L	B	Grade only.
		M	B/C	Grade only/grade and add material (water, aggregate, or 50/50 mix of calcium chloride and crushed gravel), and compact.
		H	C	Cut to base, add aggregate, shape, water, and compact.
86	Ruts	L	B	Grade only.
		M	B/C	Grade only/grade and add material, and compact.
		H	C	Cut to base, add aggregate, shape, water, and compact.
87	Loose aggregate	L	B	Grade only.
		M	B/C	Grade only/grade and add material, and compact.
		H	C	Cut to base, add aggregate, shape, water, and compact.
*Cost code guide: A = labor, overhead; B = labor, equipment, overhead, C = labor, equipment, materials, overhead.				

As noted in Deliverable 2-A, the project team found the Department of the Army's URCI method to be a good candidate method to focus on for this project because it offered a clear set of measurement requirements, the realistic possibility of collecting most of the condition indicator parameters, and the potential applicability to a wide variety of U.S. unpaved roads. The manned and unmanned systems used in this project were selected and developed so that they could collect the necessary URCI data with the required resolutions shown in Table 1. The performance review, concept of operations, and cost analysis all stem from the URCI system and related measurement requirements.

Section III: Performance Review

Description of Assessed Sites and Data Collections – Unmanned and Manned Flights

The MTRI team collected data at five sites in 2012 - Petersburg Road in Monroe County and Welch Road, Mills Macon Road, Garno Road and Piotter Hwy in eastern Lenawee County Michigan (see Figure 1). Four sites were in assessed in 2013 as well: Marsh Road and Fleming Road in northwestern Livingston County. Palmer Hwy and Piotter Hwy in eastern Lenawee County were also evaluated (also shown in Figure 1). For the purposes of this project, up to four people were sent so that ground truth data could also be collected, but the imagery needed for unpaved road assessment could be collected with just a single data collector. No single study site had all the distresses for ground truth assessments. As we eventually determined, our analysis software for locating unpaved road distresses was able to find and categorize more distresses than manual ground truth was able to do, so our "ground truth" data is better described as spot-checking reference data useful for evaluating part of the imagery analysis results. We selected roads for assessments, with the project UAVs (hexacopter/ single-rotor helicopter) and manned fixed wing aircraft based on communication with local county Road Commissions and extensive driving surveys by MTRI personnel. Often, county road commissions were unable to provide guidance on current unpaved road conditions within their counties (with the goal of narrowing the search for distressed unpaved road segments). Jay Carter of the Road Commission for Oakland County (RCOC), a partner in this project, was able to guide us to townships within the county with roads that had not been recently graded. However, it was up to the field crews to locate roads that met the data collection criteria.

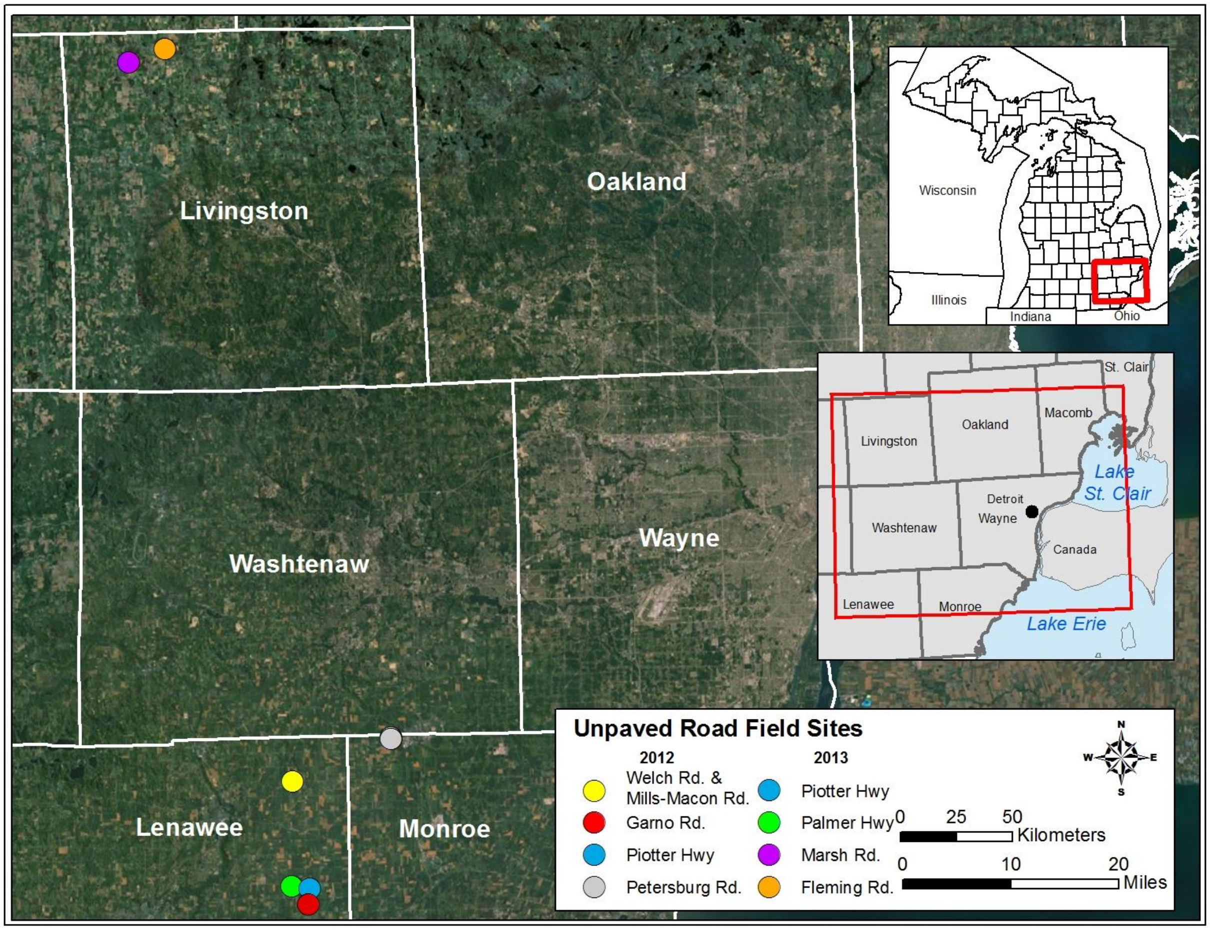
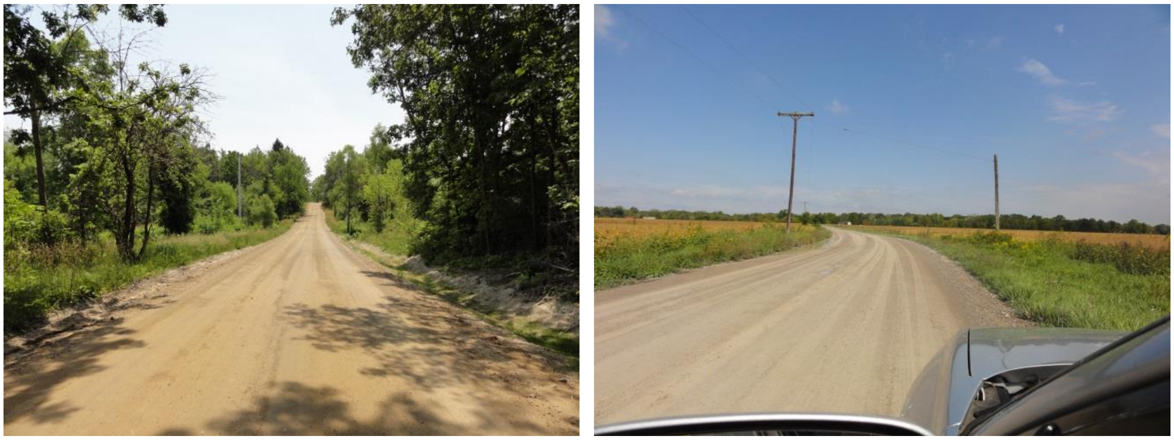
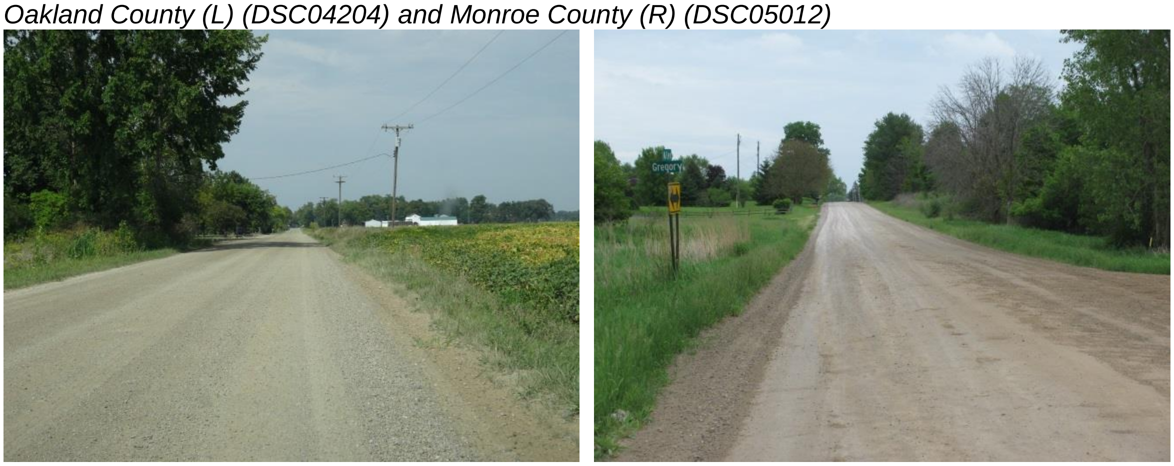


Figure 1: Locations of the eight sites were unpaved road imagery were collected in 2012-2013 for calculating road distresses and the Unsurfaced Road Condition Index.

As a result, to select unpaved roads for evaluation, we sent out field teams on driving surveys to look for distressed unpaved roads that met the conditions set for evaluation: they needed to be clearly visible from the air, had no trees or wires/poles close to the road, were lightly populated and lightly trafficked. Figure 2 shows some examples of road conditions and near-road landscapes found in unpaved road areas of southeastern Michigan.



Oakland County (L) (DSC04204) and Monroe County (R) (DSC05012)



DSC00684 Macomb County (L) DSC_4855 Livingston County (R)

Figure 2: Sample road conditions and landscapes in several counties within SEMCOG.

While the search for distressed unpaved roads included most of the member counties of the South Eastern Michigan Council of Governments (SEMCOG), suitable areas for aerial data collection were found in northwestern Livingston County, Monroe County and eastern Lenawee County in southeastern Michigan. The appropriate locations for data collection were generally in agricultural areas with open fields and few trees along the roads. The population density in the rural parts of these counties is low, the landscape is open and unpaved roads are common, making it easier to locate unpaved roads that are suitably remote and have quantifiable distresses of useful severity.

A challenge faced by the field team was staying ahead of graders once suitably distressed unpaved roads were located (see Figure 3). Often, the grader would pass over distressed unpaved roads between the time the field team identified the distresses and when the data collection team could get out to the site. This delay may have been only a day or two, but graders beat the data collection team to the distressed unpaved roads several times.

Figure 3: A road grader working on a rural road in Livingston County, MI, as seen by data collection team while looking for distressed unpaved roads.

In addition, there were two collections of opportunity in Iowa and one in Nebraska, made in late August 2013 (Figure 4). The purpose of this collection was to verify that roads maintained in other states, using potentially different materials and methods, could be characterized with the same processing suite as Michigan roads. These sites were chosen from reviews of Google Earth imagery, within several miles of I-80, to minimize transit time to the site. All three sites were judged to be undamaged, and typical of the surrounding rural roads. Examination of the results indicated that there were no problems in assessing road conditions on these other types of roads.

Figure 4: Overflight of an Iowa road, also assessed for condition.

Ground Truth Data Collection

When a study site had been identified, a "ground truth" team followed to break the road down into short (typically 100 feet/~30 meters) segments for analysis. This was needed for verification and spot-checking of image analysis results and would not typically be required as part of an operational unpaved roads assessment system. The road is marked with pavement marking paint and each segment numbered. Distresses present in each segment are measured (length, width, depth and any other attributes that may be required) and recorded on a field data sheet (see Figure 5).

Unsurfaced Road Inspection Sheet

Road Name: Fleming	Segment No.: 2	Segment length: 100'
Inspector:		Date: 6-18-13

Distress Types:	Unit	Bins		L	M	H
81 Improper Cross Section	Linear Feet	For 83 & 86	Max Depth	<1"	1"-3"	>3"
82 Inadequate Roadside Drainage	Linear Feet	Pothole Severity Levels				
83 Corrugations / Washboarding	Square Feet		Average diameter			
84 Dust (not measured)	N/A	Max Depth	<1'	1'-2'	2'-3'	>3'
85 Potholes	Number	0.5"-2"	L	L	M	M
86 Ruts	Square Feet	2"-4"	L	M	H	H
87 Loose Aggregate	Linear Feet	4"+	M	H	H	H

Distress Quantity and Severity

Feat. No.	Distress Type		Length	Width	Depth	Severity	Remarks
1	85	Pothole	30	18	1"		add 1/4" to depth measurement
2	85		31	18	1"		
3	85		24	16	.5		
4	85		35	24	1"		
5	85		54	28	.875		
6	85		31	24	1"		
7	85		31	18	1.125		
8	85		22	18	1.125		
9	85		26	20	1.25		
10	85		37	24	2.5		
11	85		35	41	1.125		
12	85		31	26	.875		
13	85		41	19	1.25		
14	85		39	28	1.875		Segment Area=

Figure 5: A completed field data collection sheet for segment 2 of Fleming Road, Livingston County. Values on this form were entered into the MS Excel version of this inspection sheet where severity calculations were performed. Note that some units of measure conversions were necessary.

Road condition attributes recorded on the field sheets are standard Army Corps of Engineers Unpaved Roads Condition Index attributes – cross section, roadside drainage, corrugations (washboarding), potholes, ruts and loose (float) aggregate. Dust is part of the URCI but was not measured as a practical part of this project. Road width was measured at each end of the segment; it was measured more often if road width varied significantly within a segment.

Each road segment to be measured was numbered and distresses present marked and numbered. It was not necessary for segments to be immediately adjacent to each other. Distresses present within the segment are mapped, measured and the values recorded on the field data collection sheet. A second page of the data collection form allowed for the mapping of distress location as well as entering data on road width, cross section (crown) drainage and float aggregate measurements.

The data recorded on the field data sheet are entered into an Excel spreadsheet that is identical to (and the source of) the field data sheets (see Figure 5). This field data sheet is an evolution of a manual system developed to capture ground conditions when the data were collected. Calculations are built into the spreadsheet to classify the distresses present into the appropriate "bin" (seen at the top of the data sheet) and produce a URCI index number. While out in the field, the ground truth team also made sketch maps of the sections to help interpret locations and types of distresses (Figure 6). To help understand how these data fed into the complete end-to-end system, three additional figures are included: Figure 7 shows a photo of the Fleming Road segment 2 data collection site (one of our representative segments needed for URCI evaluation of distress condition); Figure 8 shows the UAV-collected imagery after it has been converted into a 3-D point cloud using the project's remote sensing processing system analysis software, and Figure 9 shows a "height map" indicating that potholes could be mapped using the project's analysis software.

Unsurfaced Road Inspection Sheet

Road Name	Fleming Road	Segment No.	2			Segment length	100
Inspector		Page:	1	of	2	Date	6/18/2013

Distress Types:		Unit	Bins		L	M	H
81	Improper Cross Section	Linear Feet	For 83 & 86	Max Depth	<1"	1"-3"	>3"
82	Inadequate Roadside Drainage	Linear Feet	Pothole Severity Levels				
83	Corrugations / Washboarding	Square Feet		Average diameter			
84	Dust (not measured)	N/A	Max Depth	<1'	1'-2'	2'-3'	>3'
85	Potholes	Number	0.5"-2"	L	L	M	M
86	Ruts	Square Feet	2"-4"	L	M	H	H
87	Loose Aggregate	Linear Feet	4"+	M	H	H	H

Distress Quantity and Severity

Feat. No.	Distress Type		Length (in)	Width (in)	Depth	Severity	Remarks	
1	85	Pothole	30.0	18.0	1.250 in.	M		
2	85	Pothole	31.0	18.0	1.250 in.	M		
3	85	Pothole	24.0	16.0	0.750 in.	L		
4	85	Pothole	35.0	24.0	1.250 in.	M		
5	85	Pothole	54.0	28.0	1.125 in.	M		
6	85	Pothole	31.0	24.0	1.250 in.	M		
7	85	Pothole	31.0	18.0	1.375 in.	M		
8	85	Pothole	22.0	18.0	1.375 in.	L		
9	85	Pothole	26.0	20.0	1.500 in.	L		
10	85	Pothole	37.0	24.0	2.750 in.	H		
11	85	Pothole	35.0	41.0	1.375 in.	M		
12	85	Pothole	31.0	26.0	1.125 in.	M		
13	85	Pothole	41.0	19.0	1.500 in.	M		
14	85	Pothole	39.0	28.0	2.125 in.	H	Segment Area=	3017.5

Figure 6: A completed Unsurfaced Road Inspection Sheet, transcribed from the field data sheet above. The values on this sheet were collected from segment 2 on Fleming Road, Livingston County, MI and are actual attribute data. Values in the "Severity" column are calculated based on data entered for that particular feature.

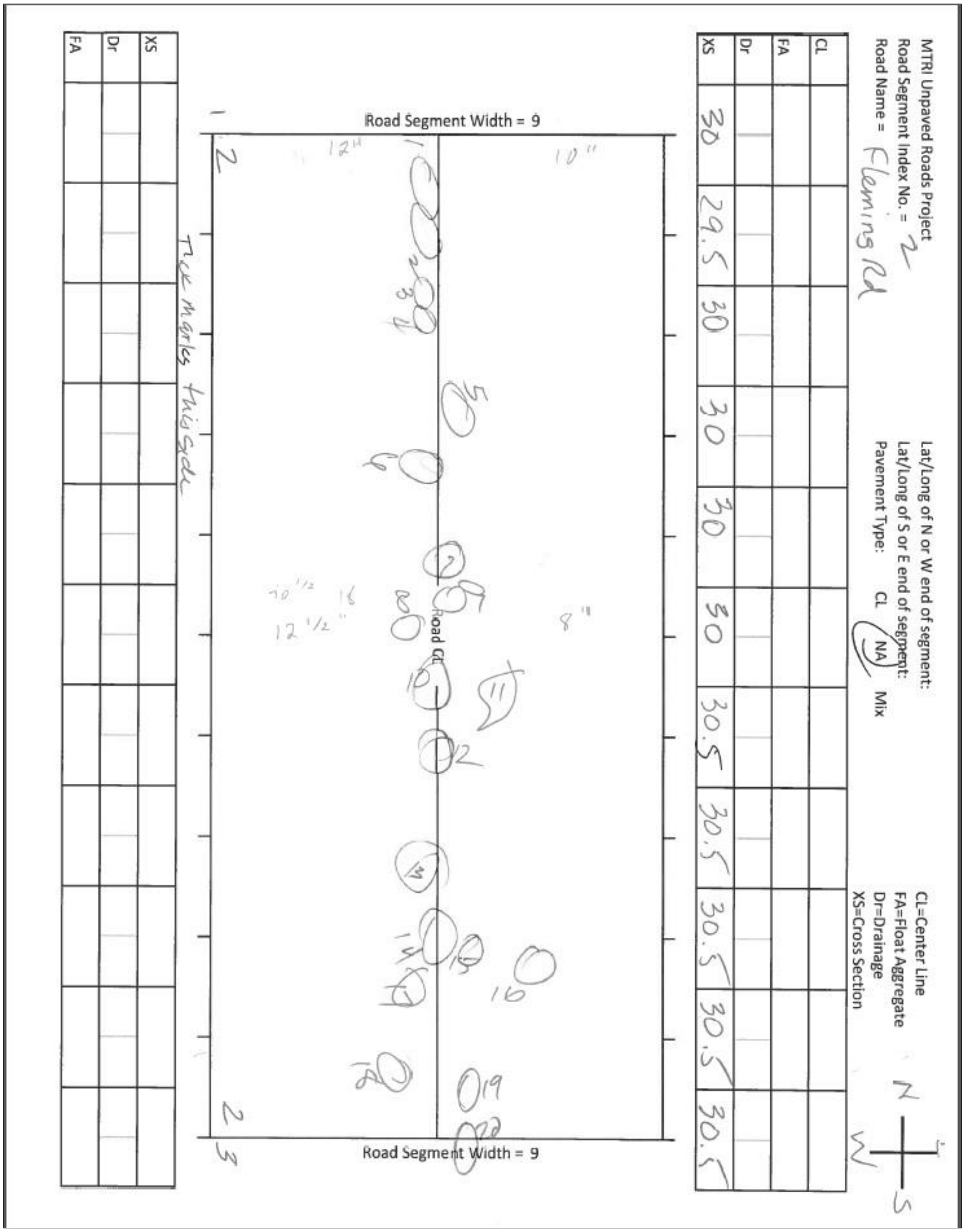


Figure 7: Distress map from segment 2 of Fleming Road. The compass rose allows orientation of the map. In this case, the distresses are mapped and numbered, correlating to numbers painted on the road next to the corresponding feature. Road width is captured every ten feet in the XS field. All twenty distresses found on this segment were mapped on this sheet although documenting them required a second field data sheet.

Figure 8: Fleming Road segment 2 looking north. Distresses have been marked, measured, mapped and numbered prior to overflight. This image correlates to the south end of the distress map above.

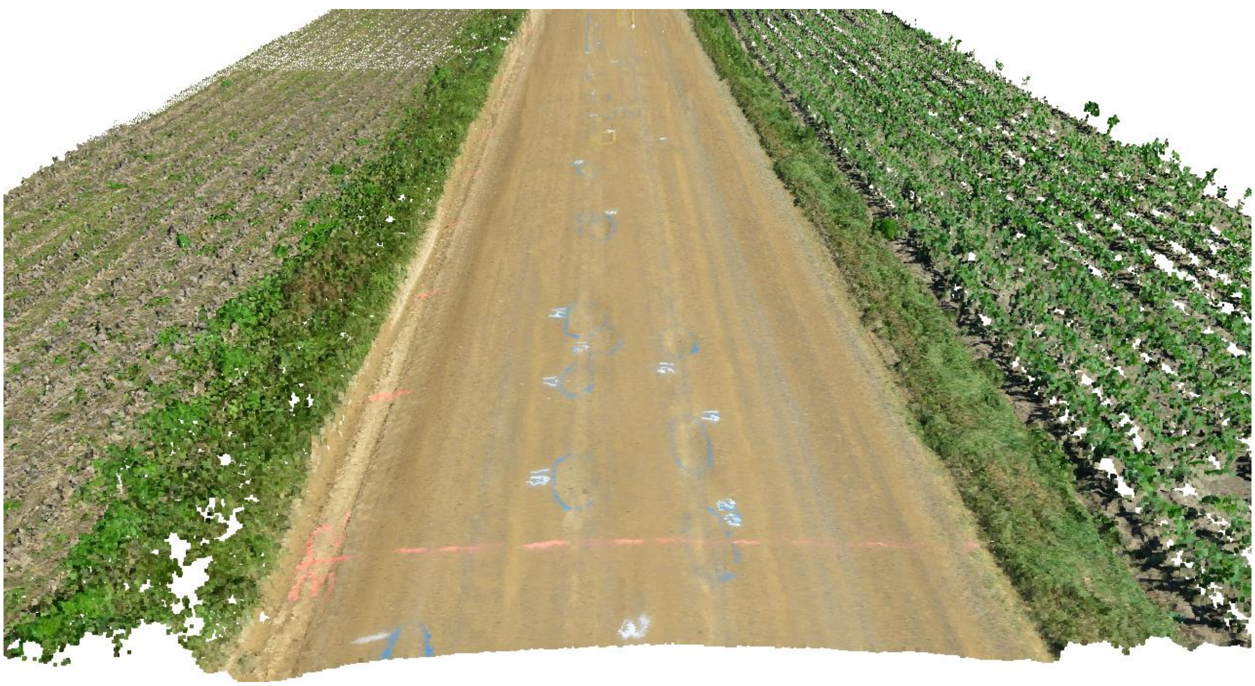


Figure 9: A 3-D point cloud generated through the project's structure-from-motion based remote sensing processing system software using overlapping UAV-collected imagery, of the same location shown in the ground photo in Figure 7.

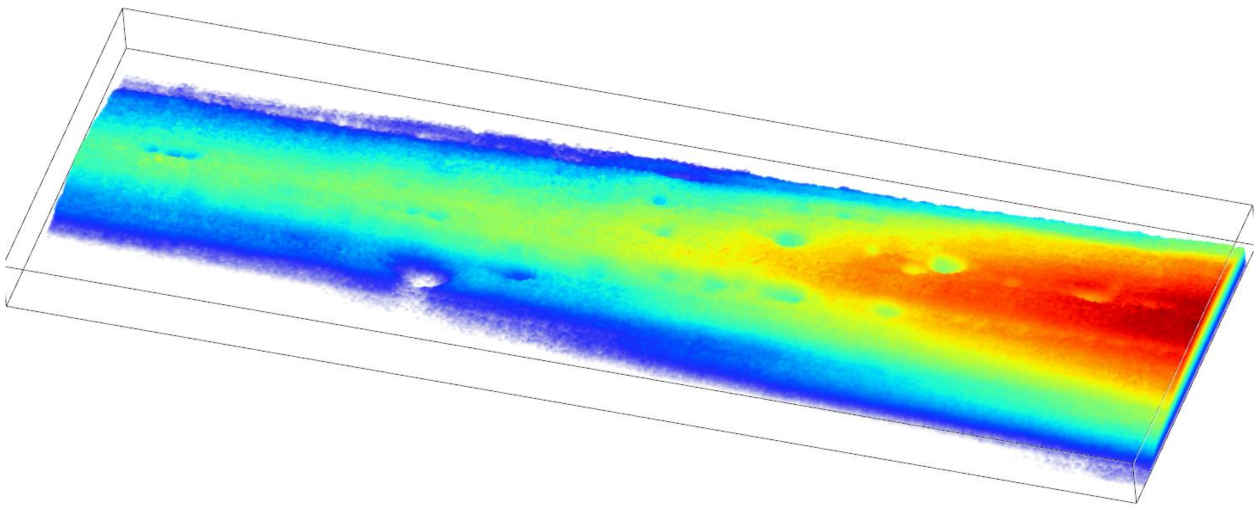


Figure 10: Part of the Fleming Road segment 2 as shown in Figure 7 and Figure 8, displaying a height map where potholes and their depths can be seen.

2012 Field Season

Figure 11 shows the five main locations evaluated during the project's initial 2012 field season: Petersburg Road, Welch Road, Mills-Macon Road, Piotter Highway, and Garno Road (see Figure 1 for their context in the rest of southeastern Michigan). Descriptions of each of the evaluated sites follow.

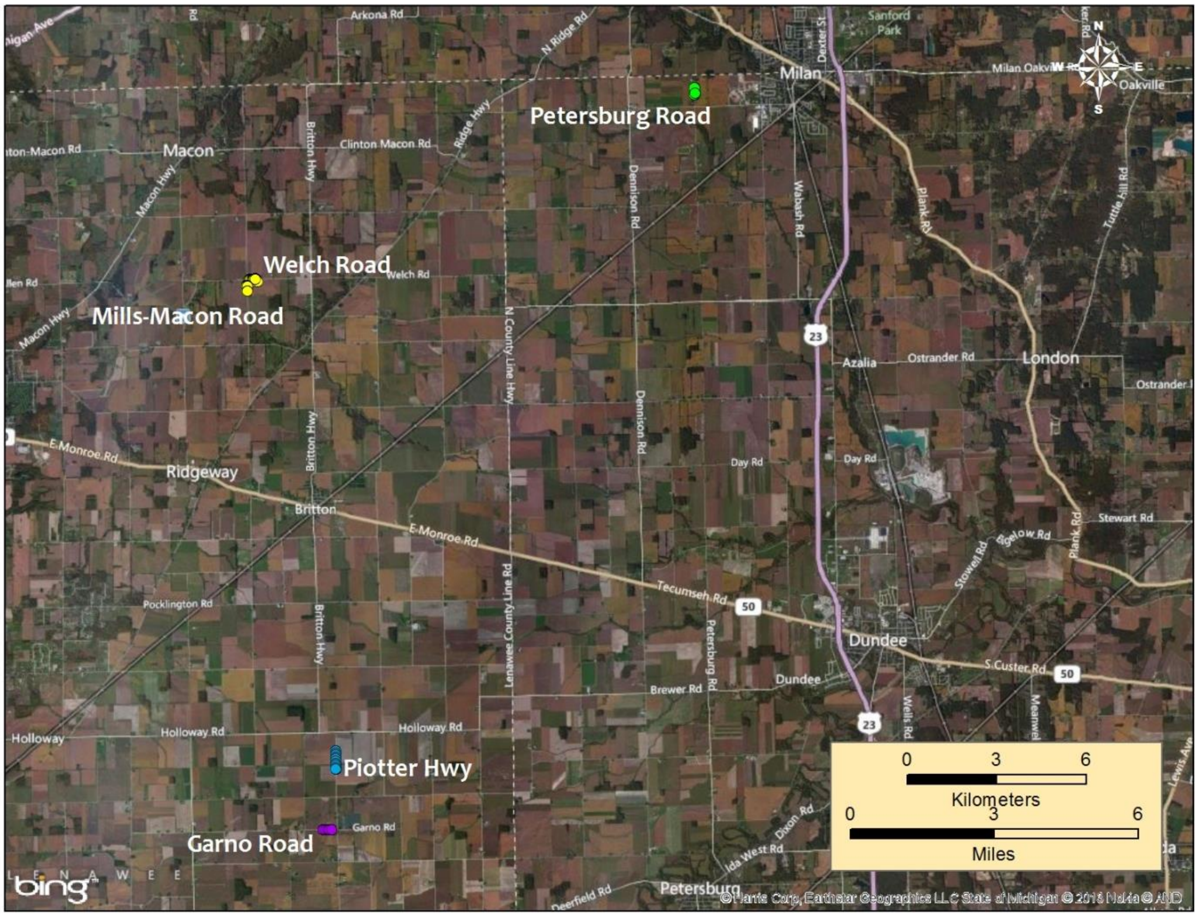


Figure 11: Focus map of the 2012 unpaved roads project field study sites.

Petersburg Road

The first flight and data collection tests were completed on Petersburg Road near Milan, Monroe County, MI on October 16 2012. This road met the conditions set for a data collect – distresses present, away from airports, no trees or poles near the road, light traffic and no buildings in the segment of the road to be flown. The road surface is crushed limestone.

The road was broken down into 100 foot / 30.5 meter segments and the segments were marked with fluorescent orange marking paint (Figure 12). The URCI method is based on taking one or two 100 foot samples to represent approximately a one mile stretch of road (Department of the Army 1995). The road width was measured and recorded, then distresses were measured and values recorded (Figure 13). While the road was marked and measured, the Bergen Tazer 800 helicopter was prepared and programmed for flight. When the helicopter was ready, the road was briefly closed for safety and to keep vehicles from passing under the helicopter during a data collection.

Figure 12: Petersburg Road near Milan MI looking north. Note visible distresses (potholes).

Figure 13: Location and attribute data about distresses found in each road segment were measured and recorded for comparison to image processing results. (three photos above): (DSC1285, DSC1295, DSC1297)

Welch Road

The surface of Welch Road consists of natural aggregate or river sand and gravel (Figure 14). This material, unlike crushed limestone, does not ‘lock’ into a hard, impermeable surface as it is compacted and is prone to plastic deformation as the road and roadbed become saturated with water and vehicles (particularly trucks) pass over the road. Welch Road runs east-west; distresses identified on the road are washboarding and potholes, with a small accumulation of float aggregate primarily along the north shoulder of the road. Figure 15 shows a single image, as collected by the single-rotor Bergen Tazer 800 UAV (in 2013, the project team switched to a simpler-to-fly Bergen hexacopter for its data collection). Figure 16 is an example of the 3-D point cloud created by our remote sensing processing system as an intermediate step in being able to locate and categorize road distresses. Figure 17 is another example of a height map that helps demonstrate that we were able to generate the 3-D data needed for unpaved road condition assessment.

Figure 14: Welch Road (facing west) near Mills-Macon Road, Lenawee County, MI. Road segmentation marks, potholes, washboarding (corrugation) and float aggregate are visible in this image. (DSC03546)

Figure 15: Aerial view of the same segment of Welch Road as Figure 14 above, seen from the MTRI remote control helicopter flying at 25 meters above the ground. Note the road segmentation marks, potholes, washboarding and float aggregate visible in both images. (DSC2865)

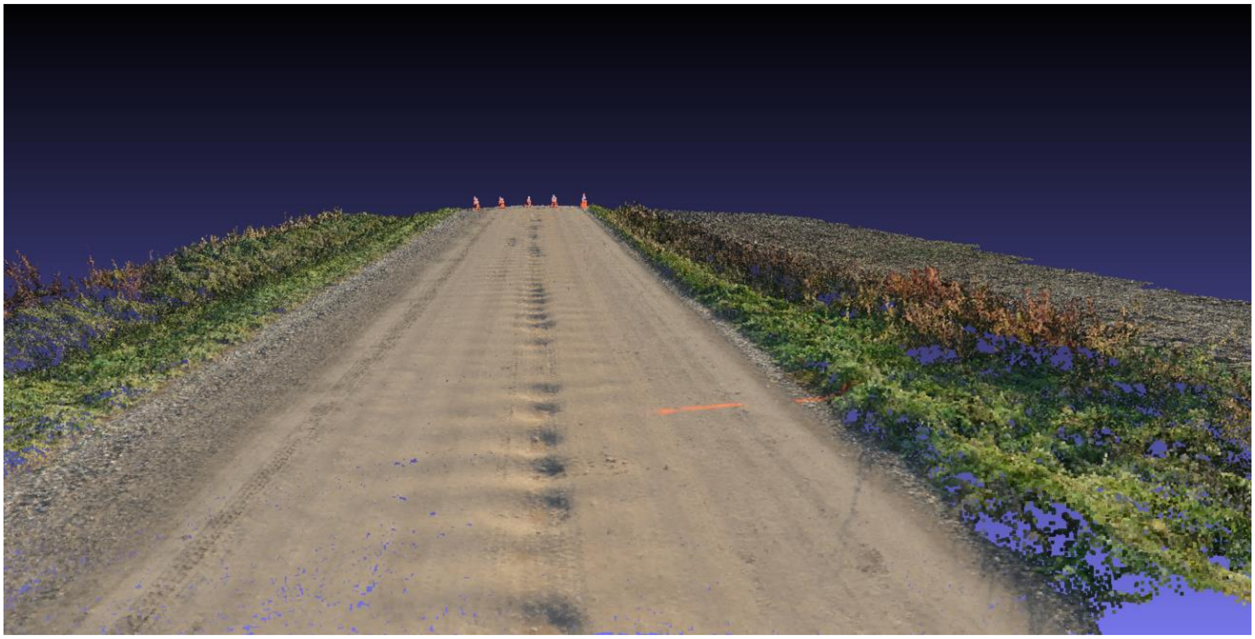


Figure 16: Example of the 3-D point cloud generated by the remote sensing processing system for the same stretch of road shown in Figure 14 using the overlapping UAV-based imagery.

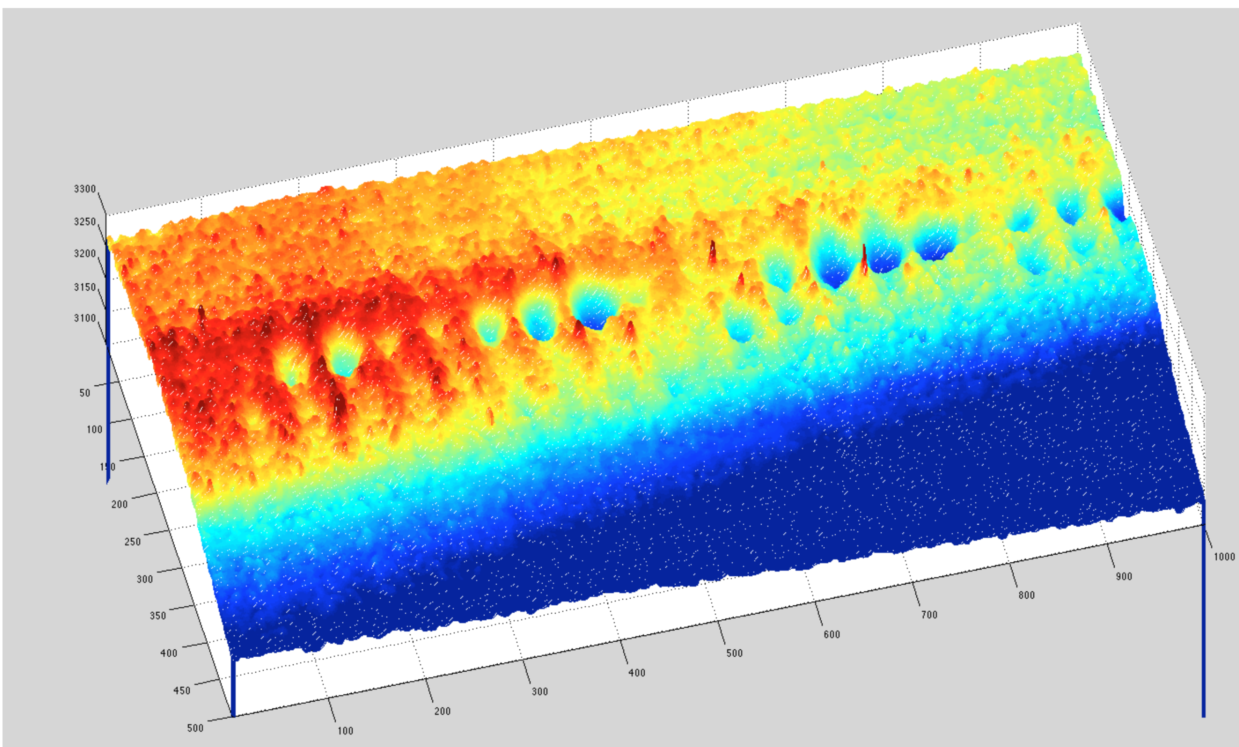


Figure 17: 3-D height map showing pothole distresses on Welch Road, as derived using the project's remote sensing processing system.

Mills Macon Road

Mills-Macon Road is a north-south road that intersects Welch Road just west of the Welch Road study area. The study area on Mills-Macon Road starts ~120 meters south of the intersection with Welch Road.

The road surface as shown in Figure 18 (from the ground) and Figure 19 (from our UAV imagery) appears to be natural aggregate, with possibly some crushed limestone added when the road was last graded. Mills-Macon Road showed no significant distresses other than a minimal crown and some loose aggregate on the road. Mills Macon Road was used for prototype analysis; this sample output with few distresses was compared to known good road surfaces.

Figure 18: Mills-Macon Road south of Welch Road looking north. Note thin layer of loose aggregate on the road surface and lack of other distresses on the road surface. (DSC03667)

Figure 19: Aerial view of same segment of Mills-Macon Road as Figure 18 above, seen from the MTRI remote control helicopter flying at 25 meters above the ground. Note the road segmentation marks and slight windrowing of the loose aggregate on the road surface. (DSC3440)

Piotter Highway

Piotter Highway is a north - south road located south of the town of Britton in eastern Lenawee County, MI. The study area is approximately midway between Laberdee and Holloway Roads. The road surface appeared, at the time of the survey, to be mostly natural aggregate although some crushed limestone may be present (Figure 20). Distresses found on Piotter Hwy in the fall of 2012 were generally potholes of various sizes irregularly scattered down the length of the study area along with a few ruts. The road was broken up into 100’ (30.5 meter) segments and marked with fluorescent orange marking paint. The location and size (length, width and depth) of distresses on the road were documented for later comparison to image processing results. Imagery was collected from the MTRI helicopter at 25 meters (about 82 feet; see Figure 21 and Figure 22) and 30 meters altitude (about 100 feet) as well as from a manned fixed wing aircraft (a Cessna 172) flying over the road at approximately 150 meters (about 500 feet) above ground level (Figure 23 and Figure 24). The helicopter captured overlapping aerial imagery at nadir, while the imagery taken from the Cessna 172 was taken out the passenger side window at an angle (Figure 25).

Figure 20: A ground level view of part of segment 6 on Piotter Hwy, Lenawee County MI. View is to the north.

Figure 21: The same segment of Piotter Hwy seen in Figure 20 above from the MTRI remote control helicopter flown at 25 meters. Few potholes are visible in this image but a long rut on the right side of the road is visible in both this image and the ground view of the same area. (DSC3449_gamma.jpg)

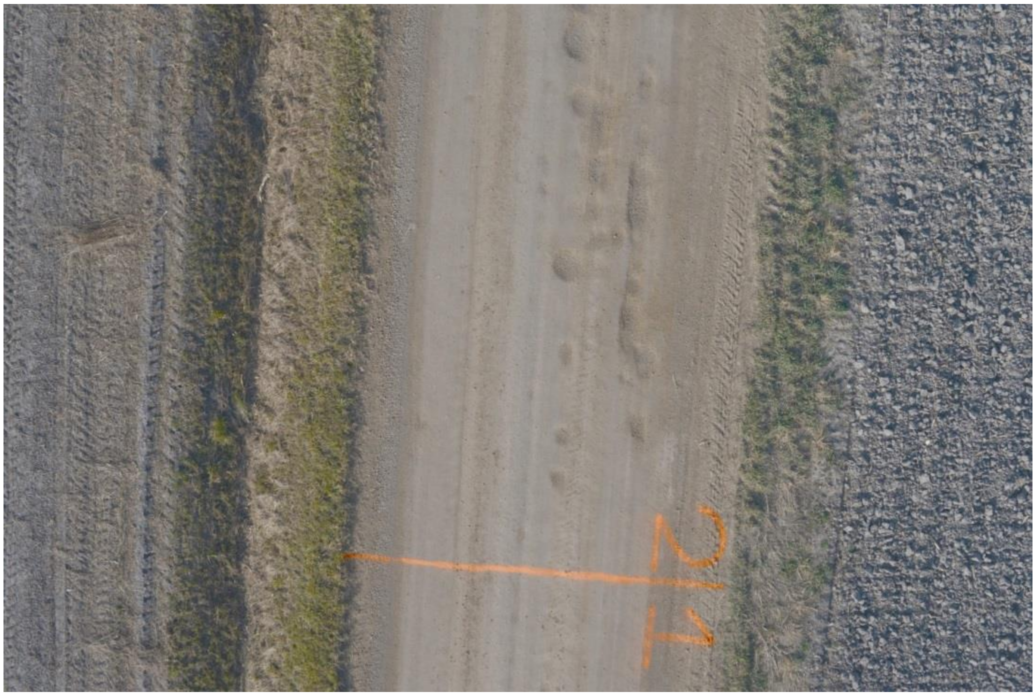


Figure 22: Aerial view of Piotter Hwy from the MTRI hexacopter flown at 25 meters altitude. Note the segment markings and clearly visible distresses (potholes) in the road surface. (DSC3227_gamma.jpg)

Figure 23: An aerial view of segment 6 of Piotter Rd from a Cessna 172 flying at approximately 500 feet above ground level. The orange segment marks are clearly visible, but distresses are difficult to identify from this angle and altitude. (DSC5879)

Figure 24: Low oblique aerial photograph of Piotter Hwy segment 2 from the Cessna 172. Markings are clearly visible but distresses while visible are too small to be characterized into classes based on size. (DSC5855)

Figure 25: View from the Cessna 172 over Piotter Rd while taking aerial photographs of the Piotter Hwy study area.

Garno Road

Garno Road is an east-west road located about one mile south and a little west of Piotter Highway in Lenawee County MI. The study site consists of four 100 foot (30.48 meter) segments between Piotter Hwy and Sisson Hwy. The only distress noted by field crews on Garno Road in the fall of 2012 was float aggregate (see Figure 26 for a ground-based view).

Data were collected on Garno Road from the MTRI helicopter and fixed wing aircraft (a Cessna 172) on the same day. The data were collected with the helicopter in the morning (Figure 27) and Garno Road, along with Piotter Hwy, was overflown in the early afternoon (Figure 28).

Figure 26: Garno Road looking east. Note the loose/float aggregate on the road shoulders and along the crown of the road.

Figure 27: Garno Road from the MTRI helicopter at 25 meters. Loose/float aggregate is the only distress present. Note the marks in the loose gravel from the tires of farm equipment.

Figure 28: Garno Road from a manned fixed wing aircraft at approximately 150 m / 500 feet agl (above ground level). The float aggregate distress is visible, but not easily characterized from this angle and altitude.

2013 Field Season

Additional roads in southeastern Michigan were selected for evaluation in 2013 and a few roads evaluated in 2012 were revisited. A review of maps of paved vs. unpaved roads that we produced using semi-automated analysis of SEMCOG-provided color-infrared aerial imagery enabled field teams to focus their search to areas with a high proportion of unpaved roads that have minimal tree cover obscuring the road surface, allowing for both hexacopter and manned fixed wing aircraft operations (see Deliverables 6-A and 6-C, Roussi et al. 2012a and Roussi et al. 2012b for the descriptions of the aerial imagery analysis to inventory the locations of unpaved roads) . The roads evaluated during the 2012 field season were located in Monroe and Lenawee counties, south of Ann Arbor. We made a concerted effort to include unpaved roads in the northern SEMCOG counties. Reconnaissance trips for 2013 data collection efforts used maps of the locations of unpaved roads that we generated to find unpaved roads with suitable distresses for evaluation.

Again, the criteria for evaluation of the roads from the air made locating unpaved roads with current distresses challenging to find. In part, this reflects the very active management of unpaved roads in southeastern Michigan by local road maintenance agencies. Gravel roads are regularly graded, and County road commissions appear to rapidly attend to problems reported by local citizens. Field crews evaluated unpaved road condition in a large part of southeastern Michigan from northern Macomb County to southern Monroe County. Many distressed unpaved roads were located but few met the criteria for evaluation. Eventually, Marsh and Fleming roads in northern Livingston County (Figure 29) and Palmer Road in eastern Lenawee County were selected for evaluation. Piotter Road in eastern Lenawee County, originally assessed in 2012, was revisited to evaluate changes in road condition (see Figure 1 for its location).

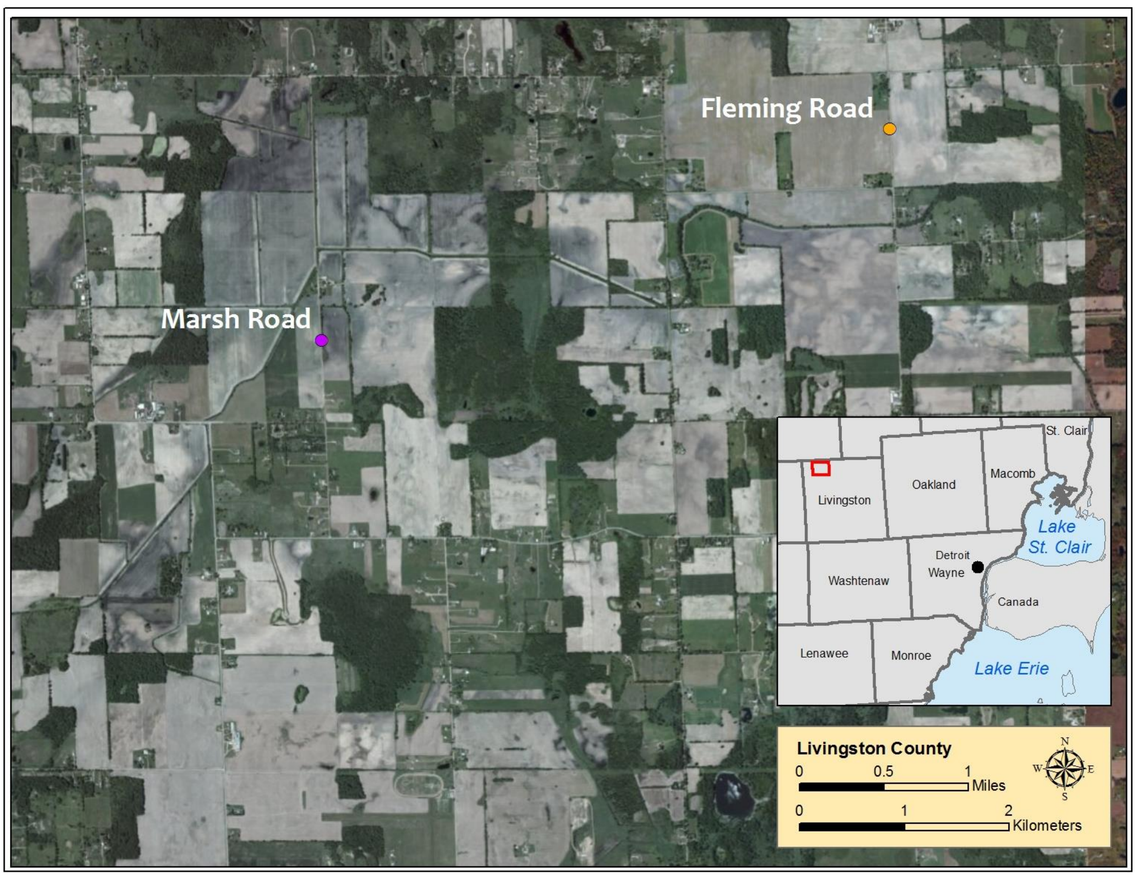


Figure 29: 2013 unpaved roads project field study sites in Livingston County.

Marsh Road

Marsh Road in northwestern Livingston County (see Figure 29) was identified as a good candidate for evaluation in late May 2013 based on presence of visible distresses. The distresses were primarily potholes and extensive washboarding over a distance of approximately a half mile (800 m). When the field evaluation team arrived on site for an evaluation, it was found that the road had been recently graded and was in excellent condition (see Figure 30 for a ground view and Figure 31 for hexacopter imagery-based view). It was decided to use the recently graded road as an example of an unpaved road with no distresses; at least crown could be assessed, which is of strong interest to local road commissions. The road surface was measured and marked; attributes were collected using the same methodology as was applied during 2012 data collection activities. Additional data were collected at this location on crown as there was substantial crown present over most of the length of the sampled area of the road.

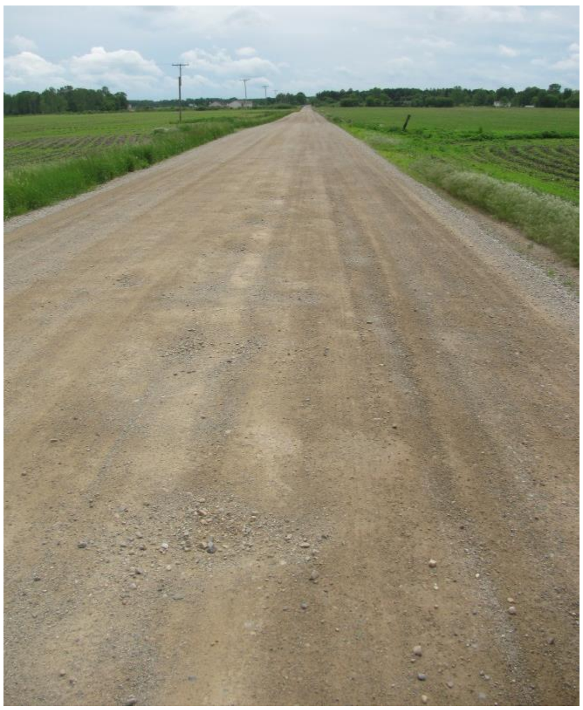


Figure 30: Marsh Road, north of Fowlerville, Livingston County, MI looking south. Image on the left illustrates some of the distresses present on May 31, 2013; the image on the right was taken June 18, 2013. (IMG_4890 (L); IMGP0030 (R))

Figure 31: A segment of Marsh Road from the MTRI hexacopter. No significant distresses were present, however crown measurements were taken on Marsh Road for comparison to the results from image processing.

Fleming Road

Fleming Road (Figure 29) is located several miles east of Marsh road in northwestern Livingston County. Distresses present on Fleming Road were primarily potholes of varying sizes and some minor ruts. Distresses on Fleming Road were measured and mapped as had been done at other study sites (see Figure 32). However, on Fleming Road, the individual distresses were marked and numbered with different colored marking paint (blue for minor potholes, yellow for moderately sized potholes) in an effort to better differentiate and correlate distresses on the road with those seen in image processing output (Figure 33, a seen using UAV-based imagery). The numbering sequence restarted for each 100 foot (30.5 m) road segment that was evaluated.

Figure 32: Distress markings on analysis segment 2, Fleming Road, Livingston County MI. Each distress feature was circled and numbered when it was mapped.

Figure 33: Part of Fleming Road segment 2 with marked, numbered distresses as captured by the MTRI hexacopter flying the Nikon D800 DSLR camera. Data were collected the day after the road was marked. Note the blue distress feature markings have been worn by passing traffic. Feature numbers were refreshed with white marking paint.

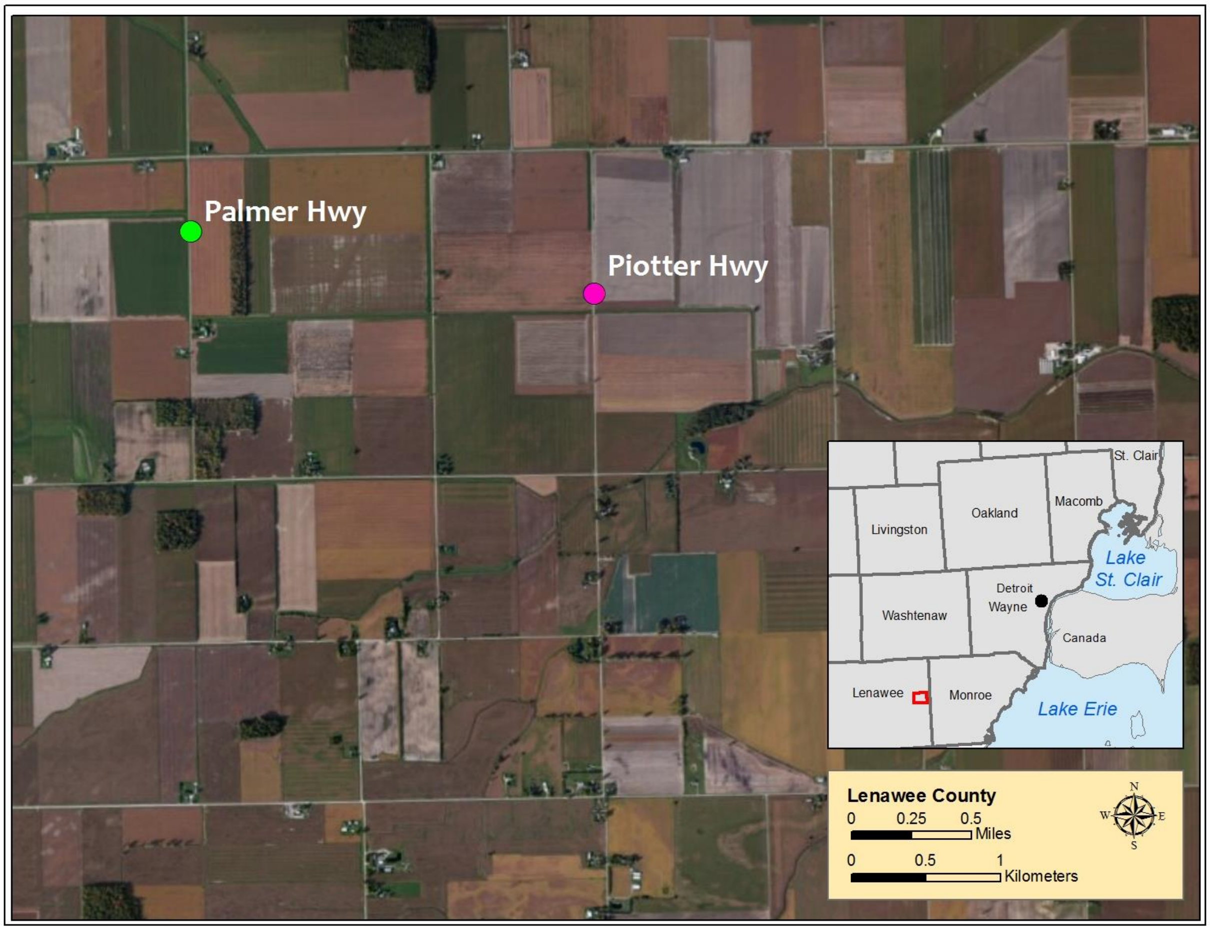


Figure 34: 2013 unpaved roads project field study sites in Lenawee County.

Piotter Highway 2013

Piotter Highway in Lenawee County, MI, (see Figure 34) was evaluated again in 2013 as it had developed distresses in similar locations as well as in different locations from those found in the 2012 data collect. Distresses on Piotter Hwy in 2013 were found in clusters down the road rather than a continuous distribution of distresses spread down the road. Potholes and ruts were the dominant distresses found on the road (Figure 35). Figure 36 shows an UAV-based view of the distresses present during the sampling period in 2013. As was the case for Fleming Road, the distresses were numbered as they were marked and mapped. Unlike Fleming Road, Piotter Hwy was broken into two groups of segments and only the northern segments were marked and mapped. The southern segments were only broken into 100 foot sections. None of the distresses in those sections were identified.

Figure 35: Piotter Hwy marked and measured during the 2013 data collection. Note the clustering of potholes at this particular location, which as a feature of the 2013 distress patterns (IMGP0262.jpg)

Figure 36: An image of Piotter Hwy from the hexacopter flight. This is approximately the same location as in the previous figure. Above, however the hexacopter flight was made before the distress features were numbered. (975-7916.jpg)

Palmer Highway

Palmer Highway, also in Lenawee County, MI (Figure 34) is a north-south road slightly more than a mile west of Piotter Hwy. It had been identified as having significant distresses in a survey earlier in the summer of 2013; however it was graded before marking and overflights could be scheduled. However, by fall 2013, some distresses had returned and it was decided to collect data on some segments of the road using both manned fixed-wing aircraft (Figure 37) and the project's hexacopter UAV (Figure 38). Distresses present on Palmer Highway at the time of survey were predominantly ruts and potholes (Figure 39). The road appeared to have reasonable crown, however, some of the ruts along the shoulder of the road prevented water from properly draining from the road, saturating the roadbed and making the ruts worse in those areas over time.

Data were collected from the MTRI hexacopter using techniques described previously as well as from a Cessna 172, using the same Nikon D800 camera as was mounted on the hexacopter but with a longer (200 mm focal length) lens (Figure 37). Data collected form the Cessna 172 were collected at the minimum safe altitude (around 500 feet / 150 m above ground level) while flying parallel to the road (Figure 40, as taken by our ground truth crew). As a side note, we found that the aerial imagery of nearby corn field areas made our team interested in potential applications of our systems for agriculture assessment as well.

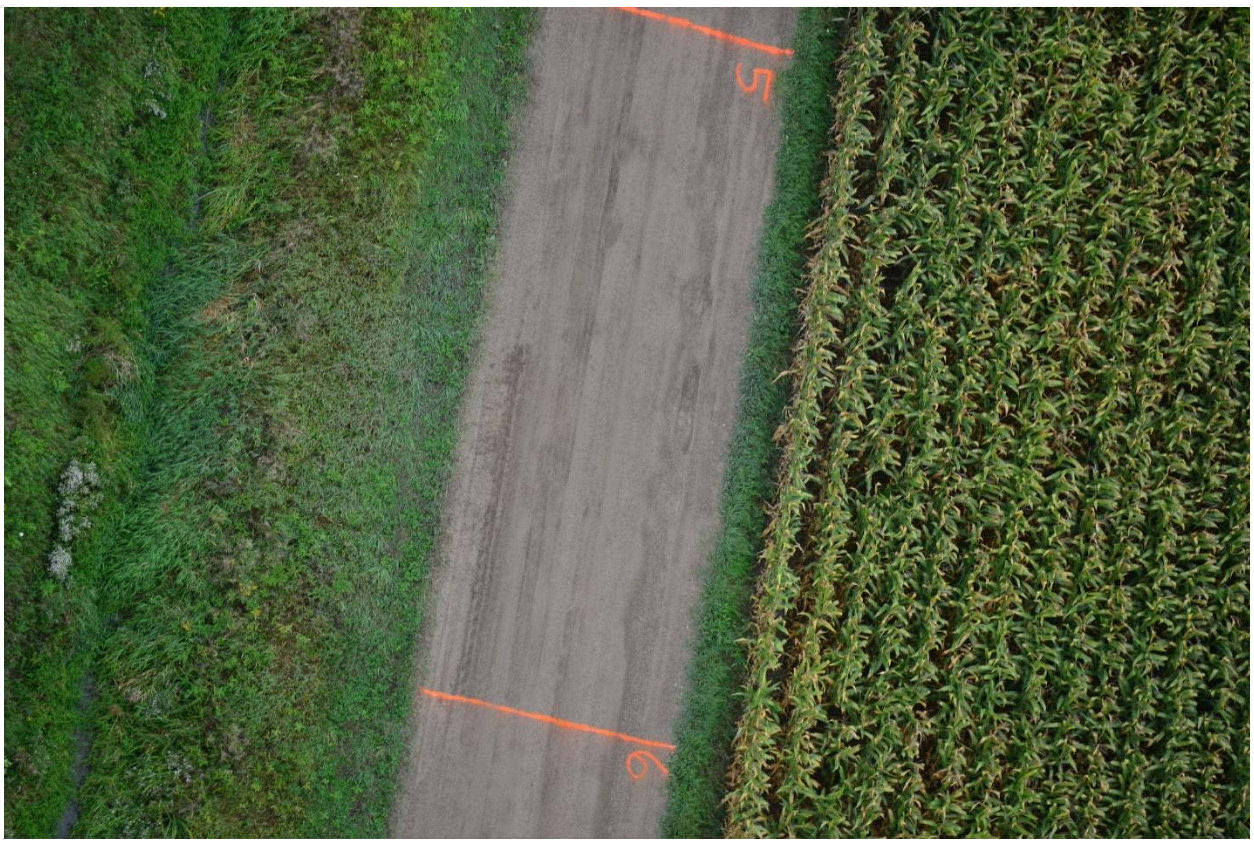


Figure 37: An image of an approximately 50 foot / 15 meter section of Palmer Hwy taken with the Nikon D800 camera with a 200mm lens from the manned Cessna 172 flight. Altitude and airspeed can make it difficult to capture usable overlapping aerial imagery from a manned fixed wing aircraft at a reasonable cost. (CJR_4426.jpg)

Figure 38: Segment 3 of Palmer Road from the MTRI hexacopter from approximately 25 meters altitude. A rut is visible on the right side of the road just above the segment line.

Figure 39: Ruts and potholes on Palmer Road. Note deformation along edge of road in left hand image. DSC00691 (R) and DSC00717 (L)

Figure 40: Cessna 172 flying over Palmer Road collecting the unpaved roads assessment project imagery. (DSC00708.jpg)

Manned Fixed Wing Collects

Data collection using a manned fixed wing aircraft has the potential to be able to collect overlapping aerial imagery of sufficient quality for extracting information on unpaved road condition. The cost of using a metric camera mounted inside a single or twin engine aircraft is beyond the cost limits for this project, so other approaches were evaluated to test the potential feasibility of using the same Nikon D800 sensor in the manned aircraft as we were using in the UAV. Part of the original challenge of this project was to see if we could use the same relatively inexpensive imaging sensor system in both our manned and unmanned platforms.

While we were able to acquire overlapping imagery from manned fixed wing flights, there were challenges acquiring the imagery easily without a metric camera. MTRI field crews made three flights to acquire aerial imagery from a manned aircraft (Figure 41). The Federal Aviation Regulations require that aircraft stay above 500 feet above ground level. In order to have enough "pixels on the road" so to speak to be able to meet resolution requirements, the road needed to fill at least a quarter of the frame. We calculated that a 200mm focal length lens should get enough of the road in the frame from 500 feet to extract road condition information. The technique we used involved flying a Cessna 172 parallel to the road but slightly to the left to allow the passenger to open the window and point the camera as close to straight down as possible. The Nikon D800 camera is triggered at approximately 2 frames per second by an intervalometer plugged into the camera. The photographer then has to keep as much of the road in the frame as much as possible while passing over the study area. A longer lens (up to 300mm focal length) would improve the ability of the photographer to keep enough of the road in the frame. It would also give some altitude flexibility to the pilot as they overfly the roads. However, such lenses are expensive and beyond the cost limitations of this project.

Challenges to this approach are many. The aircraft, in this case a Cessna 172, is typically flying at 60 - 65 knots (69 – 75 mph) even in slow flight. Depending on wind speed and direction, managing the ground speed of the aircraft may become an issue. The slipstream is strong, making it difficult to keep the camera pointed at the intended target, particularly when it fills a large portion of the frame. For best performance of the algorithm that identified and quantifies distresses on an unpaved road, the unpaved road should fill a quarter to a third of the frame. The photos should also have sufficient angular diversity to enable complete imaging of distresses such as potholes at a wide variety of angles. The relatively high speed and altitude makes this difficult. Low clouds or poor visibility can also preclude flying aerial photography missions in a manned aircraft. A UAV may be able to collect data under conditions that preclude operation of manned aircraft because of ceiling or visibility restrictions.

Cost and aircraft/pilot availability is another factor, since the aircraft must fly from the nearest airport to the study site, fly the mission and return to the airport. The study area could be a substantial distance from an airport with available aircraft and pilots. Rental for a Cessna 172 and experienced pilot recommended through the Professional Aerial Photographers Association (PAPA) in the Ann Arbor, MI area was approximately $160 to $175 per hour as of summer, 2013.

Figure 41: A first pass at determining whether good data could be collected from a manned fixed wing aircraft. At 500 feet agl over Garno Road, Lenawee County, October 2012.

A modified approach to data collection from a manned fixed wing aircraft was tried in 2013. MTRI was able to acquire a door for a Cessna 152 that had space for camera mount inside (Figure 42, Figure 43, and Figure 44). A camera mounting assembly for the Nikon D800 was designed and built by MTRI staff then mounted on a Cessna 152 and flown over Piotter Road. The concept was to fly down a study road at a low ground speed and remotely trigger the camera as the aircraft passed over the study area. When an aircraft is in slow flight, the nose is usually up, making it difficult to see and align the aircraft with the road to be photographed. A product called CamRanger allowed the pilot and photographer to view the camera perspective. The CamRanger proved a useful tool and was used as an aid to lining the aircraft up correctly over the road. However, we learned through practical testing that because the camera was not mounted on a gimbal that allowed it to move so that it would always point straight down, any change in the aircraft in pitch (nose up/down) or roll (wing up or down) of the aircraft changed where the camera was pointed making it difficult to keep the camera pointed at its subject.

Gyrostabilized camera mounts for aircraft are available but they are expensive, generally mounted on helicopters and geared toward larger cameras used for film production. A quick search did not locate any appropriately sized stabilized camera mounts usable in our small manned fixed-wing aircraft concept.

Figure 42: The door of a Cessna 152 with a fairing allowing the mounting of a camera pointed straight down (nadir).

Figure 43: The Nikon D800 camera mounted on the door of a Cessna 152. The protective shade at the end of the camera lens can be seen at the bottom of the door.

Figure 44: Preparing to fly the D800 in the door of the Cessna 152. The camera can be seen in the door, the camera trigger mechanism can be seen on the pilot seat.

Performance Evaluation Main Analysis

Sensor System Performance Evaluation

The basis for all derived distresses is the depth map created from the sensor data. This, in turn, is derived from the 3D point-cloud reconstruction which is obtained from the Structure From Motion (SFM) algorithm. A series of 2D, overlapping, images is used to extract the complete 3D information. However, the overlap must be carefully managed to obtain a consistently good reconstruction without manual intervention.

One “rule-of-thumb” is that the same object must appear in no less than 5 different images. These images may be at different distances and orientations, but they must span several degrees of angular extent. The closer to the scene the sensor, the more angular diversity is present in the overlapping images. This would imply that there is some maximum altitude, beyond which reconstruction is not possible. Although this is true, the ground sample spacing of the image pixels is actually the limiting factor at this point.

For good reconstruction, the requirement of 5 overlapping images translates into time and speed requirements. The requirements on accuracy of crown measurement (<1% variation, or about 2cm resolution), combined with the requirement that we measure both lanes and adjacent drainage, influence the sensor distance and lens specifications. A functional system that meets (or exceeds) all these requirements is a 36M-pixel sensor with a 50mm lens, firing at 2 frames-per-second, flying at an altitude of 25m at 2m/s forward speed. All of these parameters are achieved easily using readily available, inexpensive, commercial equipment. Such a system collects about 20GB of data per kilometer of road inspected.

There are three camera parameters that can be varied to obtain “correct” exposures, the ISO (the “speed” of the sensor), the aperture, and the exposure time (or shutter speed). However, there are other requirements that must be met, so not all combinations of these parameters are useful, although they will result in a properly exposed image. For example, it is important that all images be in focus, with no motion-blur. This requires a short exposure time, implying that the aperture is fully open, letting in as much light as possible. But many lenses do not have a flat focal plane when at full aperture (that is, there are distortions present at the image edges). This can be avoided by closing the aperture down 2 stops. This also has the effect of increasing the depth-of-field (although in most cases, we will be operating beyond the 10m hyperfocal distance, at which everything is in focus). It also will cause the shutter speed to be 4x slower, which can lead to motion-blur at lower light levels. To avoid this, one needs to change the ISO setting, to obtain a properly-exposed image at a shutter speed of at least 1/250s with an aperture of f/2.8.

In summary, the following data collection parameters will meet all system performance requirements:

- 24M-36M-pixel sensor
- 50mm, f/1.4 lens set at f/2.8
- 1/250s (maximum) shutter speed (shorter is better)
- ISO set as needed for proper exposure given ambient lighting
- Distance of 20m-30m from surface
- 2m/s (maximum) forward speed
- 2fps (minimum) image capture rate (obtained with a simple intervalometer)
- 64GB high-speed storage medium

It is important to note that the algorithm performance, and the ability to meet the stringent requirements on resolution, depends on the ability to collect data that has enough angular diversity to be able to reconstruct three dimensions from two dimensions. This means that enough (and sufficiently different) views of the same ground location must be taken. As the distance from the ground increases, the solid angle that any object subtends decreases, and at some point, becomes too small for high-resolution reconstruction. Experimental results, discussed in detail in the next section, shows that data taken from a an altitude of 500 feet do not meet the system requirements in resolution. That is, the reconstructed pixels have been found to be “too large”. This is due to the lack of sufficient angular diversity.

There are three possible solutions to this problem of angular diversity.

1. More data are collected with the camera points at the same point on the ground, but at oblique (as well as nadir) views. This could be done either with multiple cameras on the same platform (e.g. one pointed forward, one downward, and one rearward). This would require longer focal-length lenses, and much more accurate pointing, on the non-nadir-looking camera. The pointing system could be quite complex (and expensive).
2. Several passes over the same location can be made, with the camera at different angles. Again, focal-length changes might be needed during oblique measurements, along with accurate pointing. This would also take more time, since lining up for multiple passes is not trivial.
3. Much higher resolution sensors, with a wider-angle lens than the 200mm currently used, would allow data to be taken in a single pass. Preliminary calculations indicate that a sensor with 4-5

times the current resolution (i.e. a sensor with 140M-180M pixels) with a 100mm lens would likely provide the needed resolution. No such sensor is readily available today.

We conclude that the use of a sensor at altitudes above 400 feet is not practical at this time, with the choice of SFM as the reconstruction technique. It may be that some other reconstruction method would yield the desired resolution, but we are not aware of a method that can be used with a sensor that would be competitive in cost with manual inspection methods. At this time, only sensors flown at altitudes below 100m will meet all the performance (i.e. resolution) and cost-effectiveness requirements.

Algorithm Performance Process Overview

During the process of assembling the performance results, we began to notice that the algorithm outputs were much different than the scoring done manually. Not wrong, since we could see it was finding the distresses, but different from what the raters were reporting. It turns out that the humans measuring the road were not reporting some distresses, either because they didn't see them, or they thought that they were not sufficiently bad to report. But the algorithm finds everything, and while one might think this is a good thing, it's not, as far as the final score is concerned. It turns out that the final step in creating the URCI is to transform the deduct values (using a non-linear set of curves) to make the road score "better" if the distresses are more evenly distributed by type. That is, a road with just one, very large, distress is scored lower than a road with many small distresses that add up to the same area. Since the human raters tended to only report large damages, our automated outputs (which report everything), were routinely finding the roads less damaged than reported. This might lead one to believe the software was somehow defective. However, when a human, aided by the (very accurate) depth map, counts all the damages, we report more similar score to the algorithm outputs.

This led us to the following conclusion; we can't call the manual measurements made with rulers and levels the "ground truth"; it is nothing of the sort. It is useful to verify that, when the algorithm says the pothole is 3" deep, that we can show that it was, in fact, 3" deep. But in terms of scoring the roads, we can't use the on-the-ground measurements to create a (valid) URCI score.

The process we adopted to assess algorithm performance is to visually inspect the reconstructed height map (which is verified correct by the spot-sampling done on the ground), extract the distresses one-at-a-time using the mouse cursor and data-ruler, and then use those to (manually) form damage classifications based on the Army manual. It turns out that, while tedious, it is not as onerous as walking along a road in 98-degree heat, trying to locate, and measure, many small distresses.

The process implemented to find and characterize distresses was:

1. Use filters matched to the distress characteristics to detect possible distresses.
2. Assess filter outputs, and reject objects not matching distress characteristics.
3. Classify the resulting detected features according to rules specified in the Army manual.

Algorithm Performance Evaluation

Algorithm performance was determined by comparing a manual scoring of the distresses (as determined by careful measurements in the field of select distresses) with the automated outputs of the detection algorithms. It was extremely difficult to measure, by hand, every distress present; it was time-consuming, and error-prone. The algorithm, however, finds even the smallest variations, including ones that human testers would either ignore, or overlook. We saw that humans tended to locate, and measure, only the worst damage. As a result, the manual measurements were used only to verify that the height maps were correct. Locating distresses from the height map visually became the "ground truth" scoring of the road. This was then compared to the performance of the human observer to the algorithm outputs.

The process starts with a data collection by one of the platforms under evaluation. Data were collected from three different collection platforms, single-rotor helicopter UAV, multi-rotor helicopter UAV, and manned fixed-wing aircraft. Locations of interest were selected based on the type of damage present with an unobstructed road surface view. Each section of road was divided into sections of equal length and the select damages noted. Data were then collected using the airborne system. For a detailed description of the road segments and field measurements see the previous part of this section.

Following collection of the airborne data, the imagery was processed and a road score was generated. In the first step of the process the photographs were divided into groupings corresponding to the different measurements collected. Data were grouped according to the road segment, then based on collection platform, then separated by collection altitude and/or collection pass, and finally by sections corresponding to the marked segments for which ground measurements were made. Images not from sections of interest or images collected during takeoff and landing were excluded from analysis.

Following the grouping of the images, each group was processed through the structure from motion (SFM) algorithm. To automate this, a script was written to execute the sequence of algorithms leading to a distress characterization, resulting in an output XML file containing the report of the damages for that section of road.

To properly perform the evaluation of the algorithm, each intermediate step in the process must be checked to verify a valid output. Overall performance depends entirely on the correctness of each step. In particular, the absolute correctness of the reconstructed 3D surface is essential. For evaluation purposes here, intermediate outputs from the algorithm not usually displayed to the user will be presented. This will demonstrate the accuracy of the process, as well as provide indicators of potential problems.

Before running the algorithm, it is necessary to have collected good imagery. Photographs of the road must have sufficient angular diversity and ground resolution for construction of an accurate 3D height map. Unfocused images, or ones with motion blur, will not result in an accurate 3D surface. Shown in Figure 45 is a point cloud generated from good images. Figure 46 shows a point cloud generated from images that possessed too little angular diversity. This manifests itself as “noise” (large variations) in the locations of the point cloud not associated with “real” height variations. These will result in poor estimations of road surface conditions. It should be noted, at this point, that good reconstructions are always assured if the system is configured as recommended, and the ConOps are followed.

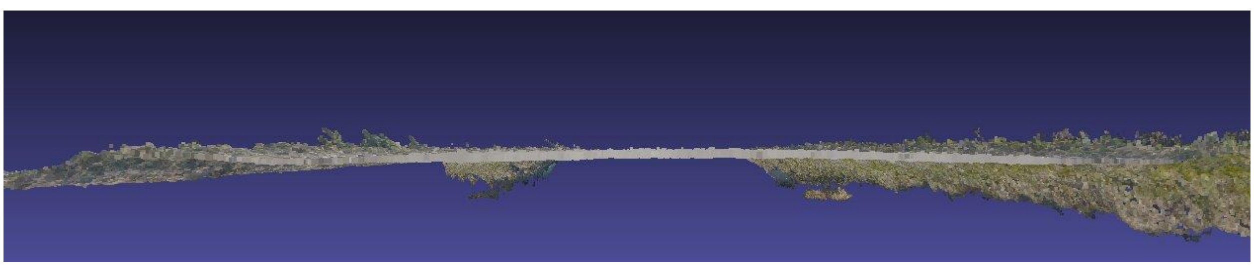


Figure 45: Good point cloud

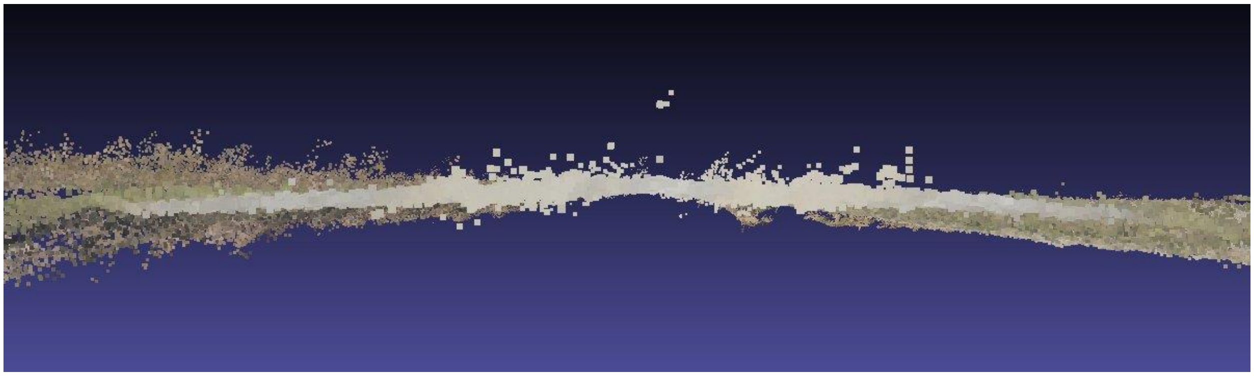


Figure 46: Noisy point cloud

Since the height map derived from the point cloud is the 3D reconstruction on which all subsequent evaluations are based, this height map must correspond to actual depths on the road to determine accurate classifications of damage. Height maps from sections of road with good reconstruction were compared against known measurements from those roads (taken manually). The depth values in the height maps have been verified to be within the required measurement error (1 inch).

Once the height map was verified to be accurate, it was used to generate damage scores in the same manner as described in the URCI Manual. A two dimensional version of the height map was displayed with colors representing the z-values (heights). The following performance discussion is based on the evaluation of 45 road segments at 7 different sites. Roads and segments with insufficient imagery resulting in poor reconstruction were excluded from analysis. Analysis was performed for sections from Palmer Rd., Piotter Rd., Welch Rd., Marsh Rd., Fleming Rd., and two roads in Iowa with no damage. Piotter Rd. was visited twice in two different years. Piotter Rd., Welch Rd., and Marsh Rd. each have more than one measurement per visit.

Potholes:

Potholes were visually identified and their sizes estimated. This was done by first getting an average z-value from around the top of the pothole. These points were also used to calculate the average diameter of the pothole. Then the z-value from the bottom of the pothole was used to calculate the depth. The potholes were then classed according to standard procedure. Shown in Figure 47 is a color coded height map with potholes numbered. Table 3 contains the manual score for those potholes.

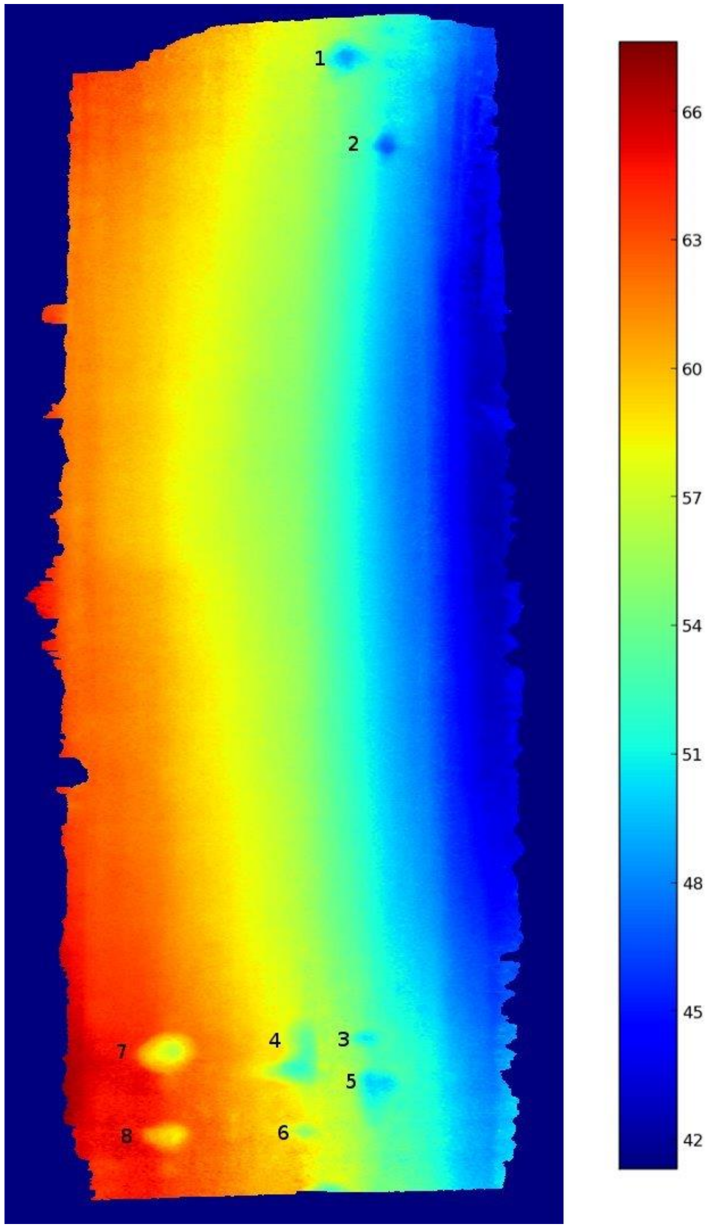


Figure 47: Height map of a 30m road segment with potholes. Values in cm.

Table 3: Manual Score of potholes

Pothole	Manual Classification
1	M
2	L
3	L
4	H
5	M
6	L
7	H
8	H

When measuring and classifying potholes, it is important to note that determining the extent of a pothole is highly subjective. Since potholes do not have uniform shapes or slope between the edge of the top of the pothole and the bottom, determining where the pothole begins and ends is dependent on the human making the assessment. Variations in depth also arise if the road surface around the pothole is not flat. For example, a large pothole in a road with a sloped surface would have different depth measurements referenced to the middle and edge of the road sides of the pothole. In manual evaluations of pothole depths and areas, a single point in the pothole is estimated. The algorithm is able to look at the entire region containing the pothole to make its assessment.

A comparison was made between the manual damage classifications and the algorithm. Several road sections representing different roads or measurements on the same section were randomly selected for analysis. Road segments having poor reconstruction were excluded from analysis. Table 4 shows the comparison of manually detected potholes to potholes detected by the algorithm. The probability of detection is the number of potholes the algorithms finds divided by the "true" number of potholes, as determined by visual inspection. The probability of false alarm is the number of falsely declared potholes divided by the true number of potholes.

Table 4: Pothole detection comparison

Potholes	Detected Potholes	Potholes misidentified	Probability of Detection	Probability of False Alarm	Probability of Correct Classification
101	96	4	95%	4%	96%

Loss of Crown:

The height map was also used to generate damage values for the crown. The segment cross section was measured visually at ten points (approximately every 10 feet) and heights at the edges and middle of the road were measured to determine the difference. The width of the road at those points was used to calculate a slope for each side of the road. The side of the road with the worst damage was used to classify the segment. The slope value was then used to classify the severity of the damage. Table 5 shows the metrics used to classify crown damage. Negative grades represent a road edge higher than the middle. Crown damages for this section of road are shown in Table 6. The total segment length was divided by the number of cross sections and this number was multiplied by the number of cross sections having the same score. This gives a linear distance along the road of a specific damage level.

Table 5: Crown Damage Metrics

Damage Class	Surface Grade
None	3% < Grade
Light	0% < Grade < 3%
Medium	-2% < Grade < 0%
High	Grade < 2%

Table 6: Crown damages measured manually

	Width (cm)	Crown A (cm)	Crown B (cm)	Grade A	Grade B	Min Grade	Damage
1	535	-8.1	10.9	-0.0302803 (-3.02%)	0.0407476 (4.07%)	-0.0302803 (-3.02%)	H
2	537	-7.4	11.5	-0.0275605	0.042830	-0.0275605	H
3	545	-7.5	12	-0.0275229	0.0440366	-0.0275229	H
4	519	-7.1	13.1	-0.0273603	0.0504816	-0.0273603	H
5	550	-7.3	12.9	-0.0265454	0.0469090	-0.0265454	H
6	539	-7.5	13	-0.0278293	0.0482374	-0.0278293	H
7	537	-6.4	13	-0.0238361	0.0484171	-0.0238361	H
8	530	-6.1	12.6	-0.0230188	0.047547	-0.0230188	H
9	525	-5.2	12.6	-0.0198095	0.048	-0.0198095	M
10	520	-7.2	11.7	-0.0276923	0.045	-0.0276923	H

In evaluation of crown measurement performance, it is important to note that the manual crown measurements were taken only a few times in a segment, and without regard to where the crown may have looked better or worse (they were evenly spaced). The process involved a water-level, two people (one in the road center, and one at the edge), and a tape-measure. The team would move to the measurement spot, and record only the crown at this point. Thus, it is likely that much of the crown variability went unmeasured. The automated detection, in contrast, takes a crown estimate at 1-inch intervals, averages them, and then produces a classification. This results in a much more accurate output in all cases than the manual estimates. Table 7 compares the crown values.

Table 7: Comparison of crown values.

Damage Class	Manual Score (meters)	Algorithm Score (meters)
L	0	13.67
M	2.7	12
H	24.3	0

Ruts:

To evaluate algorithm performance on ruts, ruts were identified from the height map visually and then area and severity measured. Shown in Figure 48 is the height map from a road segment with a large rut along the side. This rut was visually estimated to be of low severity and 34.4 square meters.

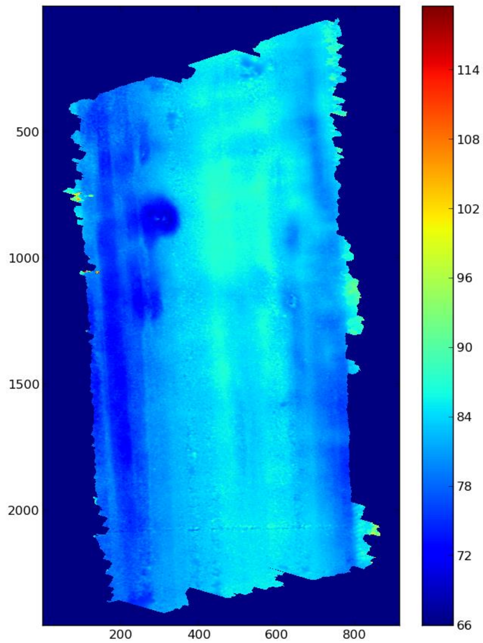


Figure 48: Height map of a 15m road segment with a rut. Values in cm.

Rut classifications were first evaluated on correct identification of areas with ruts. Road segments were visually assessed on the presence of ruts. The algorithm's detection of ruts was then compared against this manual score. The algorithm found most areas where ruts were visually detected. Missed detections occurred with very short ruts, essentially elongated potholes. False alarms occurred in areas where corrugations were present. Shown in Table 8 is the probability of detection and false alarms with rut detection.

Table 8: Rut Detection

Probability of Detection	Probability of False Alarm
67%	19%

We attribute the difference in visual and automatic performance to the fact that the algorithm parameters controlling the detections were not "tuned" to match how the rater was identifying the features. We discuss this later. But much like potholes, ruts have irregular shapes and their size estimates must be visually classified. In the field, ruts were often seen to have small ridges along the edges caused by displaced material. Depth measurements referenced between this ridge and the ground would be higher than measurements referenced to the road surface. In addition, rut depth was only manually measured at one or two locations along the rut. The algorithm is able to classify the rut along its entire length to generate a score. We have observed that the algorithm classifies approximately 30% of detected ruts into a lower rating than the manual rating.

Corrugations:

Corrugations (washboarding) were also scored in the same manner as ruts. Shown in Figure 49 is an example of a road segment exhibiting corrugation. Since this segment contains corrugations along most of the length, manual measurements were made at 6 arbitrarily selected points along the length. The measurement used to rate the distress was taken at the most severe point of damage. The width was measured and the corrugations assumed constant over the length of the 6 sections. In this segment the road was manually scored to have 40 square meters of medium damage.

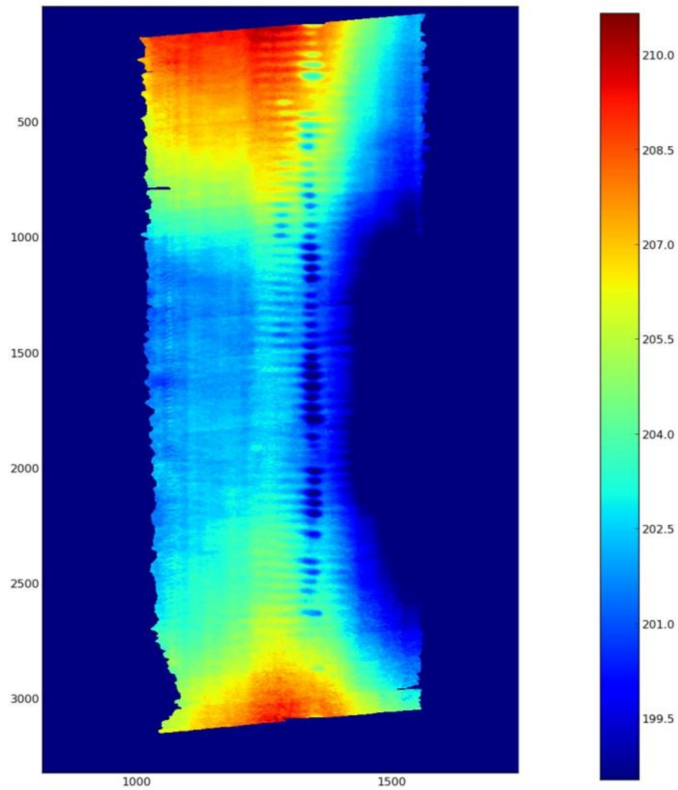


Figure 49: Height map of a 30m road segment with corrugation.

Road segments were visually assessed to see if corrugation was present anywhere on the road. The algorithm was then compared with the manual detection. The algorithm correctly identified all areas where corrugation was visually assessed to be present. The algorithm found other areas with features similar to corrugations in areas where reconstruction noise was present, and declared them as corrugations (i.e. false alarms). The probability of detection and the probability of false alarm are shown in Table 9.

Table 9: Corrugation Detection.

Probability of Detection	Probability of False Alarm
100%	38.5%

When manually scoring corrugations, it is not practical to measure all the variations. However, the algorithm assesses the corrugations at a much finer detail. This means that in a manual measurement, the entire area will be scored according to the worst damage present. The algorithm identifies 58% of the area of corrugation that was manually scored. Shown in Table 10 is a comparison of the algorithm performance compared to a manual classification. Our assessment so far is that corrugation classification needs further development for ready usage.

Table 10: Percent Total Area of Corrugation Damage Classification.

Classification	Manual Classification	Algorithm Classification
L	25%	0%
M	75%	30%
H	0%	70%

Loose Aggregate:

There were no roads found with excessive loose aggregate. But the “loose aggregate finder” is just the rut algorithm, locating “inverted ruts”. The performance should be comparable to the rut performance. This process is unable to differentiate a road surface completely covered in loose gravel from one without loose gravel.

Discussion of Performance Evaluation

Although we attempted to remotely sense the road conditions from a fixed-wing aircraft, the combination of pointing inaccuracies, and the lack of angular diversity (due to altitude effects), led to poor 3D reconstructions. These were not of sufficient quality to make road distress measurements. The following discussion applies only to UAS-based measurements.

The algorithms’ performance was evaluated by comparing the result of manual scoring of the height map. The measurements made on the ground served to verify the accuracy of the height map. We are not using those measurements as “ground truth” because we have seen that the manual distress characterization is very dependent on the skill and experience of the rater. Two raters may get different assessments of road condition in cases where the distresses are generally mild. This variability is eliminated by automating the process, which can lead to greater confidence in the overall assessment of network conditions.

The software performs well at correctly forming the height map of the road surfaces (for data collected with the UAS/UAV). In all cases where the image quality was within specifications, the height maps were noise-free, and within required resolutions. Since this map forms the basis of all subsequent distress characterizations, it must be as accurate as possible.

There are some things to note about the current implementation:

1. Sometimes ruts that have deep sections will be identified both as potholes, and ruts (Figure 50). The algorithm could be modified to detect ruts first, then exclude that section of the road from further distress detections.
2. Strings of potholes along the driving direction can be characterized as corrugation (see Figure 51 for an example of this). Again, the algorithm could be modified to prevent this.
3. Roads with a strip of grass in the road surface have poor reconstructions in that region. This causes false alarms (see Figure 52). The algorithm could be modified to handle these situations.

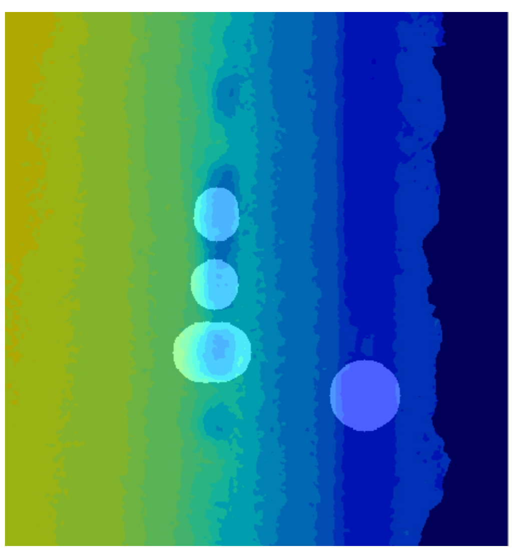


Figure 50: Pothole Detection in Rut.

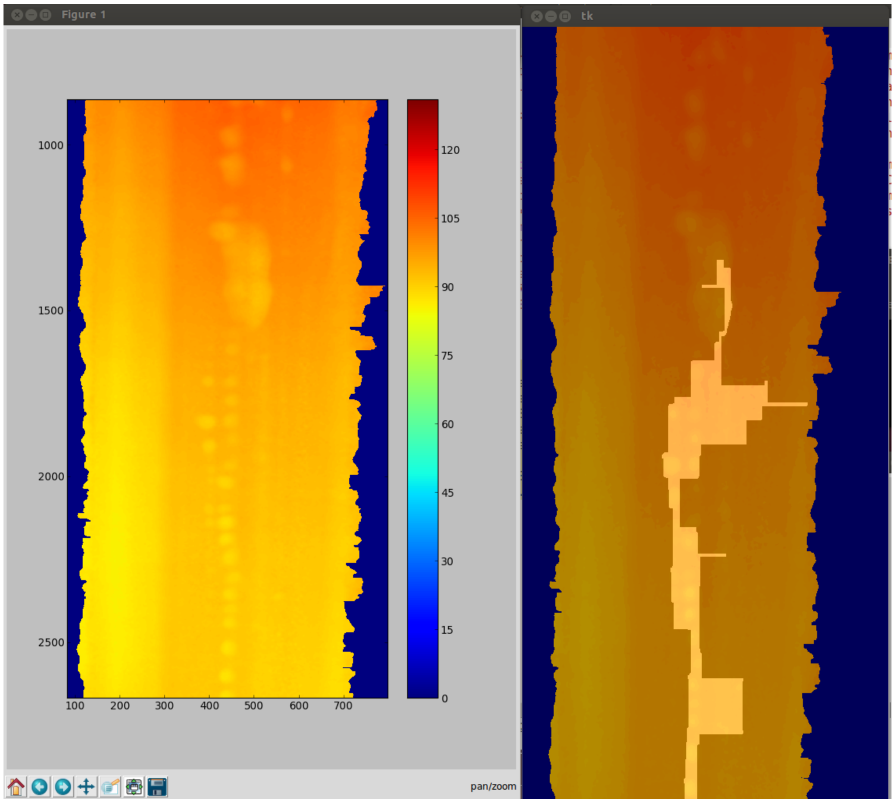


Figure 51: On left is the original image, showing potholes in a line. On the right is a mask showing the detected corrugations.

Figure 52: Road surface with grass strip that causes noisy reconstruction and false pothole detection.

We have shown that the detection of distresses is above 93%, and tends to be better for potholes. The false-alarm rate (i.e., declaring a distress when there is none) is less than 14%, and many of these were potholes found at the very edges of the road; the number could be improved, if necessary, by reducing the size of the mask used to evaluate the distresses. Once a distress is declared 96% for potholes and 70% for ruts are classified into their distress severity categories correctly. Correct classification of corrugation is 23%. The variability inherent in manual measurements due to experience and visual estimation results in measurements much coarser than the algorithms' and it extrapolates damage severity levels to larger areas than the algorithm.

There is, however, a process to make the algorithms' output closer to a human rater, called "supervised training". One would first have an experienced rater (which we lacked) score a number of road segments. One then performs a process to adjust the parameters that control the algorithm detection and classification to produce results close to the human rater. This process was not performed on the current parameters.

Although dust was not one of the distresses that we needed to measure, we noticed that, in cases where the road had very fine-grained material, we could detect and measure tire-tread patterns. In fact, they were sometime detected as corrugations, although would be excluded because they did not meet the height requirements. It may be that the existence of the tread-marks could serve as an indirect measure of fines (although their absence would not imply the lack of fines).

It should be noted that these algorithms all have multiple parameters on which their performance depends, sometimes in a complicated way. We have attempted to choose an operating point for all algorithms that balances detection and classification accuracies with acceptable false-alarm rates. However, different users may find that they must have more (or can accept less) accuracy; the algorithms can be adjusted for better detection rates, at the expense of increased false alarm rates on an application-by-application basis.

In some cases, there may be a need to assess, for example, the accuracy or consistency of a repair. In this case, it is easy to examine the height maps visually, and "measure" the crown, etc. from the displayed height map. Similarly, one can quickly score a road just by looking at the height map; the distresses are visible clearly when the map is displayed on an exaggerated height scale. This could serve as a "quick-look" capability when a complete characterization is not needed, or when the DSS need not be invoked.

Cost Performance Notes about Performance Evaluation:

We recommend being careful in making cost comparisons between remote sensing and manual characterization of road conditions. That is because the remote sensing output (which is abstracted for reporting purposes) is a centimeter-by-centimeter characterization of every part of the road segment. The manual output (compared to the automated output) is, at best, an overview of the road condition. In cases where details are important, these comparisons do not make real sense; getting the same level of detail manually is not only cost prohibitive, it is essentially impossible.

It has been shown that the UAS-based system has a per-mile cost of $0.74 (see the comparative cost section). This would be in addition to the cost of the use of a vehicle ($0.55/mi) to transport the UAS to the measurement site (which is the same cost as driving to the site to perform a manual measurement). The UAS system is actually more cost effective than purely manual rating that tried to gather the same amount and precision of data, while also providing the benefits of vastly more detailed, consistent, and accurate characterizations.

In contrast, we estimate that the manned, fixed-wing solution would cost, under reasonably generous assumptions, to cost $10.26 per mile (or worse). The advantage of such a system is a great reduction in time spent per mile, at an increase in cost. The fixed-wing system is significantly more complicated in practice than the UAS-based system, guiding us towards our hexacopter-based system to be more ready for practical deployment for unpaved road condition assessment.

Section IV: Concept of Operations Description (ConOps)

We have been developing the detailed description of the process of collecting and processing data. This is the so-called "Concept of Operations" (ConOps). The ConOps includes instructions for selecting sites, developing flight plans, pre-flight checks, sensor setup, flight operations, data quality checks, and data selection. Once data are selected, the processing is generally automated up to the point of handing the results to the RoadSoft GIS decision support package.

Background

The first step in assessing unpaved roads is to collect the data that will be used to extract road distresses. Since we evaluated two different collection platforms (manned and unmanned), there will be slightly different ConOps for each. In the discussion to follow, the more detailed unmanned ConOps will be described, with comments about the manned platform in cases where they differ.

There are two possible ways in which a system may be used for data gathering. There is an "in-house" option, where the organization dealing with roads also owns and operates the sensor, and as a contracted service from a company specializing in the data collection (and possibly processing). In the case of a manned platform, in-house ownership and operation are a significant expense, both initially to purchase the aircraft and pilot, and ongoing, for maintenance and operation. We assume that this is unlikely. However, owning and operating a small UAV (also called an Unmanned Aircraft System or UAS) is well within most county agency budgets. For the purposes of this document, we will assume the in-house, unmanned model, and describe those ConOps; the contracted service option would be significantly simpler from the point of view of the customer, since the service organization would be performing the ConOps internally.

System Preparation

The process begins compiling the system and accessories needed to perform a data collection. These include:

1. Platform parts, including the aircraft, batteries, controllers, downlink (if used), and tools for adjusting and mounting things.
2. The sensor, including the camera, lenses, batteries, memory, and intervalometer (used to set the frame rate at which photos are taken).
3. The mission-planning/ground-control system.
4. Support items such as traffic-cones, safety equipment such as vests and goggles, and survey tools, such as tape-measures, marking paint, etc.

As in many processes, a checklist can assist the user in making sure that key steps are not overlooked. As an example, consider the list below as a start for a multi-rotor system preparation checklist:

- Charge all flight batteries
- Charge avionic support batteries (radio, camera, intervalometer, on-screen-display (OSD), etc.)
- Spare rotors (both left and right pitch)
- Tools-kit for platform maintenance and site observations
- Video monitor for OSD
- Tripod
- Battery charger(s)
- Mission-planning system
- Radio controller
- Camera, including lenses, memory cards

- Spare Velcro, zip-ties, and duct-tape
- Road-cones
- Safety glasses
- Safety vests

Once the system components are ready, one needs to select a mission.

Site Selection and Mission Planning

The user needs to select a site to collect. If multiple sites are chosen, their locations should be chosen to minimize flight times and transport between sites. For the unmanned systems we tested, there is a tool that allows one to look at a site from an overhead view (using Google Earth), evaluate obstructions, choose flight lines and site access, and load a flight-path, as first described for this project in Roussi et al. 2012a – Deliverable 6-A (see http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del6A_MissionPlanningSystemReport.pdf). The platform may be programmed either during this process, or on-site, depending on the users' preferences. If fully autonomous flight is not being planned, then the programming step can be skipped.

The mission planning should include at least the following:

1. Launch and recovery locations, with an estimate of needed flight-time and distance traveled. (For a manned mission, it may be necessary to file a flight-plan if the roads are within certain classes of airspace. It is up to the pilot to determine this during mission planning.) Care should be taken to estimate the battery use based on these factors, as well as temperature and wind conditions (since hot, dry weather or high winds will reduce effective flight times). At no time, should usage exceed 75% of battery capacity, to allow for unexpected on-site maneuvers.
2. Verification that the flight path is unobstructed. This includes visual obstructions of the surface, as well as objects in the flight-path, such as power-lines, towers, etc.

Verification that the "fail-safe" return path (taken in the event of radio loss) remains unobstructed throughout the flight-path

System Deployment and Pre-Flight Checks

Once on-site, the system must be deployed in an orderly fashion. A small area to one side of the road is needed for system checks. Again, a checklist can be useful. Consider this example hexacopter checklist:

Hexacopter Pre-Flight Checklist

[ ] Arms deployed and secure
[ ] Props secure and shafts vertical
[ ] Wiring harnesses secure
[ ] All chassis screws/connectors tight
[ ] TX in GPS Mode
[ ] TX Failsafe OFF
[ ] TX Throttle Trim LOW
[ ] TX Rudder, Aileron and Elevator Trims NEUTRAL
[ ] AUX4 - NEUTRAL (not in POI or HOME mode)
[ ] TX Throttle LOW
[ ] Camera platform horizontal
[ ] Power-ON TX
[ ] Power-ON Aircraft (26,000mAh)
[ ] Power ON Video Downlink

[ ] Power ON DVR
[ ] Camera lens-cap OFF
[ ] New card inserted in camera
[ ] Power-ON camera and set mode, exposure, aperture
[ ] Power-ON Camera Controller
[ ] DVR to REC
[ ] Test camera platform
[ ] Aircraft HOT Verify Adequate Satellite Link (no red flashes)
[ ] Aircraft HOT Test Spool-up
[ ] Aircraft HOT ……ready for launch

This particular checklist is detailed and specific to the radio controller and autopilot being used. It is important that all switches on the controller be checked; if something is in the wrong position, unexpected behaviors can result, with possibly dangerous outcomes.

For a manned mission, the checklist for the pilot would include the normal checks of aircraft flight-readiness, and include the checks for the camera and controller.

Flight and Data Collection

At this point, the road should be closed to through traffic for several reasons. Vehicles moving through the scene may obstruct features, preventing their reconstruction. Also, if there is a failure in flight, this ensures that the aircraft is not run over (should it have to land quickly) and that vehicles are not hit with falling debris, which can cause direct damage, or loss of control by the driver, causing secondary damage. For a manned mission, this is not necessary, although traffic on the road can prevent full reconstruction. As technologies advance, we would anticipate the ability to not close roads for UAV-based collections, but we recommend caution for the time being to ensure safety.

Once the road is secure, flight operations can begin. Although fully autonomous launch is possible, it is preferred to take off manually, verify that the aircraft is behaving normally at a low hover, point the camera platform at the ground, take it to altitude, and then commence autonomous flight. This gives one extra confidence that preparations were complete.

During the data collection, there should be a trained pilot either in control, or ready to assume control, at all times. It is also desirable to have a second "spotter" keeping track of the OSD outputs (such as battery voltage, speed, and altitude), while the pilot keeps track of the aircraft attitude and flightpath. This is especially important if flight conditions are severe, since the pilot should not be distracted.

The typical unmanned flight parameters used during this program are listed below.

- Altitude 20m-30m (with a 50mm prime lens) – this ensures that the road and ditches are fully imaged. Lower altitudes provide better resolution, while higher altitudes provide more overlap between images.
- Forward velocity: 2m/s – this reduces motion blur, while providing a reasonable speed.
- Camera controller set at 2 frames/sec – this gives enough overlap in adjacent images to obtain high-resolution 3D reconstruction.
- Camera in manual exposure mode with shutter speed <= 1/500s, aperture 2 stops from full open, and ISO adjusted for proper exposure – this ensures that there is no motion blur, images are crisp across the entire field-of-view, and that they are properly exposed.

The typical manned parameters are somewhat different:

- Altitude ~200m (with a 200mm lens)
- ~60kn airspeed (ground speed should not exceed ~75kn)

- Camera controller set at 2fps
- Camera in manual exposure mode, with settings as listed above

At the end of the unmanned flight, although auto-landing is possible, this is time-consuming, and it is preferred that the pilot take over and land the aircraft manually. This is particularly important when the mission is approaching the maximum time-limit.

Post-flight Checks

Once the UAS has landed, there are some steps to end the process.

[ ] Throttle to LOW
[ ] Power-OFF camera
[ ] Camera lens-cap ON
[ ] Power-OFF camera controller
[ ] DVR to STOP
[ ] Power-OFF Aircraft
[ ] Power-OFF TX
[ ] Power-OFF Video Downlink
[ ] Power-OFF DVR
[ ] Stow hexacopter and gear for transport

At this point, it is likely to be worthwhile to verify that the data that were collected are acceptable in terms of focus, exposure, and overlap. A typical collection will consist of 1 image per meter of road imaged. This corresponds to 20GB of data per kilometer for this sensor.

Administrative Issues

It should be noted that current (as of October 2013) FAA regulations do not adequately address UAS operations for private entities. At this time, establishing a commercial service to perform these measurements is prohibited by 2007 FAA guidelines. The FAA document 14 CFR Part 91 (http://www.faa.gov/about/initiatives/uas/reg/media/frnotice_uas.pdf) specifically excludes individuals or companies flying model aircraft for business (commercial) purposes. This may change by 2015, when the FAA has to have established regulations dealing with Unmanned Aerial Systems (UASs) in the National Airspace System (NAS). The same document also prohibits UAS flights within the NAS without prior approval. For public entities (such as the USDOT), the process of operating a UAS involves obtaining a Certificate of Authorization (COA) for a particular mission. Each mission must have its own COA, which effectively prevents the current use of UASs for arbitrary unpaved road assessment. Thus, under current FAA guidelines, there is no way to deploy an unmanned system for this purpose. However, some agencies with COAs have been able to get them reapproved within relatively short time periods (< 1 month), thus allowing some practical current usage. The FAA has stated that it expects to have small UAS (sUAS) regulations formulated by 2015 and we expect these will significantly increase the practical usage of UASs for unpaved road assessment.

In November, 2013, the FAA released their "roadmap" for integration of civil UAS in the NAS[1]. It says, in part, "Ultimately, UAS must be integrated into the NAS without reducing existing capacity, decreasing safety, negatively impacting current operators, or increasing the risk to airspace users or persons and property on the ground any more than the integration of comparable new and novel technologies." They recognize that the rules and regulations that have been established (and which been very effective at ensuring safe operations) for manned aircraft do not map well onto UAS operations. In particular small UAS (sUAS) are called out as exceptions to most of the expected regulations (e.g. design and airworthiness certifications, filing IFR flight plans, etc.). The FAA UAS Comprehensive Plan[2] states "A Notice of Proposed Rulemaking (NPRM) on small UAS is under development with the intent to provide safe small UAS access to the NAS. The NPRM for small UAS is being drafted and is targeted for release in 2014." The first two stated goals are to allow both public and civil sUAS VLOS operations in the NAS without special authorizations (i.e. COAs or Special Airworthiness Certificates). Based on these documents, it seems likely that regulations allowing sUAS operations in line-of-sight (LOS) without prior certification or approval will be in place within the next several years. This is what we expect will make deployment of small Unmanned Aerial Systems much more practical for transportation infrastructure assessment, including unpaved roads.

In contrast to sUAS operations, deploying a manned system is quite easy at this time, although if any of the sites lie under anything but Class G (uncontrolled) airspace, the procedures can become more complicated for the pilot (especially if any of the sites lie under Class B airspace, around major metropolitan areas).

[1] http://www.faa.gov/about/initiatives/uas/media/UAS_Roadmap_2013.pdf

[2] http://www.faa.gov/about/office_org/headquarters_offices/agi/reports/media/UAS_Comprehensive_Plan.pdf

Section V: Comparative Cost Analysis

Background Considerations for Data Collection Costs

Data collection is usually the single largest cost in an asset management program, so effective management systems need a source of reliable, low cost data. Challenges when comparing the costs of distress data collection for unpaved roads include the comparison of equipment versus labor requirements across methods, the differences in labor requirements, and unavailability of reliable sources of cost information.

Most distress data collection methods are labor intensive and have few capital equipment requirements (Department of the Army 1995, Huntington G. 2011a, Cline 2003, UNH TTC 2011, Goodspeed 1994, WTTC 2010, Walker 2002 2011) so they can be easily compared to each other. Remote sensing methods can require significant capital investment; in this project's primary example platform, this includes the purchase of a UAV, the sensor, and associated software for image analysis. Automated methods that rely on equipment are difficult to compare to labor intensive methods because of these large capital investment costs for equipment and accompanying amortization assumptions which can greatly influence the outcome of the cost comparison.

Reliable cost information for unpaved road distress data collection is largely unavailable in published literature; very few studies that consider data collection efficiency or costs exist. Most cost information that is available for unpaved road data collection is from practitioners who have a history of collecting data with a specific method. In most cases this cost data is only available in the form of production rate estimates rather than formal studies. In some cases, cost information for collection of distress data for paved roads can be used to estimate costs for unpaved road collection due to the similarity of the methods, but it should be noted that when this is done, it is not an exact comparison (Huntington 2011 2013, Cline et al. 2003, Goodspeed 2011 2013, CRAM MDOT n.d.).

This cost analysis compares the costs derived from available information from several methods of unpaved road assessment and remote sensing data collection. Only methods that collect the Unsurfaced Road Condition Index (URCI) data are a direct comparison with the level of data that is produced by the remote sensing system developed for this project because the remote sensing system reported here was developed to collect URCI input data, such as the amount and severity of potholes, washboarding/corrugation, and ruts along with crown levels. Other data collection costs reported here were estimated for rating methods such as PASER and RSMS. However, it should be noted that the URCI, RSMS, and PASER method vary in terms of labor, with PASER being the least intensive, URCI the most intensive, and RSMS method falling somewhere in the between. It should also be noted that PASER and RSMS condition assessment methods produce different types of data than the URCI method, so they should not be directly compared to the remote sensing system.

Cost Basis Assumptions

Total costs for a particular rating method can be greatly influenced by assumptions made in the analysis. To compare costs across methods, assumptions were made by the research team to illustrate conditions that a transportation agency would likely encounter during data collection and for arriving at a total cost. In this cost comparison the following general assumptions are made:

- Only drive time of actual collection is included, it is assumed that the URCI method will require the same amount of transit between locations regardless if it is UAV collected or manually collected with an observer, because in both cases the representative analysis segments have to be visited..
- The majority of the roads are moderately distressed sections with multiple distresses and severities.

- Trained/experienced raters are rating efficiently (no training time or learning curve).
- Labor costs are similar for all staff completing activities: $40 per hour for trained technician or engineer.
- Capital costs for significant, specialized equipment (single use equipment or software not likely to be normally present at a transportation agency) will be amortized over its assumed useful life. Standard equipment like handheld GPS or office computers are assumed to be available at no cost as agencies are most likely to already own these.
- Cost data that is more than a year or two old will be equated to 2013 costs using a consumer price index calculator.

Calculations are provided here for each method. Assumptions should be modified as agencies deem necessary for their own priorities.

Manual Unsurfaced Road Condition Index (URCI): Wyoming, Ground Truth

The URCI method was originally developed as a manual data collection method using simple measuring devices and paper collection forms (Department of the Army 1995). The process is relatively labor intensive because each distress type and severity must be field measured and recorded by hand; however, it provides a relatively complete picture of the severity of unpaved roar distress. Samples are collected that each represent larger parts of the road network. Typically two-100 foot long sample segments can represent up to one mile of road. The identification of sample segment locations from year to year can be difficult since they are usually manually marked with stakes which may be removed or damaged from year to year (Department of the Army 1995).

Two sources of data were available for production rates and cost estimates for URCI manual collection. Phone interviews were conducted with George Huntington, P.E. from the University of Wyoming – a source familiar with all types of unsurfaced road condition assessments – (Huntington G. 2011a) and ground truth collection efforts completed during this project – to verify remote sensing efforts and to determine a production rate for URCI standard data collection.

Huntington conducted extensive unpaved road assessments using multiple road distress identification methods over the last several years in an effort to assist local and state road agencies management of increases in unpaved road distress in the state of Wyoming (Huntington G. 2011a). According to estimates from Huntington, a team of two trained people can collect URCI data on a road sampling segment in approximately 30 to 45 minutes once they have identified the sample site (Huntington G. 2011a). An additional 30 minutes (one person) was necessary to calculate deduct points and tally the final URCI rating using the manual curve graphs for each sampling location.

Cost estimate for Wyoming Manual Unsurfaced Road Condition Index (URCI)

- Assessment – 2 staff x $40/hr x 0.75hr + 1 staff x $40/hr x 0.5 hr = $80 per segment
- Assume 2 sample segments per mile of road represented = $80 x 2 = $160 per mile of unpaved road in the network

The purpose of ground truth verification was to collect data from the sample locations to compare it to the data acquired by the remote sensing system for at least spot-checking of analyzed results. Two person teams evaluated the distress extent and severity using basic measuring devices (hand tapes and wheel tapes) for ground truth verification. For distress quantification of the cross section and drainage condition a rapid and accurate measurement system using a water level and tape measure was applied. Ground truth collections were more intensive than standard production data collection as indicated by the increased time of collection, thus these measurements most likely provided more accurate data, but also lead to higher cost per mile. The amount of time to collect the data also depended on the severity of the distresses; we found that sites with dense distresses could take up to 1.5 hours.

Cost estimate for Manual URCI Ground Truth Collection:

- Assessment moderate distress– 2 staff x $40/hr x 1.0hr + 1 staff x $40/hr x 0.5 hr = $100 per segment.
- Assessment high distress 2 staff x $40/hr x 1.5hr + 1 staff x $40/hr x 0.5 hr = $140 per segment.
- $Assuming a 2 sample segments per mile of road represented = $100 X 2 = $200 per mile of road represented for moderate distress
- Assuming a 2 sample segments per mile of road represented = $140 X 2 = $280 per mile of road represented for high distress

Automated and Manual Pavement Condition Index (PCI): Army Cold Region Laboratory

The Pavement Condition Index (PCI) distress assessment method for paved roads was originally pioneered by Mohamed Y. Shahin at the Army Cold Region Laboratory (Cline et al. 2003). The PCI method assesses sample segments for severity and extent of several classifications of distresses. Field measurements of distresses are used to calculate deduct points which in turn are used to create an overall quality index. The URCI method for unsurfaced roads is a modification of the PCI method (Department of the Army 1995). The PCI method and the URCI method are very similar in application and assessment.

A 2003 study from Naval Pavement Center of Expertise assessed the cost of PCI data collected by automated and manual means (Cline et al. 2003, see Figure 53). The study concluded that the cost for either manual or automated collection was approximately the same at approximately $0.10/yd^2 of pavement data collected for areas greater than 100,000 yd^2 (Cline et al. 2003). Since the PCI and URCI methods are very similar, it is likely that PCI assessments can be used to estimate URCI measurements.

Cost estimate for Pavement Condition Index (PCI) Automated collection

- Assume a standard road segment with two **-** 12 foot wide lanes by 100 feet long sampling segment.
- Assume $0.10/yd^2 (2003 cost index) for collection costs (Cline et al. 2003).
- $0.1 yd^2 x 100' x 24' /9 ft^2/ yd^2 = $27 per segment (2003 cost index).
- Assume 2 sample segments per mile of road are represented = $27 x 2 = $54 per mile of road represented.
- Using a consumer price index calculator from 2003 to 2013 yields costs of $34.23 / segment and $66.10 per mile respectively in 2013 dollars.

The Cline study also concluded that manual data collection costs per yard were significantly higher for smaller areas of collection. Figure 53 below illustrates the change in cost per square yard for varying areas of assessment. It is likely that a typical local agency using manual collection would have between 50,000 and 100,000 ft^2 of surveyed area each year, which would produce a cost of approximately $0.15 / yd^2 for manual collection (Cline et al. 2003).

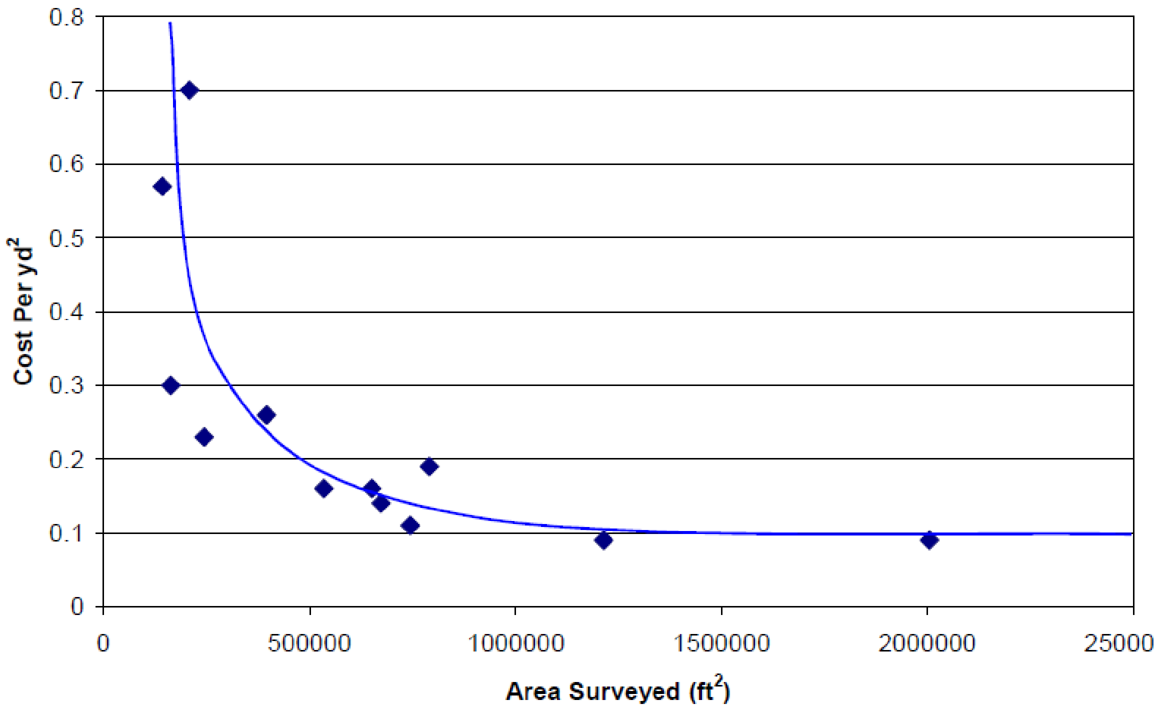


Figure 53: Manual PCI data collection costs (Cline et al. 2003).

Cost estimate for Manual Pavement Condition Index (PCI) collection

- Assume a standard road segment with two - 12 foot wide lanes x 100 feet long sampling segment.
- Assume $0.15/yd^2 (2003 cost index) for collection costs (Cline et al. 2003).
- $0.15 yd^2 x 100' x 24' /9 ft^2/ yd^2 = $40 per segment.
- Assume 2 sample segments per mile of road = $40 x 2 = $80 per mile of road.
- Using a consumer price index calculator, costs converted from 2003 to 2013 yields costs of $50.84 / segment and $101.68 per mile respectively in 2013 dollars.

Road Surface Management System (RSMS): University of New Hampshire (UNH)/FHWA

The Road Surface Management System (RSMS) is a data collection method that generates distress data with a similar level of complexity as the URCI method. The main difference between RSMS and URCI is that RSMS uses visual assessment (Goodspeed et al. 1994) to estimate the extent of distresses while the URCI method relies on physical measurement. Because RSMS relies on visual assessment, it can be completed quickly. However it requires that every mile of road must be driven, inspected and rated during a rating event, as opposed to the URCI method that only requires two 100-foot segments to be measured per road mile. More information on the RSMS method is included in project deliverable 2A – State of The Practice for Unpaved Road Condition Assessment (Brooks et al. 2011b).

According to the University of New Hampshire, a trained rating team using hand held GIS devices can collect rating data for a town of approximately 50 road miles in approximately two days (Goodspeed 2011). Goodspeed (2011) recommended that two people are necessary for data collection, one to driver and one observer. Three passes of road segment are recommended depending on the road segment.

- First pass: This pass determines the length of road segment has and that uniform cross sectional properties exist. This is normally not needed in residential or urbanized areas as a road section is typically defined from one intersection to another.
- Second pass: The observer records the 9 stress characteristics of the road as defined in the RSMS system. Each distress is rated for severity and extent of the severity.
- Third pass: This pass is driven at the posted speed so the roughness of the road can be judged.

According to Goodspeed (2013), 10 to 20 miles a day can be rated depending on the locations of the roads to be rated. More roads can be rated if the roads are densely located. Analysis of the data to develop a maintenance schedule to correct the deterioration takes one or two days (Goodspeed 2013).

Cost estimate for RSMS (manual)

- Low productivity estimate: 2 staff x $40/hr x 8 hr/day / 10 miles per day rated + $0.55 per mile for vehicle x 3 passes = $65.65 per mile rated.
- High productivity estimate 2 staff x $40/hr x 8 hr day / 20 miles per day rated + $0.55 per mile for vehicle x 3 passes = $33.65 per mile rated.
- These costs do not include cost of the GPS equipment or software which is assumed to be available at the local agency.

Wyoming Modifications of the PASER System

The PASER rating system is a visual distress rating system that uses the presence and extent of road distresses to characterize unpaved roads into one of four or five rating categories for an overall characteristic of the road in question (WTTC 2010). The level of data that is produced by PASER is much less detailed than the URCI method, because each sample is only represented by the rating category it is placed in; no intermediate measures are recorded for specific distresses. Fewer visual rating categories allows for rapid data collection for PASER compared to the higher investment of time required to collect quantitative data in the URCI method.

Staff from the University of Wyoming modified the PASER system to include additional criteria for rating that included an assessment of comfortable riding speed (WTTC 2010). More information on the Wyoming Modified PASER method is included in project deliverable 2A – State of The Practice for Unpaved Road Condition Assessment (Brooks et al. 2011b).

Huntington from the University of Wyoming summarized the use of the modified PASER rating system on local agency roads. The University of Wyoming team concluded the most efficient team consisted of two raters in a vehicle with one rating and recording while the other drives the vehicle. The two person team rated approximately 10 miles per hour rated for a team of two collecting both PASER distress data and ride data (Huntington 2011).

Cost estimate for Wyoming Modified PASER

- (8 hours x 2 staff x $40/ hour)/80 miles per day + $0.55/mile = $ 8.55 / mile

Michigan PASER Study

Transportation agencies in Michigan extensively use the PASER rating system to collect paved road data on an annual basis (Cambridge Systematics, Inc. 2007). PASER is different from URCI in that every mile of road must be driven, inspected and rated during a rating event. During a pilot rating study, the County Road Association of Michigan and the Michigan Department of Transportation extensively evaluated the cost to collect PASER data on a mix of paved and unpaved roads through a series of benchmarking tests in a number of different counties (CRAM MDOT n.d). The report concluded that teams of three (one driver, one data recorder, and one rater) could collect PASER data at an overall average speed of 16 mph for a mix of urban and rural agencies (CRAM MDOT n.d.).

Cost estimate for Michigan PASER

- 16 mph collection speed average
- 8 hours x 3 staff x $40 hours/128 miles + 128 miles * $0.55 / mile / 128 miles per day = $ 8.05 / Mile

Table 11 summarizes the costs of the various manual distress identification methods. Further comments are made when comparing these results to the UAV-based system and manned fixed-wing aircraft-based system.

Table 11: Data collection costs for selected distress identification methods.

Rating Method	$/sample segment	$/Mile
Wyoming Manual URCI (Huntington 2013)	$80	$160*
Manual URCI Ground Truth Collection moderate distress	$100	$200*
Manual URCI Ground Truth Collection high distress	$140	$280*
Army Cold Regions Automated PCI (Cline et al. 2003)	$34.23	$66.10
Army Cold Regions Manual PCI – low total area (Cline et al. 2003)	$50.84	$101.68
UNH/FHWA: RSMS – high productivity estimate (Goodspeed 2011 2013)	NA	$33.65
UNH/FHWA: RSMS – low productivity estimate (Goodspeed 2011 2013)	NA	$65.65
Wyoming Modifications of the PASER Method (Huntington 2011 2013)	NA	$8.55
Michigan PASER Method (CRAM MDOT n.d.)	NA	$8.05

** Note that this is cost per mile of road rated; with the URCI, a pair of 100-foot segments represents approximately a mile of assessed road; these costs should be divided by 26.4 (5280 feet or 1 mile divided by 200 feet) to directly compare them to rating methods that require every mile of the road to be assessed (see below in the UAV data collection rate explanation for more on this)*

Data Collection Rate for UAV System

The remote sensing system requires a moderate capital investment to purchase the UAV, the sensor and the associated software for data reduction. Most traditional data collection methods discussed in this study do not require a similar level of capital investment, but rather are labor intensive. The capital cost for the UAV system, while not excessive, must be considered in the cost analysis since road agencies do not typically own this type of equipment. For example, the Bergen Hexacopter used in the second field season cost $5400 including spare batteries (this included mission planning software), the Nikon D800 camera cost $3,000 (without lens), the intervalometer (to set photo frame rates) cost us $100, and the Nikon 50mm f/1.4 lens cost $500. The capital cost of this type of equipment must also be amortized over its useful life including the number of miles of data collected during its useful life. Two cost scenarios are presented here with differing capital cost amortization assumptions:

- Operation of the UAV system as a stand-alone or add on commercial service for firms engaged in aerial survey activity (Scenario 1).
- Operation of the UAV by a road owning agency collecting data once a year for its own purposes (Scenario 2).

UAV Cost Amortization of Capital Equipment – Scenario 1

- Assume the UAV unit is purchased and operates as a commercial service.
- Assume the UAV unit operates continuously during snow free months (April to October).
- Assume data is collected 3 days a week for 8 hours a day (60% use).
- Assume the units will last 3 years with modest maintenance
- Amortize costs based on the production rate (miles or segments) per hour x 10 hr a day x 3 days/ wk x 21 weeks.

UAV Cost Amortization of Capital Equipment – Scenario 2

- Assume the UAV unit is purchased and is operated by an agency.
- Assume unit operates only on agency owned roads or neighboring agency roads once per year (per road)
- Assume the units with last up to 3 years with modest maintenance
- Assume the agency collects data for 300 miles of gravel road each year; two sample locations per mile.
- Amortize costs based on up to 600 sample locations per year.

UAV Operation and Maintenance Costs – Scenario 1

- Batteries will need to be replaced every 300 charge-cycles (3000 flights - one flight per segment, 90 seconds each, for a total of 10 segments per charge) at a cost of $250. For the assumed 2 segments per mile, then battery replacement will be needed every 1500 miles of roads sampled.
- Assuming one typical hard landing (free fall from 5m) per year, $300 in mechanical repairs.
- Assume replacing two motors per year, for a total cost of $160.
- Production rate while at the site for continuous measurement is approximately 350' road-feet per flight-minute (106 road-meters per flight minute, or slightly under our normal 2 m/s flight speed). This translates into about 1 mile of measured road before batteries must be charged (or swapped). This is approximately 3 miles per hour, about 75 miles per week. For 2 samples per mile, the rate is 6 miles per hour, or 144 miles per work week.
- Processing of the data requires 2 hours per segment, or 576 CPU hours per week (for 144 miles). For a typical 4-core, dedicated, system, this would be 144 elapsed hours per week (essentially 1 hour of elapsed time for every mile of sampled road data).

Yearly production 21 weeks X 75 miles per week = 1,575 miles per year

It should be recalled, though, that one mile of physically measured road with URCIs represents a road network approximately 26.4 times larger, using the idea of two 100-foot segments representing one mile of road; 5280 feet (one mile) divided by 200 feet (the two representative segments) equals 26.4. So 1,575 miles of physically measured miles represents a road network of up to 41,580 miles in length.

- Yearly maintenance cost: $300 (to cover repairs after hard landing) + $160 (replacement of motors) + $250 (one set of batteries) = $710/ yr
- Capital cost for hexacoptor, sensor and controls $9000 / 3 years of service = $3000 / yr
- Labor cost for collection: 24 hours / week collection X 1 staff X $40 / hr X 21 Wk= $20,160 / yr

- Data post processing time 8 hr / wk X 21 wk/yr X $40/hr = $6,720 / yr
- Total yearly cost = $30,590

Cost per mile rated $30,590/yr/1575 mi/yr = $19.42/mi rated. To put this in terms of represented road network rather than physically measured amount of road, the cost for UAV scenario 1 (stand alone/commercial service) drops all the way to $30,590/year divided by 41,580 mi/year or $0.74/mile.

Applying same assumptions to manual URCI data collection costs of $160 per mile (Wyoming URCI data) to $280 per mile (our heavy distress manual URCI scenario), which are the most comparable to our UAV based methods and results, this gives a cost of $6.06 per mile assessed up to $10.61 per mile assessed (and $7.58 per mile assessed for our moderate distress manual URCI scenario. The importance of the URCI segment-based data collections representing a larger road network should not be under-emphasized when comparing costs.

Operation and Maintenance Costs – Scenario 2

Yearly production: 300 mi/year / X 75 miles per week = 4 weeks of collection per year

- Yearly maintenance cost: $300 (hard landing) + $160 (motors) + $250/3 (one set of batteries every three years) = $540/ yr
- Capital cost for hexicoptor sensor and controls $9000 / 3 years of service = $3000 / yr
- Labor cost for collection: 24 hours / Wk collection X 1 staff X $40 / hr X 4 Wk= $3,840 / yr
- Data post processing time 8 hr / wk X 4 wk/yr X $40/hr = $1,280 / yr
- Total yearly cost = $8,660

Cost per mile rated $8,660/ yr/300 mi/yr = $28.86/mi rated

Again, converting this to miles per year assessed, because two 100-foot rated segments represent approximately a mile of road with the URCI method, this gives a cost of $1.09 per mile of road assessed.

Cost of Fixed Wing Aircraft Collection

The cost of fixed-wing aircraft unpaved road assessment is not directly comparable to the UAV based methods, because the low-cost Nikon D800 sensor ($3500 including lens) does not produce the needed ground sample resolution for reconstructed 3D data, even when flown as low as possible (500' / 150 m). However, here we assume a more advanced, more expensive three-camera system would be capable of collecting the needed data, at a sensor system cost of approximately $10,000. Assume collecting one agency per day with 300 miles of road to collect.

We also explicitly assume here: Flight time 0.25 hr for actual collection time at 75 mph, assume 1 hour total time collection to assess several pairs of URCI segments. The total cost is very sensitive to the number of URCI segment pairs that can be assessed in an hour of flight time. In our southeast Michigan experience, our 5 sites in Lenawee County, Michigan could have been flown over with one hour of flight time starting in Ann Arbor, MI, and each site represents one mile of assessed road with two segments per site. This means 1000 feet (5 sites X 200 feet per site) of road are collected per mile flown. 300 miles of road needing to be collected divided by 5 sites assessed per flight equals 60 flights.

- Plane costs $160/hr X 1 hr = $160 / assessment flight
- Total plane costs = $160/hour X 60 one-hour flights = $9600
- Cost of Sensor $10000 / 3yr = $3500 / yr
- Staff time for collection = $40/hr X 1 hr = $40 / agency X 60 flights = $2,400 (to fly in the airplane to operate the equipment)

- Data post processing time 21 hr (for a 21-week data collection season, assuming 1 hour to cover process time per week of collection) X $40/hr = $840 / agency
- Total cost assuming 1 agency collected: $16,340 / agency

Cost per mile assessed $16,340/year for 300 mi/yr = $54.47/mi assessed (it is noteworthy that these costs are already in cost per mile of assessed road).

If we instead assume that every mile flown includes data constantly being collected for assessment, then instead of getting 1000 feet of road per mile flown we would get 5280 feet per mile flown (1:1); this drops the cost by a factor of 5.3X, yielding a cost of $10.26/mi assessed. While competitive with some manual methods, this is still significantly more expensive than our UAV-based methods, largely because of flight time costs and staff time to ensure sensor operation while in flight.

Section VI: Concluding Discussion

During the process of evaluation the performance of the system, and the associated software, several important issues arose. The successful operation of the system depends on certain key factors:

1. The quality of the 3D reconstruction is the key to a good characterization. All measurements of the road are derived from this reconstruction, and for those measurements to be accurate, the reconstruction must meet certain minimum standards, influenced by the collection:
    a. The camera MUST be set up to avoid blurring of the images, either from motion artifacts, or lens misfocus. That means careful preparation of the sensor before flight is essential, with a clear understanding of the causes of blurring.
    b. The combination of field-of-view of the sensor, and ground sample spacing of image pixels, must be such that at least 10 degrees of angular diversity are seen between images, and the samples be no larger than 1cm. In practice, this means that, for current sensors, one must not fly at an altitude of no more than 100'-150' (30 m to 45 m).
    c. To avoid having to tune software parameters, it is important that images be properly exposed; over- or under-exposure will result in either lack or surface detail, or poor camera location estimation (resulting in poor reconstruction).

In short, understanding the interplay of aperture, shutter-speed, and ISO settings is key to be able to set up the sensor for a high-quality collection. Fortunately, this can be provided in a table, to allow non-experts to be able to be assured of useful measurements.

2. The formation of the "watertight" surface from the 3D reconstructed point cloud MUST NOT perform too much smoothing. It is important that rapid changes in surface profile be preserved when forming the surface, in order to be able to find those distresses that are characterized by local height changes (e.g. potholes and ruts).

Fixed-wing collections, using the sensor system appropriate for small UASs, had several issues:

1. Pointing accuracy – because the lens needed to obtain sufficient resolution was imaging a relatively small area on the ground, it was difficult for the pilot to keep the aircraft stable enough to keep the road in the field-of-view of the camera. Any slight attitude adjustments led to slewing of the images. A gimbaled, stabilized camera mount would be needed, and this was outside the scope of this effort.
2. At the minimum possible altitude for safe flight (500' / 150 m), the angular diversity of a nadir-looking camera was insufficient to reconstruct accurate 3D surfaces. This could be corrected in three ways (all outside the scope of this effort):
    a. Using three cameras, one pointing forward, one nadir, and one astern, and combining the images to obtain enough angular extent.
    b. Multiple passes over the same road, using a single camera, but changing the angle from oblique to nadir between passes.
    c. Combining a wider-angle lens with a much larger sensor (4-5 times the number of pixels).
3. Under overcast conditions, or windy conditions, the camera could not be adjusted to obtain crisp images. Using a much higher-quality lens (on the order of $10,000 per lens) would be needed.

We plan to conclude the discussion of optimal 3D data reconstruction, tuned algorithms, assessment costs and their associated assumptions, and our comparison between small UAS and fixed-wing based collections in the project report. Based on the results detailed in this performance evaluation report, the time appears to be right for a more intensive outreach period to communicate project successes, challenges, and detailed findings to the transportation community concerned with effective and timely assessment of unpaved road condition.

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Appendix B. Unpaved Roads Assessment Technology Feasibility Questionnaire from South Dakota Demonstration

MichiganTech Research Institute

Unpaved Roads Assessment Technology Feasibility Questionnaire

Name: ________________________ Title: ____________________________

Agency: ____

Desired Purchase Model

Rank 1 – 3 with 1 indicating the most likely method you would be interested in, or indicate if you are not interested in using this based upon your information today.

- Purchase Hardware & *In-House* Software Data Analysis: 3
- Purchase Hardware & *Outsource* Software Data Analysis: 2
- Purchase Service – "Pay as you Go": 1
- Not Interested: ______________

Price-Point

Estimate the range or price point which you would reasonably feel you (or your representative agencies) could dedicate to this service or product.

- Purchase Hardware $____________
- Purchase Software License $____________
- Price per Mile $____________
- Annual Budget *Possible* to Invest in Asset Management $____________

How often would you use this equipment and software system?

When would you use this equipment and software?

Unpaved Roads Assessment Technology Feasibility Questionnaire

Continued...

How would using this equipment <u>save you money</u>?

How would using this equipment <u>save you time</u>?

How <u>would this equipment be an improvement over</u> current road assessment?

What concerns do you have about this equipment <u>being practical or useful</u> for your agency?

What questions or concerns do you have about <u>training</u> for use of the equipment?

What questions or concerns do you have about <u>maintenance</u> of the equipment or software?

Do you have any other comments regarding the system you would like to add?

If you would like us to follow-up with you after today, please list your phone number below and a team member will contact you. Thank you!!

Phone #:____

Michigan Tech Research Institute

Unpaved Roads Assessment Technology Feasibility Questionnaire

Name: Pat Brueggemann Title: Systems Engineer

Agency: SD DOT

Desired Purchase Model

Rank 1 – 3 with 1 indicating the most likely method you would be interested in, or indicate if you are not interested in using this based upon your information today.

- Purchase Hardware & *In-House* Software Data Analysis: ____________
- Purchase Hardware & *Outsource* Software Data Analysis: ____________
- Purchase Service – "Pay as you Go": ____________
- Not Interested: ____________

Price-Point

Estimate the range or price point which you would reasonably feel you (or your representative agencies) could dedicate to this service or product.

- Purchase Hardware $____________
- Purchase Software License $____________
- Price per Mile $____________
- Annual Budget *Possible* to Invest in Asset Management $____________

How often would you use this equipment and software system?

I think it would be used atleast monthly

Time of year would

When would you use this equipment and software?

Inventory, site monitoring, Picking location for RWIS stations and Permanent DMS signs

Unpaved Roads Assessment Technology Feasibility Questionnaire

Continued…

How would using this equipment save you money?

Making less site visits

How would using this equipment save you time?

less site visits

How would this equipment be an improvement over current road assessment?

What concerns do you have about this equipment being practical or useful for your agency?

What questions or concerns do you have about training for use of the equipment?

What questions or concerns do you have about maintenance of the equipment or software?

Do you have any other comments regarding the system you would like to add?

If you would like us to follow-up with you after today, please list your phone number below and a team member will contact you. Thank you!!

Phone #:____

MichiganTech Research Institute

Unpaved Roads Assessment Technology Feasibility Questionnaire

Name: Tyson Hasz Title: Research Engineer
Agency: SD DOT

Desired Purchase Model

Rank 1 – 3 with 1 indicating the most likely method you would be interested in, or indicate if you are not interested in using this based upon your information today.

- Purchase Hardware & *In-House* Software Data Analysis: 2
- Purchase Hardware & *Outsource* Software Data Analysis: 1
- Purchase Service – "Pay as you Go": 3

- Not Interested: ______________

Price-Point

Estimate the range or price point which you would reasonably feel you (or your representative agencies) could dedicate to this service or product.

- Purchase Hardware $____________
- Purchase Software License $____________
- Price per Mile $____________
- Annual Budget *Possible* to Invest in Asset Management $____________

How often would you use this equipment and software system?

Whenever it is necessary.

When would you use this equipment and software?

Disasters, road condition evaluations

Unpaved Roads Assessment Technology Feasibility Questionnaire

Continued…

How would using this equipment save you money?

How would using this equipment save you time?

How would this equipment be an improvement over current road assessment?

What concerns do you have about this equipment being practical or useful for your agency?

What questions or concerns do you have about training for use of the equipment?

What questions or concerns do you have about maintenance of the equipment or software?

Do you have any other comments regarding the system you would like to add?

If you would like us to follow-up with you after today, please list your phone number below and a team member will contact you. Thank you!!

Phone #:____

MichiganTech **Research Institute**

Unpaved Roads Assessment Technology Feasibility Questionnaire

Name: Alyssa Clemen Title: Graduate Assistant

Agency: SD LTAP

Desired Purchase Model

Rank 1 – 3 with 1 indicating the most likely method you would be interested in, or indicate if you are not interested in using this based upon your information today.

- Purchase Hardware & *In-House* Software Data Analysis: ____________
- Purchase Hardware & *Outsource* Software Data Analysis: _____________
- Purchase Service – "Pay as you Go":___________
- Not Interested:______________

Price-Point

Estimate the range or price point which you would reasonably feel you (or your representative agencies) could dedicate to this service or product.

- Purchase Hardware $____________
- Purchase Software License $____________
- Price per Mile $____________
- Annual Budget *Possible* to Invest in Asset Management $____________

How often would you use this equipment and software system?

- accessing current conditions

When would you use this equipment and software?

Unpaved Roads Assessment Technology Feasibility Questionnaire

Continued…

How would using this equipment save you money?

How would using this equipment save you time?

How would this equipment be an improvement over current road assessment?

amount of detail obtained in short amount of time

What concerns do you have about this equipment being practical or useful for your agency?

What questions or concerns do you have about training for use of the equipment?

What questions or concerns do you have about maintenance of the equipment or software?

How often it would need to be updated

Do you have any other comments regarding the system you would like to add?

If you would like us to follow-up with you after today, please list your phone number below and a team member will contact you. Thank you!!

Phone #:____

MichiganTech Research Institute

Unpaved Roads Assessment Technology Feasibility Questionnaire

Name: Larry Weiss Title: Service Provider

Agency: SDLTAP

Desired Purchase Model

Rank 1 – 3 with 1 indicating the most likely method you would be interested in, or indicate if you are not interested in using this based upon your information today.

- Purchase Hardware & *In-House* Software Data Analysis: ____________
- Purchase Hardware & *Outsource* Software Data Analysis: ____________
- Purchase Service – "Pay as you Go": ✓

- Not Interested: ____________

Price-Point

Estimate the range or price point which you would reasonably feel you (or your representative agencies) could dedicate to this service or product.

- Purchase Hardware $____________
- Purchase Software License $____________
- Price per Mile $____________
- Annual Budget *Possible* to Invest in Asset Management $____________

Uncertain – based on usage

<u>How often</u> would you use this equipment and software system?

Monthly

<u>When</u> would you use this equipment and software?

Summer season

Unpaved Roads Assessment Technology Feasibility Questionnaire

Continued…

How would using this equipment save you money? Inventory

How would using this equipment save you time? "

How would this equipment be an improvement over current road assessment?

Accuraty / detail

What concerns do you have about this equipment being practical or useful for your agency?

It appears ?

What questions or concerns do you have about training for use of the equipment?

Outsource to avoid trng.

What questions or concerns do you have about maintenance of the equipment or software?

Outsource – Included in price per hr / mile

Do you have any other comments regarding the system you would like to add?

It was a very interesting presention / demo

If you would like us to follow-up with you after today, please list your phone number below and a team member will contact you. Thank you!!

Phone #: 605 773 - ~~53~~ 4339

MichiganTech Research Institute

Unpaved Roads Assessment Technology Feasibility Questionnaire

Name: Rod Patent Title: Farmer

Agency: None

Desired Purchase Model

Rank 1 – 3 with 1 indicating the most likely method you would be interested in, or indicate if you are not interested in using this based upon your information today.

- Purchase Hardware & *In-House* Software Data Analysis: ____________
- Purchase Hardware & *Outsource* Software Data Analysis: ____________
- Purchase Service – "Pay as you Go":___________
- Not Interested:______________

Price-Point

Estimate the range or price point which you would reasonably feel you (or your representative agencies) could dedicate to this service or product.

- Purchase Hardware $____________
- Purchase Software License $____________
- Price per Mile $____________
- Annual Budget *Possible* to Invest in Asset Management $____________

How often would you use this equipment and software system?

Very Interested in the technology and Data processing.

When would you use this equipment and software?

I see multiple uses - Ag - Roads, wildlife Disaster Fire & Rescue & others

Unpaved Roads Assessment Technology Feasibility Questionnaire

Continued…

How would using this equipment <u>save you money</u>?

How would using this equipment <u>save you time</u>?

How <u>would this equipment be an improvement over</u> current road assessment?

What concerns do you have about this equipment <u>being practical or useful</u> for your agency?

Very good

What questions or concerns do you have about <u>training</u> for use of the equipment?

What questions or concerns do you have about <u>maintenance</u> of the equipment or software?

Do you have any other comments regarding the system you would like to add?

If you would like us to follow-up with you after today, please list your phone number below and a team member will contact you. Thank you!!

Phone #:____

Thank you

MichiganTech Research Institute

Unpaved Roads Assessment Technology Feasibility Questionnaire

Name: CLIFF REUER Title: Technical Assistance Provider

Agency: SD LTAP

Desired Purchase Model

Rank 1 – 3 with 1 indicating the most likely method you would be interested in, or indicate if you are not interested in using this based upon your information today.

- Purchase Hardware & *In-House* Software Data Analysis: 3
- Purchase Hardware & *Outsource* Software Data Analysis: 2
- Purchase Service – "Pay as you Go": 1

- Not Interested: ______________

Price-Point

Estimate the range or price point which you would reasonably feel you (or your representative agencies) could dedicate to this service or product.

- Purchase Hardware $?
- Purchase Software License $?
- Price per Mile $?
- Annual Budget *Possible* to Invest in Asset Management $?

How often would you use this equipment and software system?

Not often enough to justify the Cost - Would need to have ~~as~~ to outsource the project.

When would you use this equipment and software?

~~I~~ ~~In spin~~

In spring of year to inventory roadway features

Unpaved Roads Assessment Technology Feasibility Questionnaire

Continued…

How would using this equipment save you money?

How would using this equipment save you time?

How would this equipment be an improvement over current road assessment?

What concerns do you have about this equipment being practical or useful for your agency?

What questions or concerns do you have about training for use of the equipment?

What questions or concerns do you have about maintenance of the equipment or software?

Do you have any other comments regarding the system you would like to add?

If you would like us to follow-up with you after today, please list your phone number below and a team member will contact you. Thank you!!

Phone #:____

MichiganTech Research Institute

Unpaved Roads Assessment Technology Feasibility Questionnaire

Name: Megan Patent-Nygren Title: Training Coord

Agency: Nebraska LTAP

Desired Purchase Model

Rank 1 – 3 with 1 indicating the most likely method you would be interested in, or indicate if you are not interested in using this based upon your information today.

- Purchase Hardware & *In-House* Software Data Analysis: ________
- Purchase Hardware & *Outsource* Software Data Analysis: ________
- Purchase Service – "Pay as you Go":__________
- Not Interested:______________

I see our clients in each of the four categories.

Price-Point

Estimate the range or price point which you would reasonably feel you (or your representative agencies) could dedicate to this service or product.

- Purchase Hardware $____________
- Purchase Software License $____________
- Price per Mile $ 10 ?
- Annual Budget *Possible* to Invest in Asset Management $

While I think this is probably a very important data point, I think it is unlikely locals have any idea what they spend on windshield analysis now.

<u>How often</u> would you use this equipment and software system?

I could forsee using this in a training scenario and/or in a service provided scenario as an LTAP trainer. Use would be dependent on demand.

<u>When</u> would you use this equipment and software?

Build condition inventory for comparison prior to natural disaster events, change in road status, etc.

To evaluate "trouble" spots that get complaints.

To prioritize capital impr

Unpaved Roads Assessment Technology Feasibility Questionnaire

Continued...

How would using this equipment save you money?

How would using this equipment save you time?

How would this equipment be an improvement over current road assessment?

What concerns do you have about this equipment being practical or useful for your agency?

What questions or concerns do you have about training for use of the equipment?

What questions or concerns do you have about maintenance of the equipment or software?

Do you have any other comments regarding the system you would like to add?

If you would like us to follow-up with you after today, please list your phone number below and a team member will contact you. Thank you!!

Phone #:____

MichiganTech Research Institute

Unpaved Roads Assessment Technology Feasibility Questionnaire

Name: DOUG SHERMAN Title: WINNER AREA ENGINEER
Agency: SDDOT

Desired Purchase Model

Rank 1 – 3 with 1 indicating the most likely method you would be interested in, or indicate if you are not interested in using this based upon your information today.

- Purchase Hardware & *In-House* Software Data Analysis: 2
- Purchase Hardware & *Outsource* Software Data Analysis: 3
- Purchase Service – "Pay as you Go": X 1

- Not Interested: ____

Price-Point

Estimate the range or price point which you would reasonably feel you (or your representative agencies) could dedicate to this service or product.

- Purchase Hardware $____
- Purchase Software License $____
- Price per Mile $____
- Annual Budget *Possible* to Invest in Asset Management $ 25,000 - 50,000 Winner Area Alone

How often would you use this equipment and software system?

AS The TECHNOLOGY EVOLVES, I CAN SEE TREMENDOUS USE.

When would you use this equipment and software?

HAUL ROAD BEFORE & AFTER INSPECTIONS

PRE MAINTENANCE ASSESSMENT INSPECTIONS

BRIDGE INSPECTIONS

ETC.

Unpaved Roads Assessment Technology Feasibility Questionnaire

Continued…

How would using this equipment save you money?

How would using this equipment save you time?

How would this equipment be an improvement over current road assessment?

What concerns do you have about this equipment being practical or useful for your agency?

What questions or concerns do you have about training for use of the equipment?

What questions or concerns do you have about maintenance of the equipment or software?

Do you have any other comments regarding the system you would like to add?

If you would like us to follow-up with you after today, please list your phone number below and a team member will contact you. Thank you!!

Phone #:____

Michigan Tech **Research Institute**

Unpaved Roads Assessment Technology Feasibility Questionnaire

Name: Gregg Ulmer Title: Maintenance Supervisor
Agency: SD DOT

Desired Purchase Model

Rank 1 – 3 with 1 indicating the most likely method you would be interested in, or indicate if you are not interested in using this based upon your information today.

- Purchase Hardware & *In-House* Software Data Analysis: 1
- Purchase Hardware & *Outsource* Software Data Analysis: 2
- Purchase Service – "Pay as you Go": 3
- Not Interested: ______

Price-Point

Estimate the range or price point which you would reasonably feel you (or your representative agencies) could dedicate to this service or product.

- Purchase Hardware $3500.00
- Purchase Software License $______
- Price per Mile $ 20.00
- Annual Budget *Possible* to Invest in Asset Management $2500. – 3500.00

How often would you use this equipment and software system?

Could be a lot depending on road + type of Winter

When would you use this equipment and software?

mostly in Spring

Unpaved Roads Assessment Technology Feasibility Questionnaire

Continued…

How would using this equipment save you money?

By deciding on How and What type of maintenance is required

How would using this equipment save you time?

by using the ~~arreal~~ aerial photos to look at ~~and~~ compare conditions of roads

How would this equipment be an improvement over current road assessment?

would be quicker and would be able to look at photos

What concerns do you have about this equipment being practical or useful for your agency?

What questions or concerns do you have about training for use of the equipment?

What questions or concerns do you have about maintenance of the equipment or software?

would this machine have to be sent somewhere every so often to be checked out something similar to an annual inspection?

Do you have any other comments regarding the system you would like to add?

If you would like us to follow-up with you after today, please list your phone number below and a team member will contact you. Thank you!!

Phone #: 605-842-~~0~~5386

Michigan Tech Research Institute

Unpaved Roads Assessment Technology Feasibility Questionnaire

Name: Tim Huffman Title: Highway Maintenance Supervisor

Agency: SD DOT

Desired Purchase Model

Rank 1 – 3 with 1 indicating the most likely method you would be interested in, or indicate if you are not interested in using this based upon your information today.

- Purchase Hardware & *In-House* Software Data Analysis: ____________
- Purchase Hardware & *Outsource* Software Data Analysis: ____________
- Purchase Service – "Pay as you Go": Some what
- Not Interested: ____________

Price-Point

Estimate the range or price point which you would reasonably feel you (or your representative agencies) could dedicate to this service or product.

- Purchase Hardware $____________
- Purchase Software License $____________
- Price per Mile $____________
- Annual Budget *Possible* to Invest in Asset Management $ Unknown

How often would you use this equipment and software system?

Once or twice a year

When would you use this equipment and software?

Mid summer

Unpaved Roads Assessment Technology Feasibility Questionnaire

Continued…

How would using this equipment save you money? Unknown

How would using this equipment save you time?
By having a out of company person getting the info to us.

How would this equipment be an improvement over current road assessment? we would have it in a document form and not just the old eye way.

What concerns do you have about this equipment being practical or useful for your agency?
I think it would be practical to have one state wide.

What questions or concerns do you have about training for use of the equipment?
How many of hours dose it take to get up and flying the units.

What questions or concerns do you have about maintenance of the equipment or software?
None

Do you have any other comments regarding the system you would like to add?
A nice system and I think it is something we need to look ahead and be ready for it to come into play

If you would like us to follow-up with you after today, please list your phone number below and a team member will contact you. Thank you!!

Phone #: 605-842-5387

MichiganTech **Research Institute**

Unpaved Roads Assessment Technology Feasibility Questionnaire

Name: Don Hosek Title: Tech. Asst. Provider

Agency: SD LTAP

Desired Purchase Model

Rank 1 – 3 with 1 indicating the most likely method you would be interested in, or indicate if you are not interested in using this based upon your information today.

- Purchase Hardware & *In-House* Software Data Analysis: ___________
- Purchase Hardware & *Outsource* Software Data Analysis: ____________
- Purchase Service – "Pay as you Go":__________
- Not Interested:_____________

Price-Point

Estimate the range or price point which you would reasonably feel you (or your representative agencies) could dedicate to this service or product.

- Purchase Hardware $___________
- Purchase Software License $___________
- Price per Mile $___________
- Annual Budget *Possible* to Invest in Asset Management $___________

How often would you use this equipment and software system?

As often as our customers would need our assistance and when the equipment becomes available

When would you use this equipment and software?

as soon as available

Unpaved Roads Assessment Technology Feasibility Questionnaire

Continued…

How would using this equipment save you money?

Use as haul road agreements and measuring stock piles of gravel

How would using this equipment save you time?

How would this equipment be an improvement over current road assessment?

would ~~give~~ give an aerial overview vs. wind shield

What concerns do you have about this equipment being practical or useful for your agency?

cost

What questions or concerns do you have about training for use of the equipment?

will local managers support this effort?

What questions or concerns do you have about maintenance of the equipment or software?

keeping updated

Do you have any other comments regarding the system you would like to add?

wonderful product

If you would like us to follow-up with you after today, please list your phone number below and a team member will contact you. Thank you!!

Phone #:____

Michigan Tech Research Institute

Unpaved Roads Assessment Technology Feasibility Questionnaire

Name: ________________________ Title:____________________________

Agency:____

Desired Purchase Model

Rank 1 – 3 with 1 indicating the most likely method you would be interested in, or indicate if you are not interested in using this based upon your information today.

- Purchase Hardware & *In-House* Software Data Analysis: ____________
- Purchase Hardware & *Outsource* Software Data Analysis: _____________
- Purchase Service – "Pay as you Go":___________
- Not Interested:______________

Price-Point

Estimate the range or price point which you would reasonably feel you (or your representative agencies) could dedicate to this service or product.

- Purchase Hardware $____________
- Purchase Software License $____________
- Price per Mile $____________
- Annual Budget *Possible* to Invest in Asset Management $____________

How often would you use this equipment and software system?

When would you use this equipment and software?

Unpaved Roads Assessment Technology Feasibility Questionnaire

Continued…

How would using this equipment save you money?

Need to know cost to completely answer this question. However, by making better decisions and improving the roadway would pay off.

How would using this equipment save you time?

How would this equipment be an improvement over current road assessment?

Provide detailed documentation that can be enhanced by on-site visit

What concerns do you have about this equipment being practical or useful for your agency?

Data analysis issues

Cost per mile

What questions or concerns do you have about training for use of the equipment?

What questions or concerns do you have about maintenance of the equipment or software?

Do you have any other comments regarding the system you would like to add?

Would be very useful for Road Safety Audits (RSA). This would be run before RSA committee meets to evaluate specific locations. Many features can be identified with this technology that can not be seen with other imagery that is available

If you would like us to follow-up with you after today, please list your phone number below and a team member will contact you. Thank you!!

Phone #:____

MichiganTech Research Institute

Unpaved Roads Assessment Technology Feasibility Questionnaire

Name: Justin Cook Title: Research Engineer

Agency: SD DOT Office of Research

Desired Purchase Model

Rank 1 – 3 with 1 indicating the most likely method you would be interested in, or indicate if you are not interested in using this based upon your information today.

- Purchase Hardware & *In-House* Software Data Analysis: 1
- Purchase Hardware & *Outsource* Software Data Analysis: 2
- Purchase Service – "Pay as you Go": 3

- Not Interested:______________

Price-Point

Estimate the range or price point which you would reasonably feel you (or your representative agencies) could dedicate to this service or product.

- Purchase Hardware $____________
- Purchase Software License $____________
- Price per Mile $____________
- Annual Budget *Possible* to Invest in Asset Management $____________

How often would you use this equipment and software system?

10-20 times per year

When would you use this equipment and software?

Unpaved Roads Assessment Technology Feasibility Questionnaire

Continued…

How would using this equipment save you money?

Road Weather Information System (RWIS) site evaluation - better positioning of Cameras - fewer site visits

How would using this equipment save you time?

(see above)

How would this equipment be an improvement over current road assessment?

What concerns do you have about this equipment being practical or useful for your agency?

Cost - hardware/software licence/help desk (tech support)/paperwork

What questions or concerns do you have about training for use of the equipment?

who/how would perform this? Along these lines - how about FAA paperwork?

What questions or concerns do you have about maintenance of the equipment or software?

Tech support? It was stated that this was developed in house at MTRI. who will support buyers

Do you have any other comments regarding the system you would like to add?

If you would like us to follow-up with you after today, please list your phone number below and a team member will contact you. Thank you!!

Phone #:____

Appendix C. Conference Proceeding Papers

Brooks, C., Dean, D., Dobson, R., Carter, J., Roussi, C., VanderWoude, A., Colling, T. (2013). Identification of unpaved roads in a regional road network using remote sensing, **ASPRS 2013 Annual Conference**, Baltimore, Maryland - March 24-28, 2013.

Dobson, R., Brooks, C., Roussi, C., Colling, T. (2013). Developing an Unpaved Road Assessment System for Practical Deployment with High-Resolution Optical Data Collection using a Helicopter UAV. **Transportation Research Board 93rd Annual Meeting**, Washington, D.C., January 12-16, 2014.

Dobson, R., Colling, T., Brooks, C., Kueber Watkins, M., Dean, D. (2013a). Collecting Decision Support System Data via Remote Sensing of Unpaved Roads. **ICUAS 2013 - International Conference on Unmanned Aircraft Systems**, Atlanta, GA.

IDENTIFICATION OF UNPAVED ROADS IN A REGIONAL ROAD NETWORK USING REMOTE SENSING

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David Dean, Assistant Research Scientist
Richard J. Dobson, Assistant Research Scientist
Justin Carter, Intern
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ABSTRACT

An accurate inventory of the road network length class and condition within a county, state or region is important for efficient use of maintenance resources. Part of the maintenance equation is knowing where unpaved roads are and how many miles are unpaved. Local governments and transportation agencies are responsible for a large part of this unpaved infrastructure. These agencies need a cost-effective way to identify the unpaved infrastructure in order to effectively maintain these roads and optimize resource allocation. Unpaved roads typically have low traffic volumes, and consequently may receive less attention from local agencies with limited resources. Remote sensing techniques provide a way to identify unpaved roads within a county's road network. Four band optical imagery (R,G,B,IR) was acquired and an algorithm developed to separate paved and unpaved roads in two counties in Southeast Michigan as part of a larger USDOT Research and Innovative Technology Administration grant investigating remote sensing of unpaved road condition. The county road network is buffered and segmented using eCognition. An eCognition ruleset that evaluates relationships between NDVI, Principal Component (PC) 3 and the blue band, PC1-blue, IR-blue and IR-green is applied to the buffered, segmented data to separate the signature of unpaved roads from other classes. The unpaved road segments are merged with the road centerline network and then identified. Location and length of unpaved roads within a county road network can be calculated from the data, providing additional information from which road maintenance decisions can be made.

Keywords: Remote Sensing, road network, classification, unpaved roads, transportation

INTRODUCTION

According to the Federal Highway Administration (FHWA), in 2008 there were 1,324,245 miles of unpaved road in the United States, accounting for almost 33% of the over 4 million miles of road in our national transportation infrastructure (FHWA and USDOT 2010). Local governments and transportation agencies are responsible for a large part of this unpaved infrastructure. These agencies need to be able to cost-effectively assess the condition of the infrastructure on a periodic basis in order to effectively manage these roads, and to optimize for resource allocation. Most local transportation departments do not have specialized equipment to measure surface conditions, instead relying on occasional, visual, spot measurements. Unpaved roads typically have low traffic volumes and, consequently, may receive less time and attention from local agencies with limited funding and limited human resources. These limitations often prevent thorough evaluations of unpaved roads, even though timely identification of road damage is extremely important and these roads have an important role to play in connecting farmers to markets, school buses to school children, and residents to their homes. We proposed to develop an unpaved road assessment system that is practical, economical, and effective through remote sensing from an unmanned aerial vehicle (UAV) under the "Characterization of Unpaved Road Conditions through the Use of Remote Sensing", RITARS-11-H-MTU1, see www.mtri.org/unpaved. This system would enable rapid identification and characterization of unpaved roads on an inventory level and provide meaningful condition metrics as well as enable mission planning, control of the UAV, and data processing. Best engineering practices are being employed to rigorously define the requirements of the system and select the best sensor and platform technology to meet the needs of the stakeholders.

Paved roads are characterized by either a bituminous, mixed bituminous, brick, block, composite, or cement concrete cover with a surface base thickness of at least 1 inch but typically 7 inches or more (FHWA 2004). In contrast, an unpaved road has no surfacing. Unpaved roads are either covered with an aggregate or have no added surfacing. In this paper and in general use, the former are referred to as *gravel roads* and the latter as *unimproved roads*. It can be difficult to distinguish between a gravel road in poor condition and an unimproved road in the field. In general, at least 1.5 to 2 inches of gravel are necessary to be considered a gravel road; 6 to 10 inches is most desirable for areas of high traffic (Walker, Entine et al. 2002).

Unpaved road conditions can change rapidly relative to paved roads, which may remain in the same state for several years. Likewise, unpaved road maintenance cycles are significantly shorter than paved road maintenance cycles, which may span several years or even a decade. This higher rate of condition change and maintenance cycles necessitates the potential need for more frequent condition inspection than paved roads, and has been identified as a high priority by our project partners, particularly at the local road agency level. Being able to assess the mileage and condition of unpaved roads on a more comprehensive basis and on a repeatable and cost-effective manner are major objectives for our representative partners, the Road Commission for Oakland County (RCOC), the Southeast Michigan Council of Governments SEMCOG), and the State of Michigan's Transportation Asset Management Council (TAMC). Delivery of our project results in a manner that can help turn rapidly assessed unpaved road condition data into actionable results is a high priority for them, particularly at the local and regional level.

For the larger project, evaluating the capabilities of Unmanned Aerials Vehicles (UAVs) and manned fixed aircraft-based remote sensing to assess unpaved road condition, it is necessary to reliably know the location of the unpaved roads to be evaluated; particularly as part of a mission planning system. Before a flight, the roads to be examined need to be identified and a flight plan established that avoids obstacles (such as towers and powerlines) and provides optimal road coverage. To calculate the location and mileage length of unpaved roads, this project built from the methods established for the www.tarut.org study (Brooks et al. 2007), where visible-to-infrared ratios derived from 3-foot (1-m) multispectral aerial imagery and 2-foot (60-cm) Digital Globe Quickbird multispectral imagery were used to map road surface type, including unpaved roads. With that lower resolution imagery, the project team was able to map road surface types with 86% accuracy; we anticipated that with 1-foot imagery, we would be able to increase our accuracy to at least 90% with the goal of reaching 95%. Figure 1 below shows an example of 1-foot resolution imagery where the differences between natural aggregate road (A, with brown color), crushed limestone road (B, with a bright reflectance), and a paved asphalt road (C, a local highway) can all be seen. Infrared aerial imagery data, as available via SEMCOG, should make these differences even more significant. The results of this road surface type analysis, in the form of a GIS layer of unpaved road locations versus paved locations, is designed to be a major mission planning input that would allow route definition and flight path analysis.

Figure 1: Example of 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.

UAVs, operating semi-autonomously, can automate data acquisition of road conditions over the entire inventory, rapidly generating road condition metrics of importance to decision makers. Having a rapid and reliable way to obtain rural road conditions will benefit local and state agencies by reducing the effort and time needed, as well as providing more accurate and consistent condition assessment. Unpaved road assessment technologies that can be rapidly deployed after disasters, such as flood events, have also been important to the project.

METHODOLOGY

It is important to understand where unpaved roads are and how many miles there are in a road network, both for asset management and mission planning needs. Oakland County in southeastern Michigan has said that it has approximately 750 miles of unpaved roads, more than some counties in the Upper Peninsula of Michigan have in total road mileage. Figure 2 shows the priority unpaved roads mapping areas in southeastern Michigan, with the project focusing initially on Oakland County (approximately half rural and half urbanized) and Monroe County (mostly rural). Two more counties are being processed for mission planning input and sharing of results with SEMCOG.

Figure 2: Focus area in southeastern Michigan for unpaved roads mapping for inventory and mission planning inputs.

SEMCOG supplied the project team with four band 12-inch per pixel resolution aerial imagery flown in spring (leaf-off) 2010, with each image covering a 5000 by 5000 foot (1524m x 1524m) area. For more rapid processing, four scenes were mosaicked into 10,000 x 10,000 foot (3048m x 3048m) tiles. Oakland County had 285 of these merged imagery tiles, and Monroe County had 188 tiles.

Before segmentation and classification, a Principal Components Analysis (PCA) was run on the four band (red, green, blue, and near-infrared) imagery. The first three principal components were derived from the imagery, and the PCA layers were included in the segmentation processing. The first Principal Component (PC) was found to be useful for masking out shadows from trees over unpaved roads and detect bare soil areas (Nobrega 2008).

The four band and Principal Components outputs were loaded into Trimble eCognition (version 8), along with a roads layer that had been buffered by 30 feet (9.1m) around the Michigan Geographic Framework version 11 road centerline network that had also been dissolved into a single polygon in ArcGIS. Each tile was then segmented into spectrally similar image objects using eCognition. These objects were classified into five classes – Unpaved Roads, Paved Roads, Shadow, Bare Earth and Vegetation – using rules that take the spectral characteristics of each image object into account.

The process involved a chessboard segmentation, which was used to create an area that would contain a road (the Framework road centerline layer) (see Figure 3). Quadtree segmentation was run on the area of the potential roads which segments 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 is then run to combine spectrally similar areas into objects. Spectral difference segmentation is run that merges objects according to a user defined mean layer intensity value.

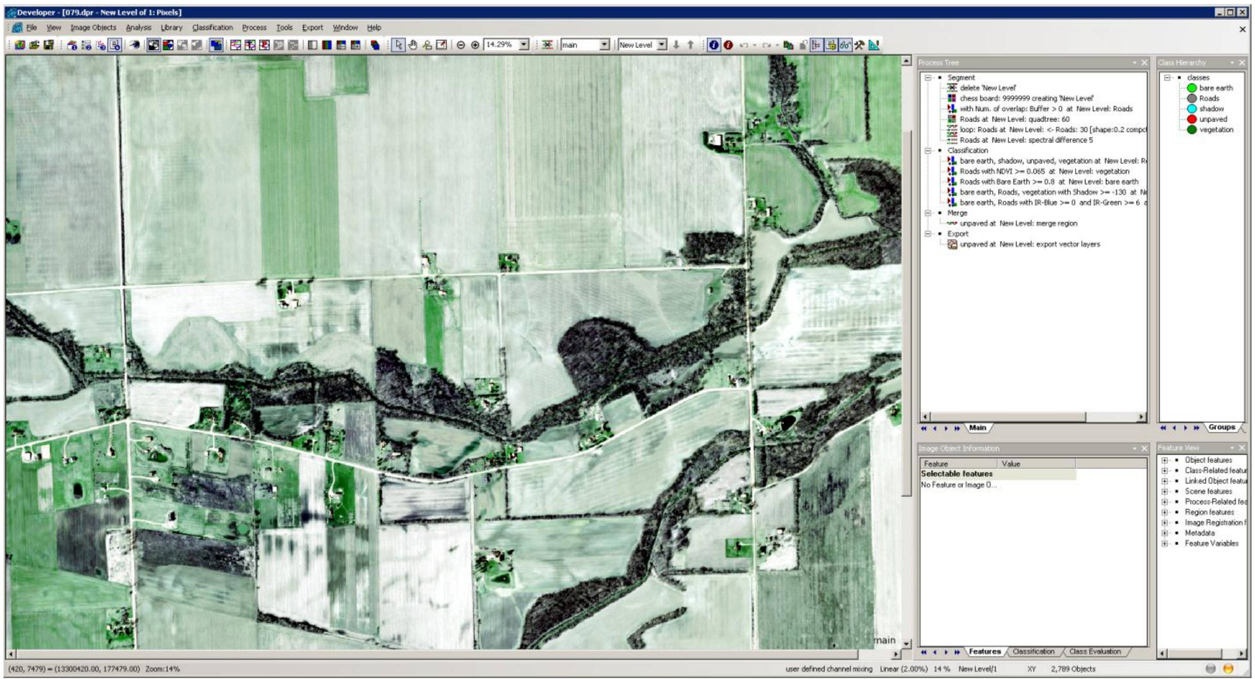

Figure 3: Four-band aerial image loaded into eCognition with rule sets for segmentation and classification at the right.

The objects that result are run through a classification routine which assigns one of the five classes to each object. A rule set was developed in eCognition to classify the resulting objects from the segmentation portion of the algorithm. This classification works as a decision tree, where a binary decision is made based upon the data within each object. For example, the first step in the project team's classification algorithm is to determine whether the object is vegetation. This is accomplished by calculating the normalized difference vegetation index (NDVI) for the object; if the calculated value is greater than a certain threshold, it is classified as vegetation. If it does not meet this threshold it is then passed on to the next step in the algorithm. This process is repeated for bare earth and shadow and finally ends with unpaved. The classification procedures for determining object classification as bare earth and shadow build from the works of Nobrega et al. (2008) and require the use of the principal component analysis to make their determinations, as described above. Initial analysis 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. This relationship was extensively tested by means of a receiver operating characteristic (ROC) curve; a graphical plot that depicts the performance of a binary classifier, in our case: paved road or unpaved road based on the values used. An ROC curve is commonly used in signal detection (Hand 2001); however, its methods can be applied here when selecting particular values for algorithm components, such as the recommended IR-Green value.

The ROC curve was calculated on the IR-Green parameter to find the optimal threshold for unpaved road detection. The ROC curve displays the fraction of true positives (TP) out of all positive results (ρ_d) plotted against the fraction of false positives (FP) out of all negative results (ρ_{fa}) for any IR-Green value. Plotting an ROC curve enables its users to find the best value for the IR-Green parameter by selecting a value that maximizes the number of true positives (ρ_d) and minimize the false positives (ρ_{fa}). The ROC curve analysis revealed that an IR-Green value of 6 (arrow) with a ρ_d of .88 and a ρ_{fa} of 0.13 returns the best results, although IR-Green values of between 0 and 6 will yield similar results (see Figure 4).

$\rho_d = \frac{TP}{TP+FN}$, Probability of True Postive

$\rho_{fa} = \frac{FP}{FP+TN}$, Probably of False Positive, where;

TP = Road pixel detected as road
FN= Road pixel detected as not road
FP = Not road pixel detected as road
TN= Not road pixel detected as not road

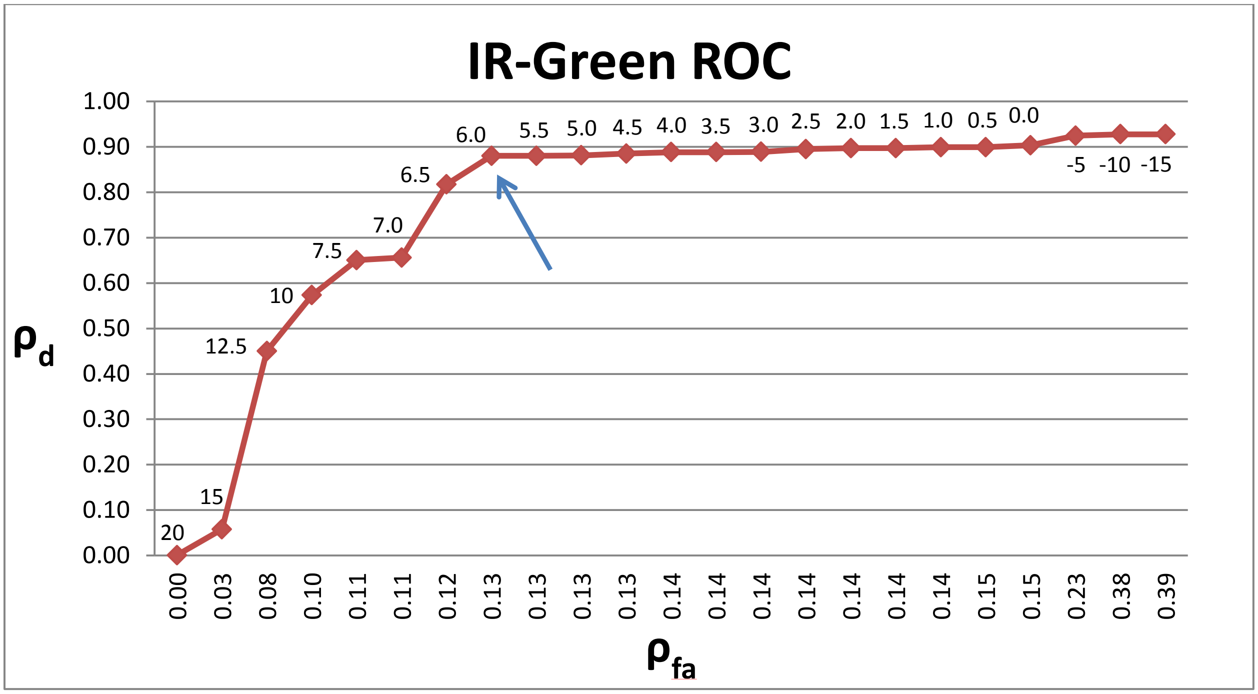

Figure 4: Receiver Operating Characteristic curve plot for the IR-Green parameter. Points on the curve are labeled with their corresponding IR-Green value.

After segmentation with eCognition and justified variable inputs, objects classified as unpaved are merged into a single object and exported as a shapefile for further processing in ESRI ArcGIS (versions 10 and 10.1). Processing in ArcGIS involves using the Union tool on the resulting eCognition output to create a shapefile that merges all the output into one dataset for the county being analyzed. This step eliminates errors associated with processing further down the line by removing edges between processed mosaics. This merged dataset is then intersected with the Framework centerline roads layer to extract portions of the roads that are unpaved. The resulting lengths of individual features outputted by the intersect tool are then compared with their respective features in the framework roads layer to derive a percentage of coverage. The road segment is then classified as unpaved based upon the coverage, or percentage of the road segment found to be unpaved.

RESULTS AND DISCUSSION

Analysis of Monroe county data yielded an initial value of 25 percent coverage as returning an unpaved road value closest to SEMCOG's Pavement Surface Evaluation and Rating (PASER) data for the locations where status of paved vs. unpaved was recorded in their PASER surveys (See Figure 5 below). Additionally, a traditional error matrix based on field verification of part of Monroe County gave additional information, where the Producer's Accuracy for unpaved roads was 95%. Monroe County PASER data report 391 miles of unpaved roads out of a total road network length of 1974 miles. When road segments with at least 25% coverage as unpaved (based on the segmentation and classification analysis) were defined as unpaved, the MTRI algorithms found 397.4 miles of unpaved roads in Monroe County (Figure 6). This resulted in approximately 98% agreement between PASER data and using the 25% coverage rule for calling a Framework road segment as unpaved.

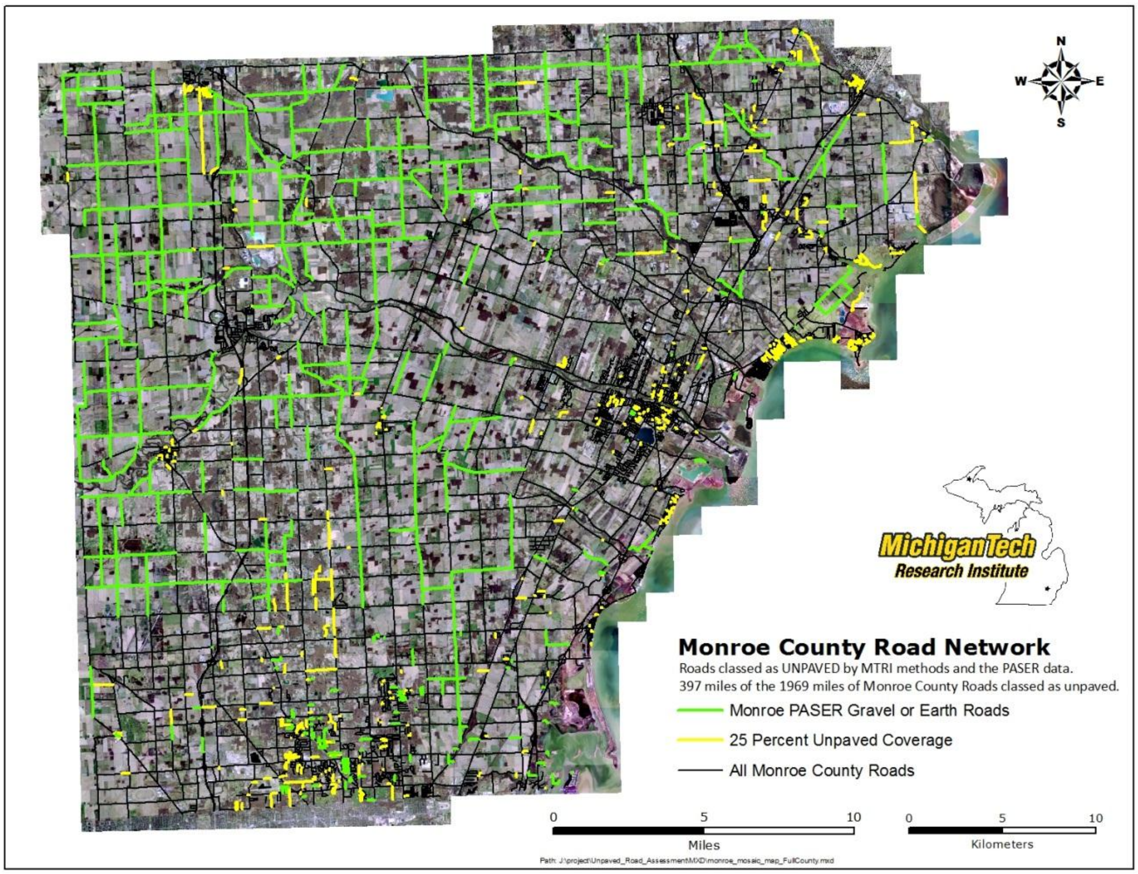

Figure 5: PASER data (green) over the MTRI 25 percent unpaved coverage (yellow) data. The PASER dataset for Monroe County contains 1656.2 miles of the 1969 miles of roads in the Monroe County Framework Roads data layer. Of the 1656 miles in the PASER dataset, 391 are classified as unpaved. The 25 Percent Unpaved Coverage layer classified 397 miles of the road network as unpaved.

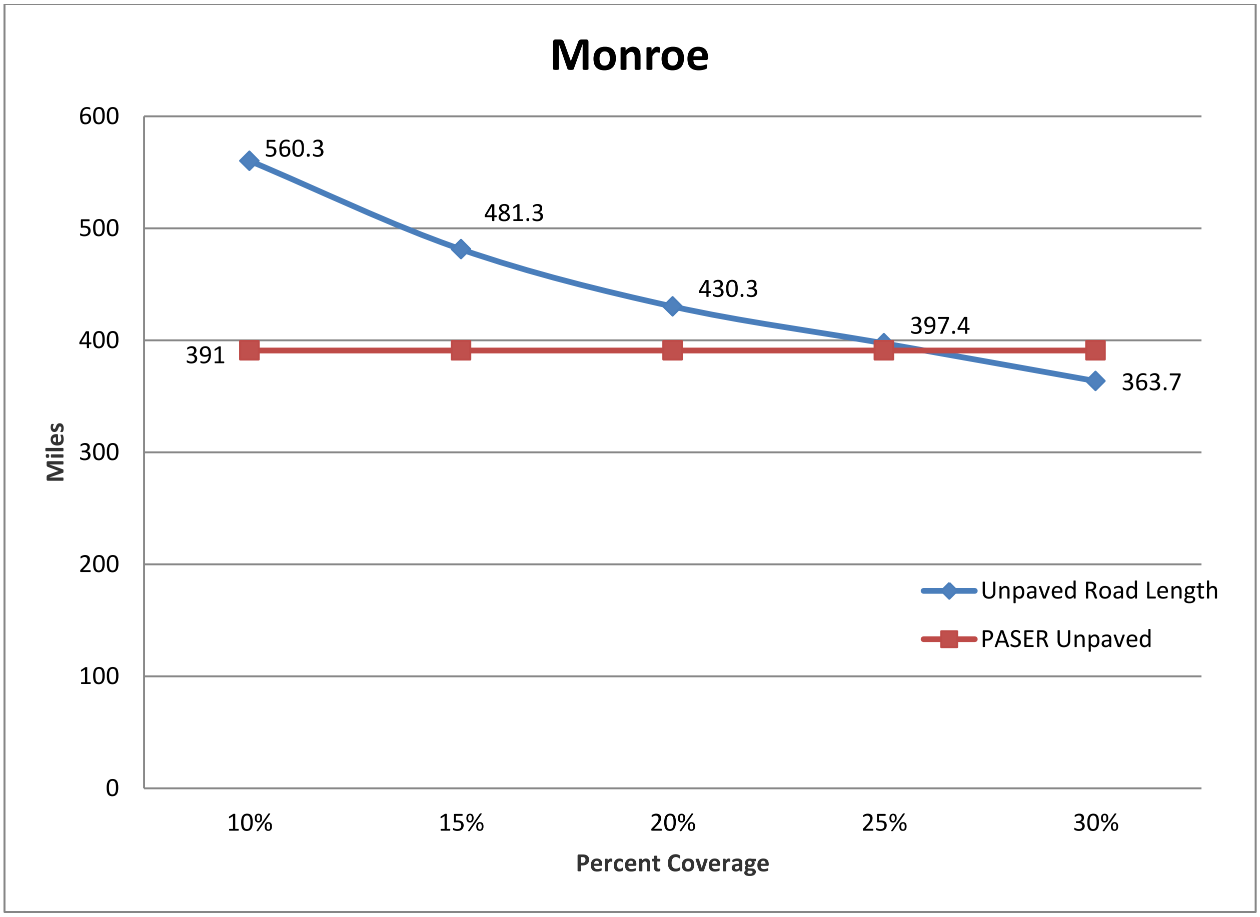

Figure 6: Agreement between PASER data and the "percent coverage" needed to label a Framework road segment as unpaved for Monroe County.

When the PASER data were superimposed over unpaved road classification results, it appeared that most errors of commission (algorithm classified roads as unpaved when the PASER data did not) occurred most frequently where the road segments were relatively short and frequently in residential areas. An initial review of roads that were classified as unpaved but are actually paved show that the IR-Green values are just above the cutoff of 6 that is used to classify a road as unpaved. Typically, paved roads have mean IR-Green values that are negative or slightly positive. Occasionally, paved roads in developed areas will be classified as unpaved as a result of IR-Green values in excess of the threshold of 6. Errors of omission (PASER data classifies a road as unpaved and the algorithm does not) occurred most frequently as a result of road centerline misalignment or unpaved roads where the IR-Green value was negative, which was more typical of a paved road. The phenomenon of an unpaved road having a strong spectral resemblance to a paved road may be a result of the local road commission using crushed limestone, a major component of both concrete and macadam pavement for the road. This phenomenon was noticed at a field data collection site and is being further evaluated to determine its influence on classification results.

The shared Oakland County PASER data was not as complete as Monroe County data and could not be used directly as a complete ground reference data set. The Michigan Framework Roads layer for Oakland County shows a total of 7662 miles of roads, although not all are the responsibility of the RCOC. The Road Commission for Oakland County states “More than 750 of the 2,700-plus miles of the Road Commission for Oakland County's (RCOC) county roads are not paved…” (RCOC, 2013).

MTRI processing found 832 miles of unpaved roads in the Oakland County road network using the 25% criteria, the same methodology as applied to the Monroe County road network (Figure 7). When compared to the

~750 miles of unpaved roads that have been quoted by Oakland County, MTRI found approximately 82 miles more unpaved roads than the RCOC estimate. Like the numbers for Monroe County, these numbers are preliminary and subject to further revision, but the comparability is promising at this stage.

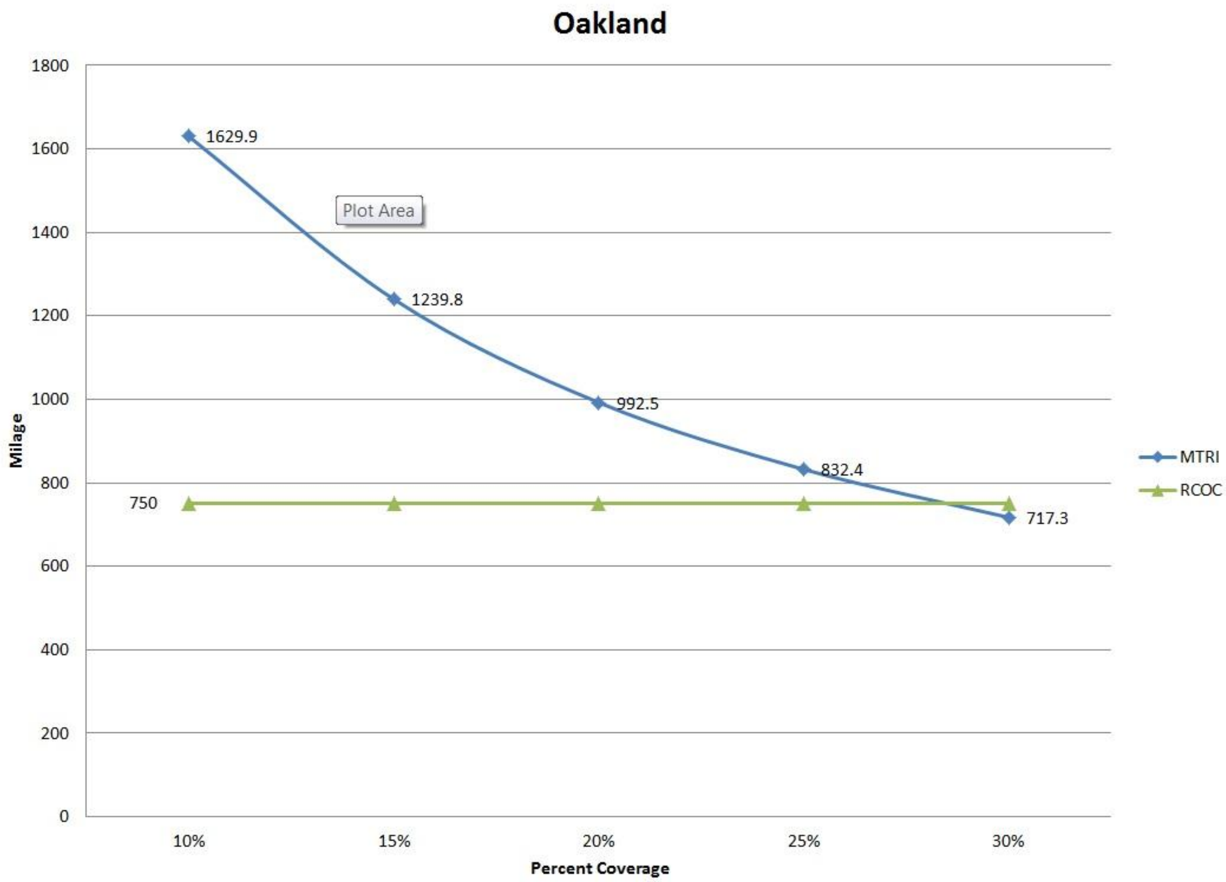

Figure 7: Agreement between PASER data and the "percent coverage" needed to label a Framework road segment as unpaved for Oakland County.

Processing challenges have primarily been the variable road network centerline accuracy when displayed over the high resolution aerial imagery. Some road centerlines align very closely to their associated feature in the four band high resolution aerial imagery while for fairly extensive lengths, others within the same roads dataset do not align closely. This may be a function of scale of which the roads are digitized, but the state-led Framework roads effort is working on a regular basis to improve centerline accuracy. Centerline accuracy issues were found to be an issue in both Monroe and Oakland counties, with more centerline issues in Oakland County.

Another challenge encountered has been spectral similarities in the four band aerial imagery between some types of road features. Concrete / old macadam and crushed limestone (which is a component of both) are spectrally very similar, which can lead to misclassification both directions. Another challenge has been bare soil and natural aggregate (such as locally sourced river sand and gravel), which are very spectrally similar. 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.

A final issue has been shadows that obscure the road and where there is extensive forest cover, making it difficult to see classify a road under the canopy. This is a known issue for remote sensing processes where forest cover limits surface visibility. The project team used the "percent coverage" rule to address this problem, whereby only a certain percentage of a road segment needed to be called unpaved for the entire segment to be labeled as such.

CONCLUSIONS AND NEXT STEPS

Knowing the location, length and condition of unpaved roads in a regional road network is important to transportation agencies who need to cost-effectively manage their roads. Limited budgets and resources add to the maintenance challenges faced by regional, county and local road commissions. This paper outlines a methodology to identify unpaved roads in a local road network using high spatial resolution (30 cm/one foot per pixel) four band imagery. The four band imagery was processed into the first three principal components, then all imagery was loaded into eCognition along with a 30 foot buffer polygon derived from county road centerline data.

The imagery was segmented and classified to extract unpaved roads from the dataset. A number of different band ratios are calculated and used to inform the classification process. It was found that the value resulting from subtracting mean IR values from the mean Green values provided a useful method for separating paved roads from unpaved roads. A Receiver Operating Characteristic (ROC) curve provided a method to find the optimal threshold for unpaved road detection. It was found that a IR-Green value of 6 provided the best compromise for maximizing the true positive classification results while minimizing the false positives. The result of the classification process is a shapefile containing unpaved road polygons.

The shapefile output from the eCognition classification process form the basis of identifying unpaved roads in the road network. The unpaved shapefiles were imported into ArcGIS and intersected with the road network, creating a shapefile that is the linear segments of the road network that are considered to be unpaved. Each road segment in this shapefile was compared to the overall length of the original segment; if more than 25 percent of the segment was classified as unpaved, then the entire segment is classified as unpaved.

The comparison process was run on all the roads in a county and the results compared to a ground truth dataset shared by the project partners at SEMCOG. In this case, a PASER dataset was used as ground truth. The project team's classification at 25 percent coverage found 397 miles of unpaved roads in the Monroe County network, compared to the PASER data which reported 391 miles of unpaved roads. Oakland County had significantly more road mileage than Monroe County but a less complete PASER dataset. When run using the same methodology as Monroe County, the MTRI Classification found 832 miles of unpaved road in Oakland County, which quotes an unpaved road mileage of approximately 750. These are preliminary but promising results.

Next, work will focus on processing data from several additional counties in southeast Michigan and refining the workflow to improve the accuracy of results. The unpaved road mapping algorithm components (segmentation rules, band differences, ArcGIS processing) will be further examined to maximize producer's and user's accuracy. The results will be used as mission planning input into a spring and summer 2013 field campaign of assessing unpaved road condition from an Unmanned Aerial Vehicle and manned fixed-wing aircraft campaign (Roussi and Brooks 2012). This fits into the larger "Characterization of Unpaved Road Conditions through the Use of Remote Sensing" project that needs to know where the unpaved roads are located before data collection missions will be flown. The unpaved vs. paved mapping results will be shared with SEMCOG and other project partners as well, such as the Transportation Asset Management Council of Michigan.

DISCLAIMER

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

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Developing an Unpaved Road Assessment System for Practical Deployment with High-Resolution Optical Data Collection using a Helicopter UAV

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Abstract— The need of local governments and transportation agencies to periodically asses the condition of unpaved roads in a cost-effective manner with rapid response times has lead to interest in the use of UAVs (Unmanned Aerial Vehicles) and remote sensing technologies. Currently these assessments are done through visual inspections with agency staff making occasional spot measurements. An unpaved road assessment system was developed to address these issues while at the same time providing a more accurate means of characterizing distresses and determining the roads condition for inspectors. This system uses a single-rotor UAV with a Digital Single-lens Reflex (DSLR) camera to capture overlapping imagery of unpaved roads. The UAV is equipped with a full combination GPS plus IMU (Inertial Measurement Unit) that allows it to fly predetermined waypoints with great stability while at the same time allowing the pilot the ability to take over at any time. Collected imagery is analyzed to locate road distresses. The imagery is run through a Structure From Motion (SfM) algorithm that generates a 3D model of the road surface from which additional condition information can be characterized. This system is easily transported and rapidly deployable to sections of unpaved roads for assessment.

Keywords—UAV; Unpaved Roads; 3D Model; Road Characterization; Transportation

I. Introduction

Local governments and transportation agencies are mostly responsible for the maintenance of unpaved roads within the United States. But with almost 33% of the road infrastructure being unpaved, these agencies often lack specialized equipment for measuring condition (FHWA and USDOT 2010). The low traffic volume of unpaved roads and because of this receive less attention and funding than paved roads. Despite this, they play an important role connecting farmers to markets, school busses to children of rural areas and residents to homes.

Unpaved road condition is based on distress parameters that include washboarding, potholes, rutting, dust, raveling and loss of cross-section (Skorseth 2000). These distresses are used to rate sections of unpaved roads either individually or combined into a numerical index. An example of a distress rating system is the Unsurfaced Road Condition Index or URCI (Department of the

Army 1995). This project does not focus on dust as it would be difficult to measure by taking imagery of the unpaved road.

Because of this there has been growing interest in technologies that assist in rapidly and cost-effectively assess the condition of unpaved roads. Research in using UAVs have been shown to be a low cost option for acquiring imagery for monitoring in other fields including agriculture (Xiang and Tian 2011).

A potential limitation to some types of research or commercialization of using UAVs come from regulations, which are currently being updated. The Federal Aviation Administration (FAA) has set limited guidelines that will govern UAVs that are smaller than 22.7 kg. Under the current regulations the UAV must operate at an altitude of less than 122 m keeping it out of US airspace, away from built up areas and at least 5 km away from airports. In order to fly over populated areas or beyond the line of sight of the operator a Certificate of Authorization needs to be obtained through the FAA (more information on FAA UAV/UAS integration is available at http://www.faa.gov/about/initiatives/uas with more information in its February 19th, 2013 Fact Sheet available at http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=14153).

II. Methods

A. Camera Sensor Selection

The selection of an appropriate camera was critical to the project. The requirements were to detect a distress of about 25 mm in size from about 30 m above the ground and a Field of View (FOV) of at least 22 m. The FOV was important since it allowed for the collection of not only the unpaved road surface but also nearby drainage ditches.

Fig. 1: The Nikon D800 selected as the primary sensor for this unpaved road assessment project.

In order to fulfill these requirements with a DSLR the right combination of camera and lens was essential (see the Roussi and Brooks 2012a "Deliverable 4-A: Sensor Selection for Use in Remote Sensing the Phenomena of Unpaved Road Conditions" for additional detail).

The focal length of the lens to be used was important for not only the FOV but also the resolution that can be achieved. Rough calculations showed that to achieve the desired FOV from an altitude of at least 30 m a focal length of 61 mm would be necessary. Since the lens also affects the cameras resolution, the Nyquist sampling criterion (Blackman and Tukey 1958) was applied and determined that the camera sensor needed to be about 4 Mp (megapixels) in order to measure 25 mm on the ground (Stern and Javidi 2004). Given a shorter focal length and camera with a larger sensor array (i.e. more pixels) would allow for greater ground sample distance.

A shorter focal length lens would also allow for more light to pass to the sensor which would allow for faster shutter speeds and reducing motion blur. Shorter focal lengths also have a better depth of field which allows for a wider range in altitude for the UAV while keeping the images in focus.

Shorter focal lengths would also allow for the UAV to fly at lower altitudes to achieve the same FOV. A prime lens was also preferred due to the improved image quality over zoom lenses (Shortis et al. 2006) and weighing less than alternative lenses. For these reasons, a 50 mm prime lens was chosen for the system.

A variety of commercially available DSLRs can fit these requirements. For this project a Nikon D800 which has a 36.3 megapixel (mp) sensor and can continuously shoot at 4 frames per second was chosen (Fig. 1). The most important feature of the camera was the 36.3 mp sensor which would allow for the shorter focal length lens as well as to help ensure that sufficient ground spacing was achieved.

B. UAV Selection

For the selecting the aerial platform, there were key requirements needed to conduct successful missions. These include collection altitude and speed, payload and endurance (see also Roussi and Brooks 2012b "Deliverable 5-A: Candidate and Recommended Remote Sensing Platforms for Unpaved Road Condition Assessment") . These parameters were determined based on the camera that was chosen for this project since it is the limiting factor. The field-of-view, maximum sustained frame rate and the weight of the camera system all play a role in determining the requirements of the UAV. A major limiting factor was the payload size. In order to fly a Nikon D800 with a lens, control-system and battery with a safety margin the UAV needed to be able to carry about 5 kg.

Fig. 2: The Tazer 800 helicopter, about to be deployed data collection at an unpaved road site.

Fixed-winged UAVs were ruled out quickly since they do not meet some of the requirements. In order to carry the camera system the UAV would have to be at least 10 m in size which is too large for practical deployment and storage. Also a large fixed wing UAV would have to operate at speeds of at least 10 meters per second (m/s). Since the UAV will be flying at an altitude of less than 50 m above the ground at a speed of about 2 m/s fixed winged UAVs would not be able could not be used. It should be noted that in a related part of this project, the same sensor is being deployed in a manned fixed wing aircraft (such as a Cessna 172) to test if that platform can also collect the required resolution of data.

Rotary-winged UAVs are not limited to a specific range of flying speeds as they have the ability to hover and fly at slow speeds. Because of this, they also take off vertically which makes deployment easier since there is no need for a runway. They are also more easily transported to various locations and can be rapidly deployed.

Multi-rotor helicopters such as quadracopters and hexacopters offer a stable platform for collecting photos but they are not typically able to carry the same payload as the selected single-rotor helicopter. Also, because of the reduced payload the batteries that they carry are smaller and therefore they have reduced flight time as well. Since it was necessary to carry up to a 5 kg payload, multi-rotor helicopters could not currently fulfill the requirements. However, the project team is monitoring advancements in multi-rotor UAVs and will periodically review them as they become more capable, because of their normally simpler operation.

The Bergan Tazer 800 single-rotor electric helicopter was chosen for this study (Fig. 2) (see also http://bergenrc.com/). It is capable of carrying up to a 5 kg payload with a flight time of about 18 minutes, although a 4 kg is the limit the project team is currently using. Although a fuel-powered helicopter (nitro, etc.) would have longer flight time, an electric helicopter was chosen since there is less motor vibration and sensor equipment would not be fouled by exhaust. This would also help ensure that the camera is flown on a steady platform.

The selected Tazer 800, as delivered for the project, has a full GPS IMU (Internal Measurement Unit) which gives it the ability to fly to specific waypoints at a predetermined speed and altitude with increased stability. This is necessary so that during collects the helicopter maintains a specific altitude and speed to ensure the correct FOV and overlap of the photos. This feature is also necessary to ensure the stability of the platform as the auto pilot system make constant adjustments to keep the helicopter stable even in wind speeds up to 5 mps. For test collects, flight altitudes of 25 m and 30 m were used.

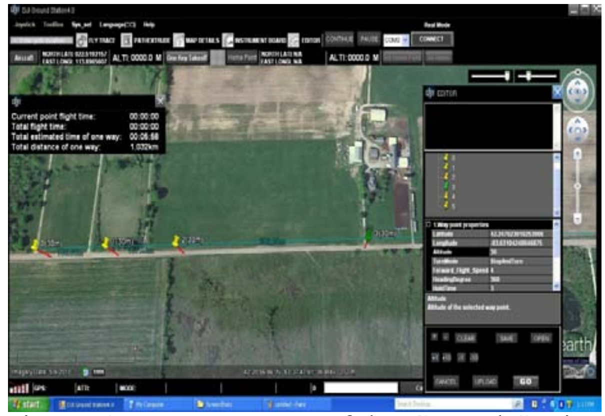

Fig. 3: A screen capture of the Ground Station mission planning software used to select waypoints for a data collection.

This system uses a software called Ground Station in order to set waypoints (Fig.3). Ground Station enables the user to add waypoints on Google Earth imagery and the coordinates can be adjusted manually through the waypoint editor. Once the waypoints are set, they are downloaded to the helicopter remotely through the control antenna.

C. Algorithm

The road surface itself can contain some (or all) of the distresses that we need to find. All of the distresses involve changes in height of the road surface, either over short distances (e.g. corrugations) or long distances (e.g. loss of crown). In addition to height variations, color and color-texture are also valuable indicators of changes in the road surface, and should not be ignored.

The process of obtaining the damages begins with a series of photographs taken over the road surface. For our purposes, we need at least 5 images containing the same field-of-view, taken from different aspects, in order to reconstruct the 3D height-field from the 2D images.

1. This is done using a structure from motion (SfM) algorithm (Brostow et al. 2008) that uses the Bundler software (see http://phototour.cs.washington.edu/bundler/#S1). This generates a sparse 3D point-cloud.

2. We densify the point cloud using a dense muti-view stereo algorithm that takes the SfM output, and the images, and creates a much finer point cloud using the Patch-based Multi-View Stereo Software (PVMS, see http://www.di.ens.fr/pmvs/ and Furukawa et al. 2010).

3. A watertight surface is formed from the point cloud using a Fourier-based technique (Khazdan 2005).

4. The best plane for the surface is found using Singular Value Decomposition (SVD, see Golub et al. 1965), and the model is rotated so the z-axis is normal to the road surface. The z-value of the surface vertices is now the height-field from which all subsequent dameage severities are estimated.

5. The road is segmented from the rest of the image, since we want to only calculate damages on the road surface itself (holes in the nearby field are not wanted). This is done by computing the local entropy of the height-field, and choosing the area where the entropy (which is related to the local height changes) is the lowest (the road is, for the most part, a flat surface).

6. Potholes are found using the Circular Hough Transform (Rizon et al. 2005). This locates the potholes and calculates their diameters. A mask is formed from this detection ouptut, and applied to the height field, from which the depths are derived.

7. Ruts and washboarding are found using Gabor filters (Grigorescu et al. 2002) which are tuned to the directions in which the damages are expected. Ruts only form along the direction of travel on the road, and corrugations only form perpendicular to that. Masks are formed from these detectors, and the mask applied to the height-field to characterize the extent of the damages.

8. Crown variations are determined by the center-to-edge variation in road height, taken as a cut through the hieght-field, and is measured every 10ft along the road.

9. Loose agregate typically piles up along the road edges and are detected as berms, whose height is measured.

10. Drainage is estimated using the area just off the road, and a profile taken from the 3D reconstructed data to find depth.

III. Results

A. UAV Performance

The Tazer 800 proved to be easily transported and was able to be deployed quickly. Once at the site the helicopter could be set up with the sensing equipment and in the air within 15 minutes. To collect a 200 m segment of road, from takeoff to landing, took 5 minutes at a flight speed of 2 m/s. Figure 4 shows an example of the Tazer 800 approaching a landing while under control of a project team member; the Nikon D800 camera sensor can be seen underneath the helicopter. Note the helicopter was easily transportable with a typical vehicle (in this case, a Toyota Prius).

Fig. 4: The Tazer 800 remote control helicopter coming in for a landing after assessing a representative stretch of unpaved road.

Accuracy of the waypoints used to provide navigation assistance were enhanced by taking a GPS point using a Trimble GeoXH GPS unit at the beginning and end of the segments while the road surface was being marked (note that marking was only required for testing data collection and is not a requirement for condition assessment with the system).

Figures 5 and 6 below shows examples of the high-resolution imagery collected with the Tazer 800 helicopter. Distresses such as potholes can easily be seen as collected during initial field trials that will be continuing in 2013 at additional unpaved road sites.

B. Distress Detection

The distress detection from the collected imagery is currently undergoing additional development by the project team. Figure 7 below shows an example of finding washboarding using an enhanced Gabor-filter based analysis in simulated data; this is now being applied to imagery collected with the UAV. Figure 8 shows an example of automated "pothole" detection with the Hough Circle Transform, using another simulated data set; in this, both circular and more elliptical features can be detected. Radius data (to measure size) is also automatically calculated. This method is also now being applied to imagery collected during recent data flights.

Fig. 5: Photo of an unpaved road with distresses taken by the Nikon D800 camera sensor while deployed via the Tazer 800 helicopter at an elevation of 25m.

Fig. 6: Photo of an unpaved road with distresses taken by the Nikon D800 camera sensor while deployed via the Tazer 800 helicopter at an elevation of 30m.

The output of the Structure from Motion process can be seen in Figure 9, which shows a point cloud run through Blender software and densified with PVMS. Potholes in this representative stretch can easily be seen in the reconstructed 3D data.

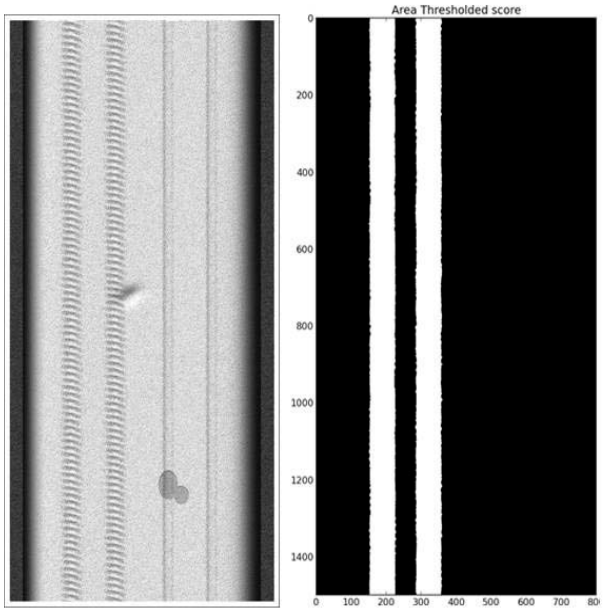

Fig. 7: An example of automatically detecting washboarding using the Gabor filter in simulated unpaved road data.

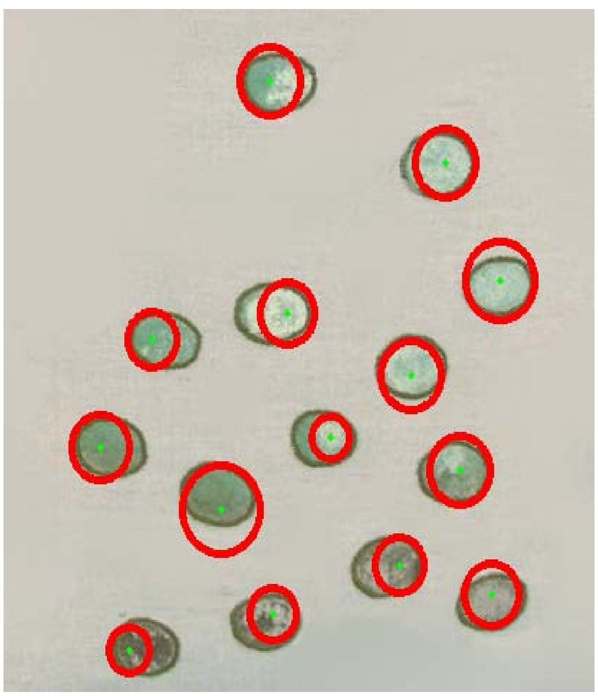

Fig. 8: An example of automatically detecting pothole-like features using the Hough Circle Transform method that is now being applied to field imagery collected by the UAV of unpaved road distresses.

Fig. 9: An example of a densified point cloud from PVMS; unpaved road distresses can easily be seen in the 3D image.

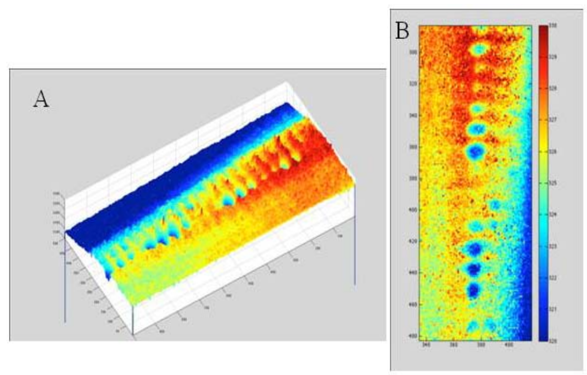

Fig. 10a and 10b: Examples of depth maps reconstructed from high-resolution digital imagery collected by the UAV sensor system that can be used to categorize the severity of detected distresses.

Figures 10a and 10b show an example of the depth maps that have been created using the input imagery collected with the project's UAV sensor system. The scale is in mm on Figure 10a (left) and in cm on Figure 10b (right). Pothole features with depths of up to 10cm can clearly be seen in the data. This is critical to classifying distresses into categories of severity, which is needed for calculating the Unsurfaced Road Condition Index. Resolution of 0.9cm (<1cm) have been reliably obtained so far. The characterized distress data in URCI format is being made available for querying and decision making within the Roadsoft GIS Decision Support System and asset management tool (see http://roadsoft.org/).

IV. Conclusion

The unpaved road assessment system described in this paper has been deployed to collect sub-centimeter resolution data and identify distresses that are needed to rapidly assess unpaved road condition. The analyzed data are being used to categorize representative segments of unpaved road networks so that larger areas can be categorized to help with asset management of a critical transportation resource. The existing system is best for rural areas with little to no tree cover where a camera-borne UAV has the opportunity to image the road segment being analyzed. Additional flexible platforms such as a hexacopter and sensors such as small LiDAR, radar, and thermal infrared detectors are being considered for potential future use. The existing prototype that is coming out of the current project will be ready for use in assessing the condition of rural unpaved roads as the project is completed over the next year.

Disclaimer

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

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Collecting Decision Support System Data via Remote Sensing of Unpaved Roads

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ABSTRACT

Unpaved roads make up roughly 33 percent road system within the United States and are vitally important to rural communities to transport people and goods. Effective asset management of unpaved roads requires frequent inspections to determine the asset's condition and the appropriate preventive maintenance or rehabilitation. The major challenge with managing unpaved roads is collecting low-cost, condition data that is compatible with a decision support system (DSS). The advent of cheap, reliable remote sensing platforms such as unmanned aerial vehicles (UAVs) along with the development of commercial off-the-shelf image analysis algorithms provides a revolutionary opportunity to overcome these data volume and efficiency issues.

This paper outlines the development of a market-ready system to detect unpaved road distress that are compatible with a DSS by taking advantage of these technological leaps. The system uses areal imagery that can be collected from a remote controlled (RC) helicopter or manned fixed-wing aircraft to create a three dimensional model of sensed road segments. Condition information on potholes, ruts, washboarding, loss of crown and float aggregate berms are then detected and characterized to determine the extent and severity of the distresses. Once detection and analysis is complete, the data are imported into a GIS-based DSS (Roadsoft) for use by road managers to prioritize preventive maintenance and rehabilitation efforts.

INTRODUCTION

There are over 1.3 million miles of unpaved roads in the United States (*1*). In rural areas of the country, unpaved roads act as primary surface routes providing access to agricultural, forest and recreational lands. Unpaved roads allow adequate and cost-efficient service to rural areas with low traffic volumes; below a specific traffic volume it is difficult to justify the economics of paving low volume rural roads (*2*). The current economic conditions are making it difficult for state and local governments to maintain their existing paved road networks due to declining budgets and reduced purchasing power. In many road agencies the act of "de-paving" is becoming commonplace for lower volume roads. In Michigan, at least 38 of the 83 counties have converted some asphalt roads to gravel in recent years. Last year, South Dakota turned at least 100 miles of asphalt road surfaces to gravel (*3*). The economic attractiveness for low volume roads and reduced funding for maintenance ensure that transportation agencies will continue to build and maintain unsurfaced roads far into the foreseeable future.

Unlike paved roads, which can go years between required maintenance cycles, unsurfaced roads require frequent attention to maintain serviceable conditions and protect their structure. Unsurfaced roads can require several minor maintenance events per year such as grading and top dressing with gravel, particularly after major weather events. Failure to anticipate these minor maintenance events can lead to reduced levels of service as well as costly damage to the road structure.

Asset management systems and distress surveys have become commonplace for paved roads. Using asset management systems helps transportation agencies provide guidance on selecting the type and timing of maintenance activities based on field-observed distress data. The adoption of asset management systems for unpaved roads has been slow and is not as common as paved roads. The balance between low-cost distress data and the usefulness of that data for making decisions has limited the adoption of asset management systems for unpaved roads. Detailed road distress survey methods common for paved roads provide a rich source of data; however the development of similar distress identification methods for unpaved roads has been hampered by the cost to collect the necessary detailed data using standard techniques. The increased frequency necessary to collect distress data also makes unpaved road asset management systems a challenge. In some cases, the cost to collect detailed distress data can rival the cost of unpaved road maintenance. To overcome this cost barrier for data collection, a simplified rating system could provide basic condition data. These systems can be cost-effective, but the usefulness in decision-making can be greatly limited do to their subjectivity and simplicity.

Remote sensing technologies have the ability to overcome the cost vs. data quality barriers that have hindered unpaved road management by providing usable data that is compatible with a Decision Support System (DSS) that can be cost-effectively and quickly collected in a repeatable manner. The quickly declining price of flight platforms ranging from unmanned aerial vehicles (UAV) to small manned fixed-wing aircraft combined with commercial off the shelf image analysis software have the potential to change the economics of unpaved road condition assessment. This paper outlines a project to develop, test and demonstrate a prototype system for remote assessment of unpaved roads using both UAVs and standard aircraft flights.

METHODS

This work has been developed through a cooperative agreement between the USDOT Research and Innovative Technology Administration's (RITA) and Michigan Technological University through USDOT\RITA's Commercial Remote Sensing and Spatial Information (CRS&SI) program under project number RITARS-11-H-MTU1. The goals of this research project have been to develop a sensor for, and demonstrate the utility of remote sensing platforms for unpaved road assessment. The project was designed to enable the platform to be typical manned fixed-wing aircraft, a UAV, or both, depending on their relative strengths and weaknesses in meeting user community requirements for unpaved road assessment. To be cost-efficient, the project was designed so that the same sensor modality would be shared if more than platform was used. Further, the remote sensing method chosen had to be practical, economical, and effective for use by the transportation community. The sensor and platforms would allow for rapid identification and characterization of unpaved roads on an inventory level and provide meaningful condition metrics as well as enable mission planning, control of the sensor system, and data processing. Best engineering practices would rigorously define the requirements of the system and select the best sensor and platform technology to meet the needs of the stakeholders. At the end of the project the capabilities of the prototype system or systems would be demonstrated to stakeholders for their potential implementation. The results of the project, as described here, reflect the project team's commitment to meeting these project goals.

Selection of Distress Factors to Sense for Unpaved Roads

A review of the state of practice of unpaved road condition assessment methods was able to uncover over ten discrete assessment methods (domestic and national), with some having multiple variations (*4*). These methods can be classified into three categories: Visual methods which rely on trained data collectors' ability to estimate condition based on visual observations; Combination methods which rely on a mix of direct distress measurement and visual estimates, and Indirect Data Acquisition which relies on sensors to measure parameters that may be indicative of distresses.

Indirect Data Acquisition methods would appear to be easily adaptable to remote sensing systems. However, the cost of these types of systems and the fact that most current technology, such as ground penetrating radar, are required to be used in close proximity with the surface of the unpaved road makes Indirect Data Acquisition unsuitable for rapid remote sensing of unpaved roads.

Visual methods are poor choices for use with remote sensing systems because it is difficult to develop the rules for analysis using these methods without human intervention. Computerized distress assessment systems require a concise set of rules to follow for analysis, and hence have difficulty dealing with the subjectivity of these condition assessment methods. For this reason all Visual assessment methods were found to be unsuitable for this project.

The project team selected the Unsurfaced Road Condition Index (URCI) distress identification system (Combination method) as the method of choice for analysis by remote sensing. The URCI method was developed by U.S. Army Corps of Engineers and is described in Technical Manual 5-626 (*5*). The method provides specific information about the type and extent of specific distresses as well as provides a combined index which acts as an overall condition metric. The URCI method also has an accompanying set of maintenance intervention guidelines that give users direction on the appropriate maintenance activity based on a combination of condition ratings. The URCI method was the least subjective of all the methods identified by this study because almost all of its condition assessment metrics relate to specific, quantifiable measurements that rely less on rater judgment. Table 1 below outlines the distress parameters and the general criteria used to assess them in the URCI method.

TABLE 1. Unsurfaced Road Condition Index distresses (*5*)

Road Characteristics and Distresses	Assessment Criteria
Improper Cross Section	Minimal evidence of ponded surface water warrants a "low severity" rating while large amounts of ponded water or severely depresses cross sections warrant either medium or high severity rating in this category. This criterion was modified for this project to use a range of average cross slope to quantify the low, medium and high severity criteria. The length of roadway exhibiting each of the three severity levels of this factor is recorded and used as a measure of density.
Drainage	Drainage features that allow water to pond, are eroded, or are overgrown with vegetation are classified into either low, medium or high severity. This criterion was modified for this project to use ranges the difference in depth between the ditch bottom or standing water level and the edge of pavement to quantify the low, medium and high severity criteria. The length of roadway exhibiting each of the three severity levels of this factor is recorded as a measure of the factor's density.
Corrugations	Corrugated surface areas are classified into the following three bins: corrugations up to one inch (2.5 cm) deep are low severity, corrugations one inch to three inches deep (2.5 cm - 7.6 cm) are medium severity, and corrugations greater than three inches (>7.6 cm) are high severity. The square area of each bin of corrugated surface is measured to determine density.
Dust	If dust is present but visibility is not obscured, the factor is considered low severity.
Potholes	Potholes are classified as either low, medium or high severity based on a matrix of the frequency of their occurrence and classified into diameter and depth ranges of: less than two inches (5.1cm) , two to four inches (5.1 cm - 10.2 cm) , and over four inches (>10.2 cm).
Ruts	Minimum width of a typical vehicle tire is six to seven inches wide (15.2 cm - 17.8 cm) and can be as large as the wheel path travel area of the lane, approximately 24 inches wide (0.61 m). Ruts are classified based on their depth in the following three bins: ruts up to one inch deep (2.5 cm) are low severity, ruts one inch to three inches deep (2.5 cm - 7.6 cm) are medium severity, and ruts greater than three inches (>7.6 cm) are high severity. The total surface area is measured for each rutting depth bind for the sample unit.

Three of the six distresses assessed by the URCI system (Improper Cross Section, Dust and Drainage) are defined by qualitative criteria. The project team determined it was infeasible to collect Dust data using remote sensing because it was not practical to wait for a vehicle to disturb dust in order evaluate. The project team developed quantitative criteria for both Improper Cross Section and Drainage distress assessments based on interpretations of condition drawing provided in the assessment manual. More information on the development of these criteria is available in the document Deliverable 6B, "Decision Support System for Managing Unpaved Roads in RoadSoft" (*6*).

Imagery Collection

In order to characterize distresses down to 2.5 cm from at least 20 m above the road, a high-resolution optical sensor was necessary. The Nikon D800 was chosen for imagery collection since it is an easily accessible consumer grade DSLR (Digital Single-lens Reflex) camera with a 36.3 megapixel (MP) sensor. This high-resolution camera is also ideal for its relatively light weight (900g) which can easily be mounted to a RC helicopter. The D800 is also capable of continuous frame rates of up to 4 fps. Higher frame rates would allow for the aircraft to fly faster and still enable the collection of overlapping imagery necessary for generating 3D models.

For flights done at the lower altitudes a 50 mm prime lens was used. A prime lens was also preferred due to the improved image quality over zoom lenses (*7*) and weighing less than alternative lenses. This lens also has an aperture f/1.4 which allows for more light to pass to the sensor and subsequently faster shutter speeds. This is necessary to minimize potential motion blur in the imagery. The focal length was chosen as it would have a horizontal Field of View (FOV) of at least 16 m which is wide enough to capture the entire road and adjacent ditches in a single pass.

During collects the camera's collection rate is controlled by an add-on controller that can be set to collect images at 1 - 4 fps. Another feature is the built-in delay for starting the imagery collection. This allows the pilot time to turn the system on, move to a safe distance and lift the helicopter to the desired altitude before imagery collection starts.

Collection altitude and speed, payload and endurance were taken into account for the selection of a suitable RC platform. During these collections the camera would be flown at an altitude of 20 - 30 m. Given the vertical FOV of the camera system, a flight speed of roughly 2 mps is necessary to provide enough image overlap. Given this low speed and weight of the camera system a fixed-winged RC aircraft would not be feasible. For this reason, a single-rotor RC helicopter and hexacopter have been used. Helicopter based platforms also offer greater stability than fixed-winged RC aircraft, they are able to take off and land vertically and do not have a minimum flight speed. Both platforms are electric-powered rather than fuel-powered, as electric helicopters have less motor vibration and sensor equipment would not be fouled by exhaust. This also ensures that the camera is flown on a steady platform.

The first RC helicopter was the Bergen Tazer 800 single rotor (Figure 1a). This helicopter has a payload capacity of 10 kg and can fly for up to 18 minutes when loaded. The Tazer 800 is also equipped with a full GPS IMU (Internal Measurement Unit) that allows for additional stability and the ability to program waypoints. The waypoints are programmed by using Ground Station software. Ground Station uses Google Earth imagery to assist in locating where waypoints are to be placed. For collects, a GPS point was taken at the beginning and at the end of the road section. This is necessary as imagery referencing in Google Earth was not accurate enough for the RC helicopter to fly the exact centerline of the road. Within Ground Station there is functionality to manually edit the latitude and longitude as well as the altitude and flight speed. With this system, the Tazer 800 was manually maneuvered to the approximate collection altitude and over the centerline of the road. Ground Station was then activated via a laptop which started the waypoint mission with the pilot able to take back control of the helicopter at any time. Once the waypoint mission is completed the pilot takes back control of the helicopter and manually lands it.

A second multirotor RC helicopter was also used for imagery collects (Figure 1b). The hexacopter does not have the payload capability (8 kg) or endurance (12 minutes loaded) as the single-rotor helicopter but it is a more stable platform that is easier to fly. This system also has a GPS IMU which allows for a more stable flight but it does not have waypoint functionality. Instead of flying waypoints, the hexacopter is manually flown down the centerline of the road. A small camera mounted next to the D800 sends a video feed to a monitor on the ground. This monitor also displays the altitude and speed of the hexacopter which a copilot uses to assist the pilot in maintaining the correct flight path, altitude and speed during collects.

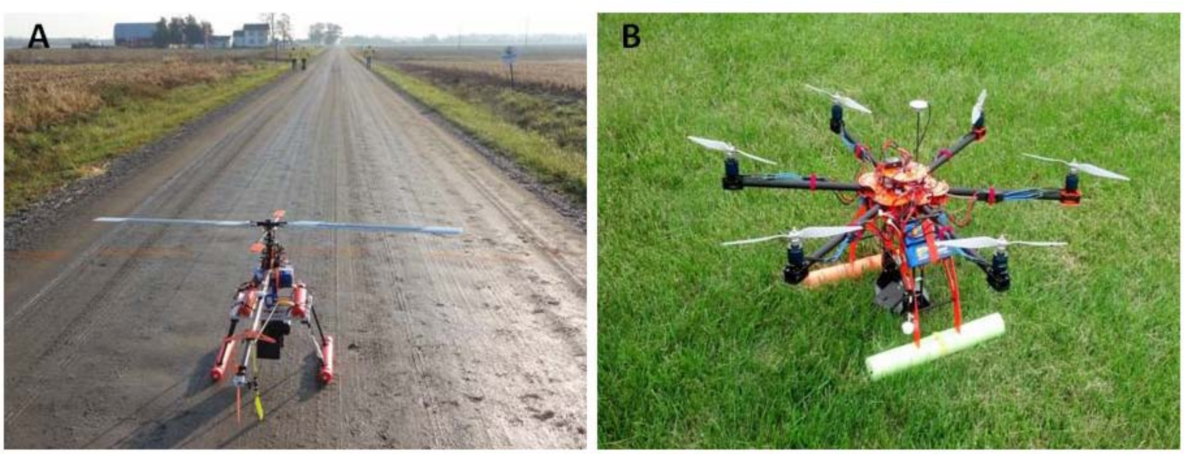

Figure 1a and 1b: The Tazer 800 RC helicopter, with camera mounted underneath, ready for collecting unpaved road condition data (A). The Bergen Hexacopter was acquired as an easier to fly, more stable remote sensing platform (B).

Imagery of the unpaved roads was also collected using manned fixed-winged aircraft. The manned fixed-winged aircraft were a Cessna 152 and 172. The first flight was done with the Cessna 172 flying parallel to the road at 65 knots (120 kph). The D800 used a 100 mm lens and was pointed out of the aircraft window (Figure 2a). For the Cessna 152 flights, the aircraft was flying directly above the road at 50 knots (93 kph) with the D800 using a 200mm lens and mounted in the door (Figure 2b). The door-mounted configuration allowed for the imagery to be collected near nadir. Both aircraft were flying at an altitude of 152 m. The 200 mm lens was used for the manned aircraft collects in order to maintain higher ground sample spacing. The 50 mm lens would have had an FOV significantly larger than necessary which would have lowered the resolution enough that it would not be able to resolve distresses down to 2.5 cm.

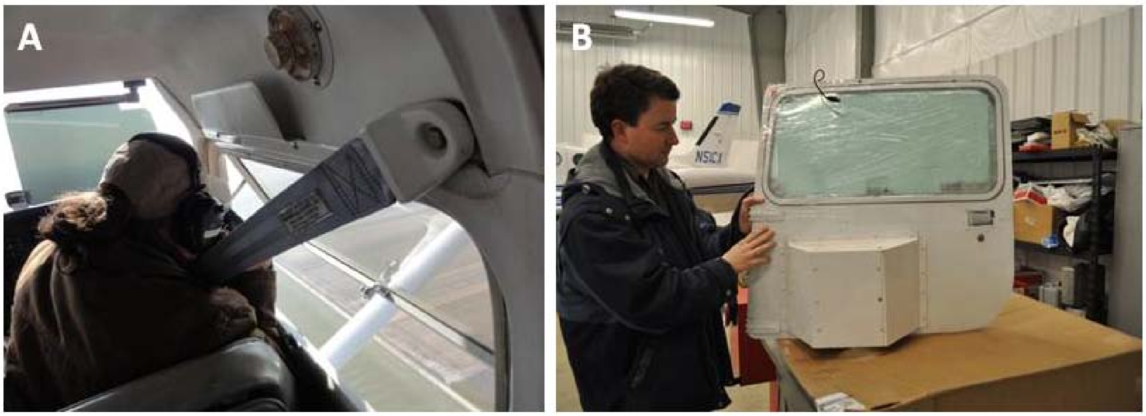

FIGURE 2a and 2b: The window-based camera deployment setup used in the Cessna 172 (A) and the Cessna 152 door being prepared for direct overhead imagery collection (B).

Distress Detection Algorithm

The distress detection algorithm is comprised of a series of Commercial Off The Shelf (COTS) algorithms that have been combined to extract condition information that falls within predetermined size bins. These individual algorithms are combined using Python and run through the Bash Shell. The main algorithm that generates the 3D point cloud from collected imagery is Structure from Motion (SfM) that uses Bundler software (*8*)(*9*). This process needs at least five images containing the same field-of-view, taken from different aspects, in order to reconstruct the 3D height-field from the 2D images. The optimal camera position for each of the photos is calculated during this step as the altitude of the helicopter will vary slightly during the collect.

The resulting point cloud is then densified using a dense multi-view stereo algorithm that takes the SfM output, and the images, and creates a much finer point cloud using Scale-Invariant Feature Transform (SIFT) and Patch-based Multi-View Stereo (PVMS) software (*10*). A watertight surface is formed from the point cloud using a Fourier-based technique (*11*). This process generates a height field for which a scale will be added.

Before distresses can be located, the road has to be isolated from the adjacent land. For this a windowed entropy filter is applied to locate the road surface. Since the road is relatively smoother (lower entropy) than the surrounding fields, the unpaved road can be extracted as a mask. Fiducials are placed on the edges of the mask and a scale is determined based on the road width measured as ground truth during the collect. The mask will also be used to constrain all road distress detections to parts of the point cloud that represent the actual road surface.

In order to locate potholes, the Canny Edge Detection algorithm is run on the extracted road surface to locate edges. This is then run through the Circular Hough Transform (*12*) which locates the potholes and calculates their diameters. A mask is formed from this detection output, and applied to the height field, from which the depths are derived. Statistics are then calculated to categorize the detected potholes into one of three bins to be imported into the DSS. In order to locate ruts and washboarding, the best plane for the surface need to be found. This is done by using Singular Value Decomposition. The model is rotated so the z-axis is normal to the road surface and rotated to a cardinal direction. The height field is then run through the Smooth Guardband and Gabor Filter (*13*). The Gabor Filter is a convolutionbased filter that gives localized, directional frequency information. Ruts only form along the direction of travel on the road, and corrugations only form perpendicular to that. Masks are formed from these detectors and are applied to the height-field to characterize the extent of the damages.

Crown variations are determined by the center-to-edge variation in road height. The height filed is broken into 3 m subsections. The grade is then averaged within each subsection and the minimal grade on each side of the center of the road is reported.

For the purposes of verify the accuracy of the distress detection algorithm, ground truth data was collected at the time of collection. Each flight collections site was broken up into 50 m sections to help with measurements and mapping distress locations. Detailed measurements (length, width and depth) were taken of each of the distresses and their location within the 50 m sections were recorded .

Integration with DSS

The post-processed data sets created by the remote sensing system and summarized by condition for each distress type are available for use in a DSS via an XML export. The export created for this project was specifically made to interface with the Roadsoft software for the purposes of demonstrating compatibility with a DSS. Roadsoft is a commercially-available transportation asset management software developed at Michigan Technological University in cooperation with the Michigan Department of Transportation. The software is used by over 400 transportation agencies within and outside Michigan for managing pavements and other roadway assets.

The data elements collected by the URCI method are ideal for integration with DSS. The URCI method provides severity and extent data on the six cardinal unpaved road distresses as well as providing a combined overall condition index. The URCI method also provides guidance criteria for maintenance alternatives based on the presence and severity of specific distresses. Maintenance criteria from Table 4-1 of Technical Manual 5-626 from the Department of the Army form the backbone of the DSS (5). Users can also develop their own distress criteria for suggested maintenance options based on their business practice or local conditions.

The DSS stores data associated with the URCI ratings derived from the collected imagery in a geospatial database. This provides quick access to the data through a map interface that relates the data to a physical location. The data from distress surveys can be filtered and sorted based on user-entered criteria that can be used to identify candidate projects for maintenance or rehabilitation. Figure 3 illustrates the use of the Roadsoft DSS in identifying candidate projects based on their condition. As a start users can get guidance from the Corps of Engineers maintenance criteria or can develop their own criteria for specific maintenance types.

Once candidates have been identified for specific maintenance, the activity can be scheduled and tracked in the DSS. Tracking maintenance in the DSS provides a permanent record that can assist road managers with tracking projects and balancing workloads. The records of completed maintenance work stored in the DSS also provide road managers a convenient method to review historical work activities alongside condition data to determine when major interventions are necessary.

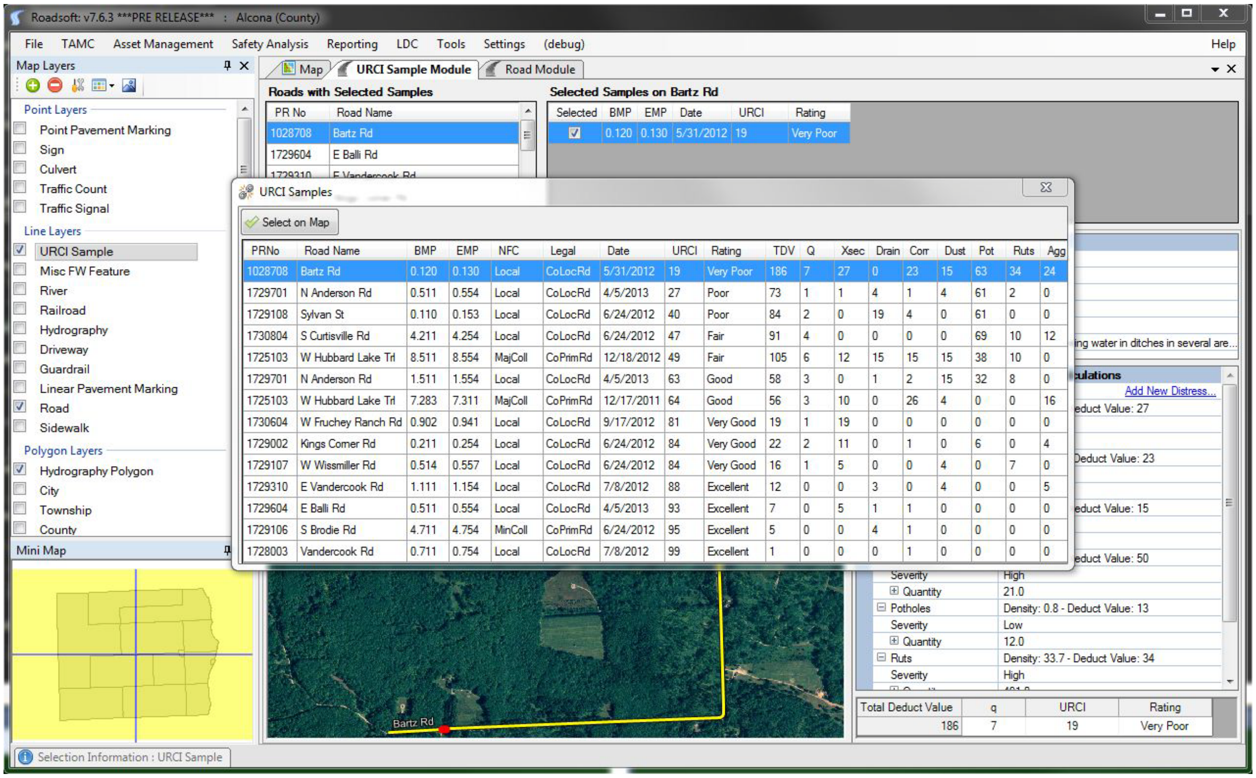

FIGURE 3: Unpaved road project candidate ranking matrix based on condition and inventory as displayed through the Roadsoft DSS.

RESULTS

Imagery Collection

Both RC helicopters were easily transported and were able to collect the necessary imagery for distress characterization. The most noticeable difference between the two systems was the time needed to deploy. The Tazer 800 took up to 15 minutes for setup of the waypoints and flying the mission. A large portion of this time was involved with the collection of the GPS positions of the road centerline and adjusting the waypoints in Ground Station.

In comparison the hexacopter took only five minutes for the same collects. Once the team arrived at the site the hexacopter was ready for flight in about a minute. Engine startup, flying the mission, landing and engine shutdown t took three minutes. The hexacopter was then loaded back in the vehicle ready to be taken to the next site in less than a minute.

Other advantages of the hexacopter over the Tazer 800 include reliability, cost and safety. There are fewer moving parts on the hexacopter which allows for greater reliability. The Tazer 800 has over 30 linkages, gears, and bearings which are all points of failure and difficult to repair. Because of this an in-depth preflight inspection is necessary on the Tazer 800 since the failure of a single part could lead to losing control of the helicopter. In comparison the hexacopter has only six moving parts which are the electric motors. A preflight inspection is also necessary for the hexacopter but it is not as time consuming as it is considerably simpler. The Tazer 800 is also more expensive than the hexacopter. The Tazer 800 cost $14,000 while a hexacopter with the same waypoint capability cost $6,000.

The six small rotors of the hexacopter are safer to operate than the single rotor of the Tazer 800. This is because each rotor blade on the Tazer 800 is carbon-composite with lead weights on their leading edges. This could cause serious injuries for individuals that are struck by the blade. In comparison the rotor blades of the hexacopter are considerably smaller and are made of molded plastic which translates to less inertia. If an individual is stuck with this blade it would not be considered serious.

Imagery collected from the manned fixed-winged aircraft was not of sufficient quality to be used for the distress detection algorithm. The first set of imagery was taken from the Cessna 172 with the 100 mm lens. With the FOV of this setup there was sufficient overlap of the imagery to produce 3D models of the road. A drawback of this wider FOV is that the resolution was too reduced to extract useful condition information. The second flight was from the Cessna 152 with a 200 mm lens pointed at nadir. It was thought that with the longer focal length and narrower FOV that this would improve the resolution. This setup however also proved to be ineffective. With the narrower FOV, any minor adjustments made by the pilot to correct for turbulence resulted in the road falling outside of the camera FOV. In order for this setup to be successful, the camera would need to be isolated from the roll, pitch and yaw motions of the aircraft and remain level. These setups are expensive and outside the scope of this project.

Distress Detection Algorithm

Imagery collected from both RC helicopter platforms was run though the distress detection algorithm(Figure 4a). After running the imagery through SfM, Blender software and PVMS, densified point cloud has a resolution of about 1 mm in x, y and z directions. This is more than sufficient for the required minimum distress size. Potholes can easily be seen in the reconstructed 3D point cloud (Figure 4b). The distress detection algorithm development has been successful in locating and categorizing distresses into size bins needed for importing into the DSS.

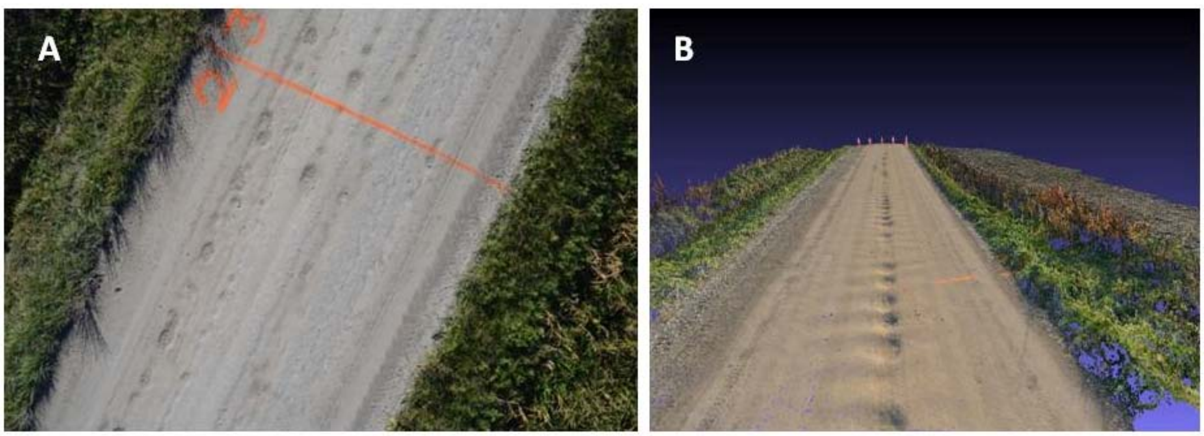

FIGURE 4a and 4b: High-resolution (36.3 MP) photo taken of the sampled unpaved road (A). A colored point cloud representing 3D data reconstructed from the overlapping imagery collected by the RC helicopter platform (B).

Figures 5a and 5b show an example of the depth maps created from the densified point cloud. Pothole features can clearly be seen in the data. This is critical to classifying distresses into categories of severity, which is needed for calculating the UCRI. The characterized distress data in URCI format is being made available for querying and decision making within the DSS and asset management tool.

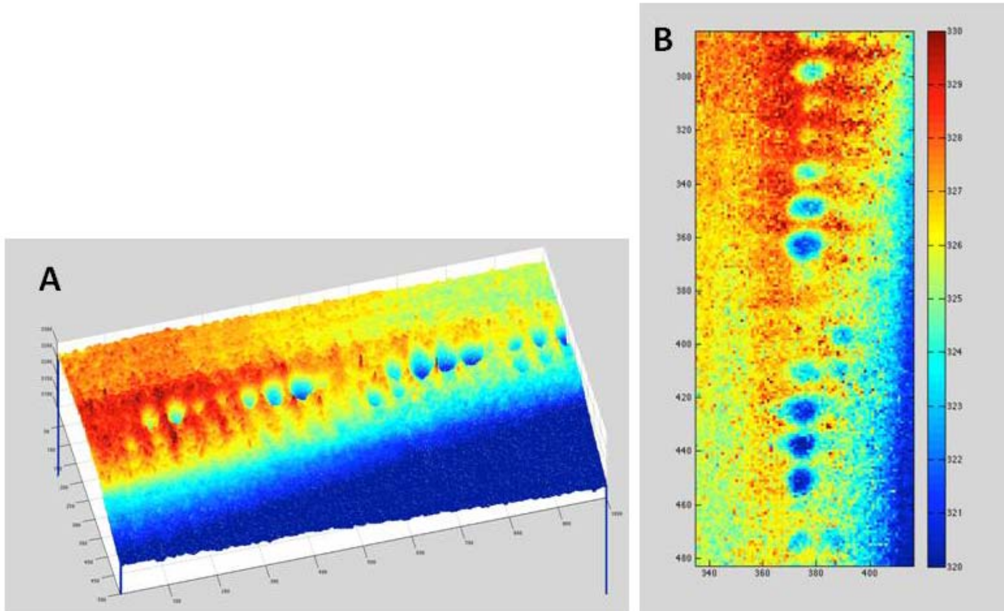

FIGURE 5a and 5b: Examples of the 3D depth maps for the same area, showing clear characterization of pothole locations in the unpaved road.

The output from the windowed entropy filter proved successful in separating the unpaved road from the adjacent vegetation. From the mask of the unpaved road, an absolute scale was generated using in situ measurements of the road width. Errors in the scale are introduced from varying road width and grass and other debris on the edges of the road. Grouping distresses into good, fair and poor categories allows for some error in the individual measurements of the distresses without compromising the overall determination of the road condition. All distress detection routines start with the height field that is extracted from this road mask.

The two-step process of locating potholes starts with the Canny Edge Detection and then followed by the Hough Circle Transform Figure 6a and 6b show the results of a pothole detection analysis. Running time for this part of the algorithm is approximately 10 seconds per 10 m section.

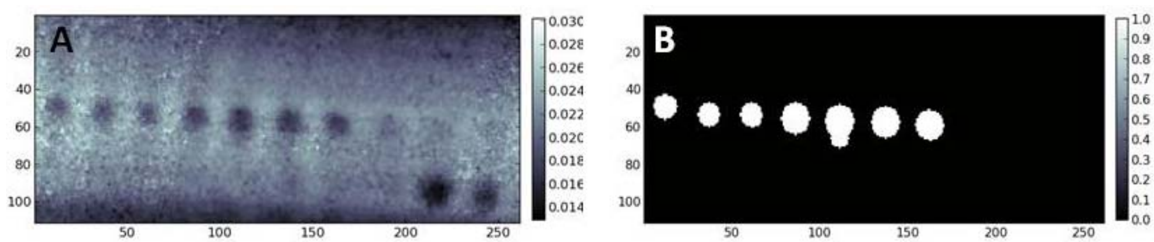

FIGURE 6a and 6b: The left (A) figure depicts the potholes with a depth map; the right (B) figure shows the potholes after a Circular Hough Transform.

The detection of washboarding is made by first re-orientating the road so that the lanes are rotated to a cardinal axis as this distress occurs perpendicular to the direction of travel. Figure 7a shows an area analyzed for washboarding. The Gabor filtering determines the localized directional frequency information and locates potential washboarding (Figure 7b). An area threshold is then run on the potential washboarding as smaller areas could have a higher incidence of false detections and confusions with other distresses (Figure 7c). This process takes approximately 1 - 5 minutes per 10-meter section depending on the extent of the distresses.

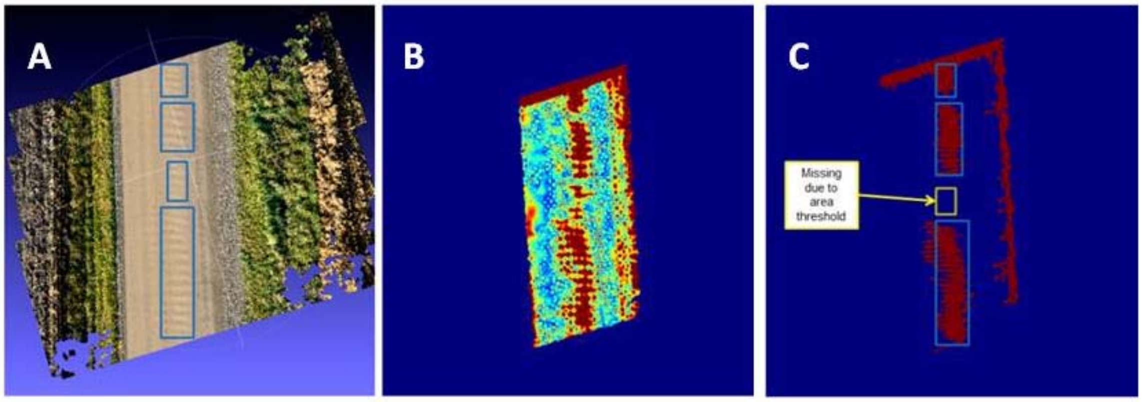

FIGURE 7a, 7b, and 7c: Examples of extracting washboarding locations from collected imagery. The blue boxes represent washboarding that was visually determined.

Crown measurements are taken at 3 m intervals within the 200 m representative section. For each of the 3 m subsections an average profile was calculated. Then the grade from both edges to the center of the road is computed, resulting in two coherent grades (Figure 8). After this, the minimum grade between the left and right sides is taken, in the event that the crown is damaged far worse on one side. The grades of each subsection are classified into bins that are reported to a DSS.

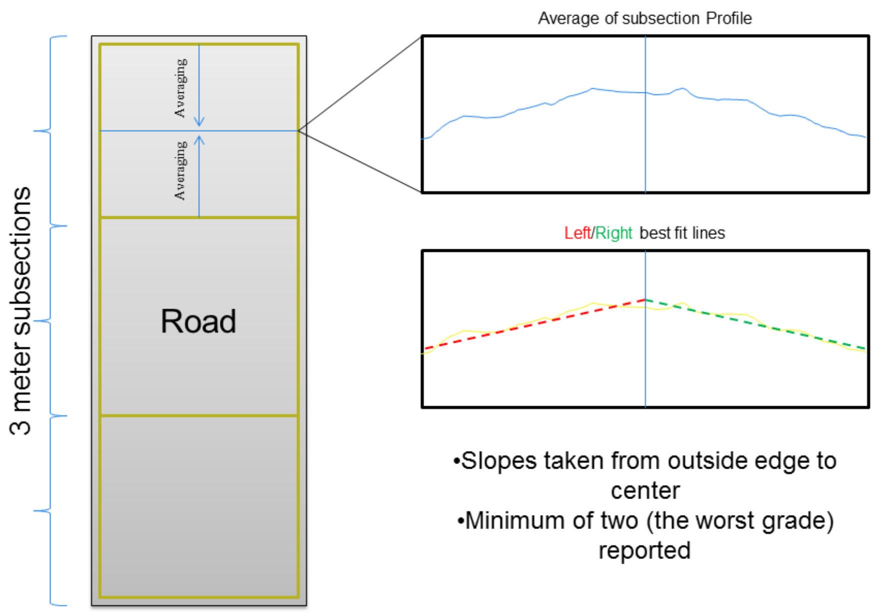

FIGURE 8: Representation of crown distress detection analysis showing how the crown is measured and how best-fit lines are derived.

CONCLUSION

Comparison of the remote sensing system for unpaved roads has shown that the URCI method produces high-quality, reliable distress identification. The system is cost-effective based on comparisons to manual assessments. The URCI method produces data that can be used in a DSS for effective management of unsurfaced roads either by using the maintenance activity triggers developed by the Corps of Engineers or using locally developed criteria. In addition to the cost-effectiveness of the URCI method, the remote sensing system described in this paper provides other valuable data that would not normally be collected during a manual survey. The additional data products created by the remote sensing system include the aerial photos and the three dimensional point cloud, both of which have significant value to road management professionals. While research is still ongoing for the Cessna 152/172 platform, the RC helicopter platforms have demonstrated that they can collect the high-resolution data necessary to objectively collect road distress data on a rapid, repeatable basis.

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Appendix D. Outreach Articles

List of Recent Popular Press Articles Released Concerning Colin Brooks' UAV Focused Unpaved Roads and Related Research

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Table Of Contents

Up in the sky! Is it

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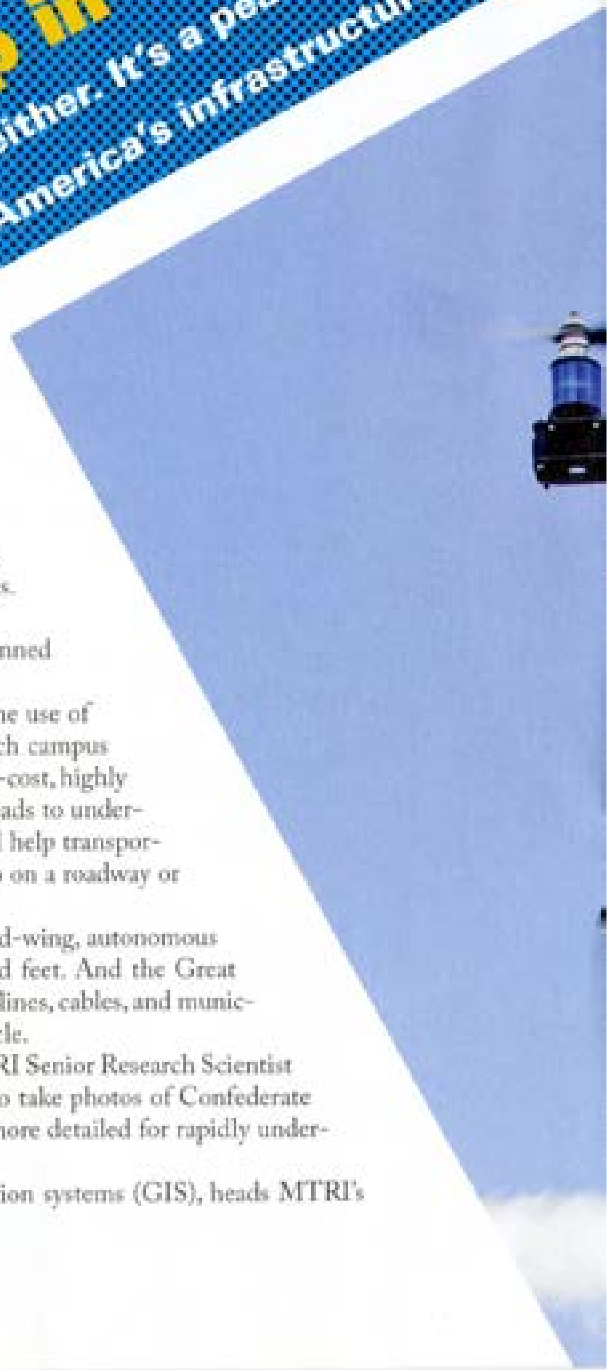

The friendly drones of Michigan Tech

BY JENNIFER DONOVAN

Everyone knows what drones are, right? Drones are unmanned flying machines, and they've gained visibility—and notoriety—in military and spying operations. But they have a wide variety of friendly, beneficial applications here at home.

Researchers at Michigan Tech are working with three different kinds of unmanned vehicles—aka drones—and not all of them fly through the air.

The Michigan Tech Research Institute (MTRI) in Ann Arbor is looking into the use of drones in transportation. MTRI scientists and faculty from the main Michigan Tech campus are using unmanned aerial vehicles (UAVs) to help government agencies develop low-cost, highly efficient ways to handle tasks that range from mapping the condition of unpaved roads to understanding traffic jams and evaluating the conditions inside culverts. The research will help transportation agencies save money and reduce risk to staff who would otherwise have to go on a roadway or bridge, or inside a confined space, to understand infrastructure conditions there.

Meanwhile, a graduate student in the School of Technology is developing a fixed-wing, autonomous aerial vehicle to take high-resolution digital images from heights of three hundred feet. And the Great Lakes Research Center is saving time, money, and lives by checking underwater pipelines, cables, and municipal water intakes with Iver 3, the latest generation of autonomous underwater vehicle.

Using aerial imagery to understand conditions on the ground is nothing new, MTRI Senior Research Scientist Colin Brooks points out. "During the Civil War, the Union Army used balloons to take photos of Confederate earthworks," he said. "We're just making data-gathering quicker, easier, safer, and more detailed for rapidly understanding our transportation infrastructure."

Brooks, who specializes in remote sensing technology and geographic information systems (GIS), heads MTRI's project team evaluating uses of UAVs.

a bird? A plane?

f many on the front line of the battle to fix ds and bridges to underwater pipelines.

Pothole prowler

UAVs like this one at the Michigan Tech Research Institute may soon be cruising America's highways and bridges and reporting back on their condition.

Michigan Technological University researchers are using remotely controlled helicopter drones to take high-resolution photos of roadways.

Researchers Have High Hopes For Drone Use in Transportation

FEDERAL REGULATORS are poised to allow more widespread domestic use of drone aircraft in the coming years, and researchers say that the technology will greatly help in monitoring the nation's roadway infrastructure. Researchers at Michigan Technological University are studying the feasibility of using drones, or, more formally, unmanned aerial vehicles (UAVs), as a more efficient, less expensive way to assess road conditions than current manual techniques.

Small UAVs weighing less than 55 lb could be used to capture high-resolution images of roads and bridges and supply valuable road and traffic data without the need for intensive fieldwork and road closures, says Colin Brooks, a senior research scientist at the Michigan Tech Research Institute, which is part of Michigan Technological University. Brooks says that the technology could be especially useful in monitoring unpaved roads, which make up nearly one-third of all roads in the United States and are especially difficult to access and maintain.

The researchers at the Michigan Tech Research Institute are in the final stages of a study in which they've used small, remotely controlled multirotor helicopters equipped with digital cameras to study unpaved roads for such deficiencies as potholes, ruts, and insufficient crown. They say that the technology has been remarkably effective, delivering images of up to 1 cm in resolution at a cost that is about one-fifth that of traditional surveying techniques, and they see the drones as extremely promising transportation engineering tools.

"The technology we've developed can be used essentially to create subcentimeter-resolution 3-D models of any surface. We could be flying this to evaluate paved roads and over bridges," says Brooks, who is leading the research team. "We can do this on a repeatable basis that we think is cost competitive, instead of having to get out on the road with a ruler and a level."

The \$2.4-million unpaved road study is being conducted in conjunction with the U.S. Department of Transportation's Research and Innovation Technology Administration, which is sharing the funding equally with the university. The study began in 2011, and researchers expect to complete it this spring.

The research team has spent more than two years using a pair of camera-equipped helicopters from Bergen R/C Helicopters, of Cassopolis, Michigan, to look primarily at gravel roads. The researchers for the most part have used a large single-rotor UAV helicopter, but more recently they have been working with a sturdier six-blade model that weighs 11 lb, has a 4 ft rotor span, is simpler to fly, and costs \$5,000.

The helicopters are operated from the ground and flown at altitudes of 80 to 100 ft, from which they photograph representative sections of unpaved roads. These images are used

Aerial images captured by the drones are used to create three-dimensional models of roads that enable researchers to detect damage.

to detect such problems as bumps, ditches, and "washboards," and they are enabling the researchers to extrapolate and gain an insight into the overall health of the road network.

The UAVs have a vast array of potential uses that go beyond assessing road damage, Brooks says. He notes that his research team and the Michigan Department of Transportation have discussed the possibility of using drones equipped with lidar remote-sensing technology and thermal sensors to detect surface and subsurface damage in bridges.

Another proposal involves using tethered unmanned blimps to monitor traffic patterns, especially where it may be difficult or expensive to install standard traffic cameras. Furthermore, small drones could be used to evaluate the quality of road maintenance work, assess flooding, take road sign inventories, and otherwise gather data in areas that do not offer easy access, he adds.

Such drones could also eventually be equipped with sensors to gauge air quality and with other devices to assess atmospheric conditions. By using drones for this work, Brooks says, "you have a chance to have less impact on the traveling public and also increase safety."

Brooks points out that even though many of the drone technologies that are being tested are working well, scientists and research organizations are awaiting approval from the Federal Aviation Administration before using the devices on a more widespread basis. The agency currently allows UAVs to be used only by government agencies and public universities.

The agency is expected to issue regulations in the coming years that will allow private and commercial use of drones. Regulations permitting broader use of small UAVs of the type used by the Michigan Tech Research Institute are expected to be proposed this fall, while broad commercial regulations are expected to be issued by September 2015.

Privacy concerns have led to some misgivings, but Brooks notes that airplanes and automobiles are already being used in an identical capacity to collect images and survey public areas. He says that small UAVs would have the advantage of being able to capture overhead images not available from cars; they could also fly lower and provide images of higher resolution than can be obtained from planes. Privacy laws would continue to be followed.

Brooks adds that drones could help to address one of the biggest problems facing the United States—its deteriorating infrastructure and the massive costs associated with it. He points out that because the demand for new roads and the cost of maintaining existing ones far outpace available funding, drones would present a welcome option to reduce maintenance costs while increasing efficiency.

"All these states and local agencies are trying to do more with less," he says. "And if this can be a cost-efficient way of helping to assess the condition of gravel roads and bridges and increase safety, then this could be a very good set of technologies." —DAVID HILL

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Big Savings

See pages 6-7A

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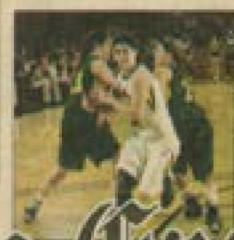

Perttu pours in 30 as Tech women fend off Northern

See page 1B

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PARTLY CLOUDY 10/-6 — Tuesday, February 4, 2014

High-tech solutions for low-tech problems

Drones outfitted by Michigan Tech to be used to inspect gravel roadways

By DAN ROBLEE
droblee@mininggazette.com

HOUGHTON — Michigan Technological University researchers are outfitting high-tech unmanned aerial vehicles to inspect some less modern infrastructure elements: gravel roads.

The research team, based out of the Michigan Tech Research Institute in Ann Arbor, is hoping to partner with a private company and have their UAVs — commonly known as drones — available for Departments of Transportation and contractors when expected FAA regulations make flying the vehicles commercially legal, likely by the end of next year.

MTRI Senior Research Scientist Colin Brooks said the purpose of the technology is to save DOTs money by helping them pinpoint gravel roadway problems more efficiently than if they had relied on complaints and physically sending people out to assess problems.

"We want to help them save money and repair the roads more efficiently," Brooks said. "It's better than driving all over the place."

The UAV's primary components, a six-bladed remote control helicopter that can fly by remote control or on its own from one GPS waypoint to another — if that becomes legal — and a 36-megapixel camera, are both available off the shelf. That leaves MTRI scientists to focus on job-specific modifications and the automated imaging software that will help the systems earn their keep.

"For less than $10,000 we can have a system that flies unpaved roads," Brooks said.

Photo courtesy Michigan Tech

He said the UAV's are essentially ready for market, with team members now focusing on reaching out to potential business partners and clients, and developing better algorithms to help computers analyze the images the drones will gather.

Michigan Tech professor and Houghton-based team member Tim Colling is an expert on road maintenance who works regularly with the Michigan Department of Transportation. He helped MTRI garner a $2.4 million federal DOT grant in 2011 that's funded the UAV research, and has shared his expertise with the project ever since.

Colling said the demand for better analysis systems grew out of a strategy called asset management that helps DOTs get maximum benefit from their road-repair dollars.

"If you do repairs way too soon it won't give you the benefit, but if you wait you'll have lasting damage," he said.

Pinpointing the most cost-

See TECH Page 10A

TECH/Drones will help study gravel

Continued from Page 1A

effective opportunities for repair is where the UAV photos and analysis enter the picture.

"We're using technology that's relatively cheap to collect better data to make better decisions," Colling said.

With UAVs flying at about 80 to 100 feet, Brooks said the systems are able to accurately photograph representative stretches of road in 3-D, with high enough resolution to see even minor surface variations.

"If you're looking at it with a 36-megapixel camera, you can see individual pieces of gravel," he said. "Any pothole greater than half an inch in depth, I'm going to be able to see."

Logging 100- to 200-foot segments of road each mile, he said, is generally enough to provide an accurate assessment of a road's overall condition. Photographing each of those segments takes only about 15 minutes, he added.

Brooks said MTRI is also working on a second UAV project, funded by a $250,000 grant from the Michigan DOT, to design UAVs that will fly in culverts and other enclosed spaces. Cameras on those UAVs are designed mainly to gather real-time images rather than to record, for basic inspection and to determine whether it's safe to send a worker into the space.

"Even if all you do is send out a live video feed, these hand-held systems are less than $2,000," Brooks said. "That's cheap compared to putting a person at risk."

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Michigan May Use Drones to Study Unpaved Roads

BY GOVERNMENT TECHNOLOGY | JANUARY 31, 2014

By Colin Wood

Drones are getting a lot of play in the public safety field, but can they do anything for transportation agencies?

Researchers at the Michigan Tech Research Institute (MTRI) are working to find out; engineers, computer scientists and transportation researchers are looking for cost-effective unmanned aerial vehicle (UAV) projects that could replace today's processes for mapping roads and roadside features, identifying potholes and understanding traffic.

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One project funded through the U.S. Department of Transportation's Research and Innovation Technology Administration (USDOT/RITA), called Unpaved Roads, aims to help departments of transportation across the country assess and predict repairs needed on unpaved roads more quickly and cheaply.

"We're making data-gathering quicker, easier, safer and more detailed for rapidly understanding our transportation infrastructure," MTRI Senior Research Scientist Colin Brooks told Michigan Tech News. "[The UAVs] can show us how many potholes are in a road and how deep they are, the degree of crown in a roadway, identify rutting conditions in a roadway, wash-boarding, drainage, and evaluate density and severity of road and bridge problems."

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Researchers are experimenting with UAVs of varying size and cost on the project, which is scheduled for completion this year. One hexacopter being used costs $5,000, weighs about 11 pounds, and can hold a full-sized digital SLR camera. A smaller drone being used cost $700 and can hold a smaller camera, like a GoPro. The collected imagery is used to create 3-D models, which are often accurate to within a centimeter, said Assistant Research Scientist Richard Dobson.

"We would like to see either local DOTs using this to assess their roads or help them with planning out when they need to go out and re-grade unpaved roads rather than relying on complaints from locals who live on the roads," Dobson said. "If they can figure out how quickly their unpaved roads degrade in certain areas or how quickly after major storm events, if they can better understand that, then they can be more on top of taking care of them before they become a problem."

Instead of governments taking control and managing fleets of UAVs themselves, Dobson predicted that companies will begin offering such UAV technology as a service to DOTs, once the Federal Aviation Administration (FAA) relaxes their policies in 2015, following research in six test UAV test sites. Current methods of assessing damage to roads by on-foot personnel can be time-consuming and expensive for agencies, and contracting a UAV service fits with the public-sector trend of purchasing technology as a service rather than managing it in-house.

This research will wrap up in the next few months, Dobson said, concluding a project that was started in late 2011.

Though strides they've made in their research could lead to new products and services, he noted that there is one shortcoming: an inability to create a piece of cohesive software that removes some of the manual processes required by the user. The team lacked both time and funding to make that happen.

"There's a fair amount of handholding right now," he said. "It's not a user-friendly, single piece of software that you can throw imagery at and get your characterization of the unpaved road at the other end."

All the software components, such as the 3-D model maker and stress detection, work separately, Dobson added, and the user has to really know what he's doing to work the software. In terms of raw performance, however, the software works great.

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Michigan Tech Researches Feasibility of Drone Use in Transportation

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By **Jennifer Donovan**
906-487-4521, **jbdonova@mtu.edu**

Rick Dobson, Andre Clover (MDOT) and Colin Brooks, left to right, look at the DJI Phantom UAV.

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Athletics

January 13, 2014—Everyone knows what drones are, right? They have gained visibility for use in military and monitoring applications, but have a wide variety of more 'friendly', useful applications here at home, such as helping understand the condition of our transportation infrastructure. They are flying machines, operated for a given purpose either autonomously or remotely, that have uses well beyond their better-known reputation.

The Michigan Tech Research Institute (MTRI, **www.mtri.org**) is currently looking into the use of drones from a transportation perspective. MTRI scientists and faculty from the main Michigan Tech campus are using unmanned aerial vehicles —popularly called drones—to help the US Department of Transportation's Research and Innovation Technology Administration (USDOT/RITA) and other agencies to develop low-cost, highly-efficient ways to handle tasks that range from mapping the condition of unpaved roads to understanding traffic jams and evaluating the conditions inside culverts. **The research** is designed to help transportation agencies save money and reduce risk to staff that would usually have to always be in a roadway, on a bridge, or inside a confined space to understand infrastructure condition.

Using high-resolution aerial imagery to understand conditions on the ground is nothing new, MTRI Senior Research Scientist Colin Brooks points out. "During the Civil War, the Union Army used balloons to take photos of Confederate earthworks," he said. "We're just making data-gathering quicker, easier, safer and more detailed for rapidly understanding our transportation infrastructure."

Brooks, who specializes in remote sensing technology and geographic information systems (GIS), heads MTRI's project team evaluating uses of unmanned aerial vehicles (UAV). But it's a real team effort, with computer scientists programming analysis software, electrical engineers upgrading UAV flight capabilities, Michigan Tech Center for Technology and Training scientists providing gravel road and Roadsoft GIS expertise, and professors from the Geological and Mining Engineering and Sciences, Civil and Environmental Engineering, and

Electrical and Computer Engineering departments sharing their knowledge.

Now about those “drones.” The Michigan Tech ones look like miniature helicopters, and MTRI has two UAVs it is currently using: a Bergen hexacopter and a DJI Phantom quadcopter. The hexacopter; largest of the two, it has six blades and a four-foot rotor span. It costs $5,000 as configured for research and weighs just over 11 pounds and can fly a digital camera like a Nikon D800. The smaller UAV has four blades that spin in a two-foot diameter. It weighs only two pounds and costs just $700 and can fly smaller cameras like the Go Pro that is a favorite among action sports users.

Both UAVs take full-sized high-definition digital images, with the higher resolution ones capable of better than one centimeter 3D resolution. “They can show us how many potholes are in a road and how deep they are, the degree of crown (curve) in a roadway, identify rutting conditions in a roadway, wash-boarding, drainage, and evaluate density and severity of road and bridge problems,” says Brooks. Up to now, agencies responsible for roads have been reactive, checking out problems after someone calls to complain, he explains. “This technology turns reactive responses to proactive responses through improved asset management practices,” he says.

David Dean and Richard Dobson, assistant research scientists at MTRI, specializes in interpreting aerial photographs. They see what the camera is seeing as the UAV flies over a road or bridge, or even inside a pump station or culvert; and they stitches still photos together into a three-dimensional model.

The UAVs’ flight is controlled by a “pilot” on the ground, reminiscent of remote-control model airplanes, but if they have to, they can find their own way home. They fly about 100 feet above the ground, well below the Federal Aviation Administration’s permitted ceiling of 400 feet. Both have cameras, GPS, and on-board stability systems.

And MTRI is experimenting with another, even smaller quadcopter, the open source Crazyflie, for inspecting confined spaces and seeing if it's safe to send a person inside there. It weighs two-thirds of an ounce and costs $179. "Its controller is bigger than the vehicle," Brooks remarks.

MTRI's UAV work for US DOT/RITA is a $2.4 million project to analyze unpaved road conditions using remote sensing technology.

Right now, UAVs can only be used regularly by government agencies including public universities. But the FAA is expected to issue regulations by September 2015 that will allow their commercial use in the national airspace.

MTRI also represents the University in the Michigan Advanced Aerial Systems Consortium (MIAASC), which was working to get the Alpena, MI area designated one of six unmanned aerial systems FAA test sites nationwide.

"We are on the cusp of an explosion in UAV data collection that can help save money and increase safety during our inspections of roads, bridges, and confined spaces," Brooks predicts. MTRI's work with UAVs will lead the way.

DISCLAIMER: The views, opinions, findings and conclusions reflected in this press release are the responsibility of the authors only and do not represent the official policy or position of the US Department of Transportation/RITA, or any State or other entity.

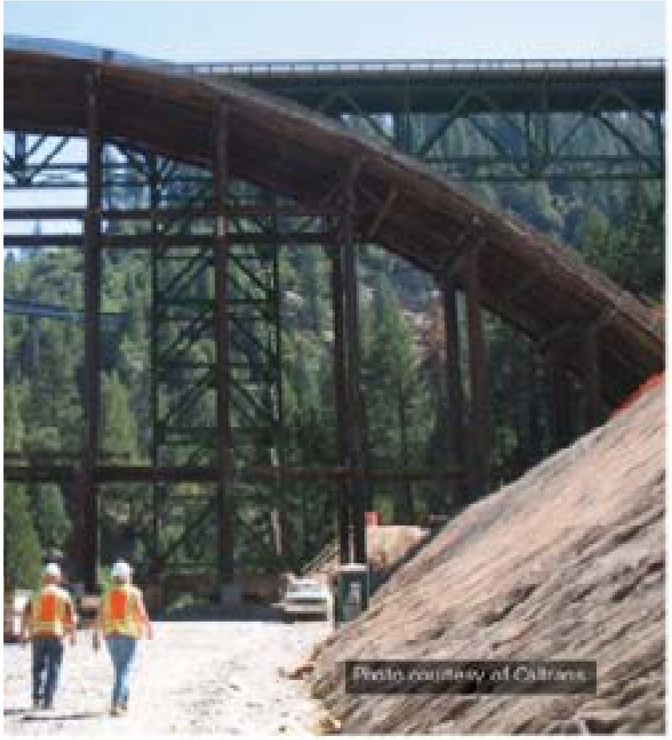

Photo courtesy of Caltrans

Photos courtesy of Michigan Tech Research Institute

Photo courtesy of Metropolitan Transportation Authority.
Photographer: Patrick Cashin.

Over, Under, Around & Through

by J.J. McCoy

While today's sophisticated transportation construction project innovations aren't rolled out from "Sesame Street," an old song from the classic children's TV show ironically sums up some of the latest trends of going "Over, Under, Around and Through."

This article, another in an ongoing "Transportation Builder" series on innovation, spotlights how some recent projects from all across the country addressed such obstacles in the effort to get people and businesses where they need to go. It also highlights how the use of unmanned aerial vehicle technology might have applicability beyond delivering packages for Amazon or over the battlefields of Afghanistan. What they all share in common are knacks for imagination and initiative to keep Americans and commerce rolling safely along their respective paths to prosperity.

Photos courtesy of Karl Nielsen, MTC.

CALDECOTT TUNNEL FOURTH BORE

While a journey of one thousand miles begins with a first step, Bay Area motorists now enjoy a fourth tunnel for the reverse commute.

After three years of construction, the Caldecott Tunnel's fourth bore opened to traffic last fall between Oakland and Contra Costa County, Calif. For nearly 50 years—ever since the California Department of Transportation (Caltrans) opened the third bore in 1964—traffic in the middle tunnel was directed to accommodate the heaviest flow (a practice which could change several times a day), invariably creating a bottleneck as drivers heading the opposite direction funneled from four lanes into two, through a single tunnel. With the fourth bore designed to reduce congestion and travel times for traffic traveling in the off peak direction, motorists in normal conditions are saving 15 to 20 minutes with traffic flowing freely.

The fourth bore is unfamiliar from its elders: the 3,348-foot tunnel is roomier (both wider and taller) and brighter. It features a 10-foot-wide shoulder along with walkways and safety passages, and is outfitted with modern ventilation, traffic lights, air and traffic monitoring systems, and electronic message boards. Nineteen bi-directional jet fans mounted to the ceiling are designed to maintain air quality in the tunnel, and to blow smoke away from motorists in the event of a fire. The emphasis on such state-of-the-art fire and life safety systems stems from an infamous 1982 fire, in which seven were killed through a chain reaction of accidents in the third bore.

The new tunnel's incident-detection and response systems underwent extensive testing before opening, allowing monitors and first responders to prepare for threats including detecting and suppressing fires and other hazards while providing real-time information to help motorists safely exit in an emergency.

It opened ahead of schedule and about $3 million under its $420 million budget, with most of the funding ($180 million) from the 2009 federal stimulus program, Contra Costa taxpayers raising $125 million from transportation sales taxes, and the remainder supplied through bridge tolls and state and regional allocations.

Even so, such efficiencies didn't come easily while tunneling nearly two-thirds of a mile through the hills. "The project was incredibly complex," Caltrans spokeswoman Ivy Morrison said. "The toughest challenges were dealing with the geology... especially given the Bay Area and its tectonic movement. Though we'd done extensive core-sampling, because of the conditions you don't know for certain until you're in, how the ground will behave."

The changing soil conditions forced the excavation crews to use different equipment along the way. Since pockets of methane presented potential for explosion, the excavator itself had to be retrofitted from diesel power to electric in order to minimize sparking. Meanwhile, smoking, open flames, radios, cell phones, cameras and even remote-control keys for cars were prohibited in the tunnels.

Sequential excavation was performed using the "New Austrian Tunneling Method" (NATM), in which the initial support system is pillared to the ground immediately around it—which through the fourth bore might vary between

extremes of sandstone and shale, with various gradations in between.

"We'd learned a lot through the construction of the first three tunnels," Morrison explained. "Another way we addressed the abruptly changing ground conditions was by probing, which is a way to assess the ground conditions ahead to 150 feet. [That] allowed us to know what we'd be getting into before excavating, and also to gradually and safely release the gases."

Deploying a sequential excavation method meant that less structural support was required than in some other types of rock. Concrete was sprayed on as soon as the ground was excavated. "Any engineering project offers new challenges, but Jacobs Associates [a San Francisco-based engineering and construction management firm] has a wealth of experience worldwide, so those conversations [included] a lot of back and forth, which was very important," Morrison said. "Caltrans is not typically in the practice of tunneling projects. We relied on their expertise, which really contributed to the success of the project."

SPANISH CREEK BRIDGE

For about 80 years, locals, truckers and outdoors enthusiasts visiting the Plumas National Forest east of Chico, Calif., relied on a steel deck truss bridge to cross over Spanish Creek bisected by State Route 70. But the 1932 Spanish Creek Bridge has now been replaced by a seven-span, box-girder bridge featuring an open spandrel arch. Though the new, 627-foot bridge is one of the longest conventionally reinforced concrete spans in California, its form is out-shown by its function. It has a bicycle-friendly path with see-through railing, designed both to be aesthetically pleasing while also helpful in the removal of snow amid the northern Sierra Nevada.

Like a Hollywood beauty, though, the site itself was rather high-maintenance, as Caltrans and C.C. Myers, Inc., of Rancho Cordova, Calif., discovered. Located about 10 miles outside of Quincy (pop. 1,728), the bridge stands 160 feet above a rugged creek bed in an earthquake-prone forest. The new crossing had to meet both modern highway design standards and current seismic standards, while also accommodating interregional transportation needs (i.e., the new bridge extends the shoulder width to eight feet, and quadruples the weight-carrying capacity of its predecessor). Even so, it was the oldest element in its construction which proved to be the bridge's most innovative aspect.

"Going in, I could tell that there was a challenge in the transportation of equipment and the supply of required energy involved for the project," said David Clark, Caltrans' resident engineer, in describing the project's rural setting.

But Clark also realized that the runoff from the high Sierra meant the site had a ready, nonstop supply of cold water literally underfoot. Whereas typically Caltrans projects would ship in big chillers requiring lots of energy to cool the concrete pour, they decided instead to pump cold water from the creek through the 364-foot arches' pour—resulting in both a savings of time and an estimated $200,000 compared to other methods.

continued on next page

There were other concerns: the lack of local infrastructure required factoring a five-hour detour into the schedule in order to haul supplies from one side to the other. Then the original concrete supplier proved unequal to the task. The road alignment's design required finessed blasting mere feet from an existing railroad tunnel; one of the abutments from the soil-nail design suffered some listing, and moved before they had to stabilize it with tie-backs before constructing the rest of the wall. Then, one of the mountains next to the existing bridge slipped, forcing an unexpected closure of the bridge while taking out power lines and knocking out electricity to Quincy for a time.

And then, of course, there were the fish.

"The creek is a temperature-sensitive environment," Clark said. "I was able to use a lot of the available data to make sure that the construction wouldn't affect the temperature [beyond 1 degree F]." The problems of maintaining the fishes' pH balance were avoided because the water ran through [PVC] tubes, instead of concrete, which causes the pH in the water to rise becoming harmful to the fish when the cooling water returns to the stream.

"The way we went about it was unusual," Clark noted. "I'm not aware of anyone having done it this way before. We had to do some preliminary research about any potential negative impacts, but it worked out. Despite the complications and in the push to get everything up, construction of the bridge itself didn't skip a beat" from groundbreaking in June 2010 until opening the new bridge to traffic in July 2012.

"Contributing to the success of the project was the partnering relationship created with the project team," said Bob Coupe, senior project manager with C.C. Myers. "The owner, contractor and subcontractors worked together as one toward a common goal. This facilitated the project's early completion, in excess of 100 working days, and helped to achieve the zero injury record that the project enjoyed."

Photos courtesy of Michigan Tech Research Institute.

DRONE: UNSURFACED ROAD CONDITIONS ASSESSMENT SYSTEM

Drones, or more precisely unmanned aerial vehicles (UAVs) have made recent headlines for everything from Afghanistan to border patrol to deliveries from Amazon.com. But in a first-of-its-kind application, the Michigan Tech Research Institute (MTRI) has developed a UAV system using high-resolution photography and 3D modeling to perform assessment of unpaved roads, which according to the Federal Highway Administration (FHWA) account for nearly a third of the more than four million miles of road in our national transportation infrastructure.

Many of those 1.3 million miles of unpaved stretches—relied upon by rural residents to reach their homes, jobs and mail, farmers going to commodity markets, and kids to schools—fall to the responsibility of local governments and transportation agencies.

The cutting-edge technology of the Unsurfaced Road Conditions Assessment System (URCAS) provides local road managers with information needed for decision-making about maintenance and repairs. Using the URCAS portfolio of detailed information and imagery lets them analyze damage including potholes, washboarding (corrugation), crown damage and rut detection—and for a pittance of the cost otherwise. The technology translates to cost of analysis about $1 per mile, or a fraction of the rate even for the least expensive Pavement Surface Evaluation and Rating (PASER) method at approximately $8 per mile.

The ultimate goals of the research-and-development program, funded by the U.S. Department of Transportation's Commercial Remote Sensing and Spatial Information Program, were to design, build, and test a prototype remote sensing-based unpaved road condition assessment system that can compete with manual methods, and to incorporate such measurements into a decision support system (DSS) to aid in managing an unpaved road network.

"We looked at a few different ways to do it, and a UAV system gives us the ability to rapidly gather the imagery needed to understand the road conditions and distresses. Managers were looking for a way to accurately assess the severity and amount of problems," explained Program Director Colin Brooks of MTRI. "Most often we're talking about gravel roads, so to be able to see those kinds of distresses, we're looking at checking changes in the crown of the road. You need pretty high resolution data to do that. We fly a hexacopter at 80 to 100 feet high, so at a low altitude with a very high-resolution camera to make a 3D image of the road surface."

All told, the system requires the UAV platform to collect the data—a hexacopter is both easy to operate and very stable in flight—using an off-the-shelf digital camera as its sensor for the two pieces of software that form the remote sensor processing system—one to collect that data, while the other detects the location and severity of the distresses.

Meeting the parameters of the industry-standard "Unpaved Road Condition Index" requires only about five minutes of flight time for gathering the sample segments. The Federal Aviation Administration (FAA) is expected to finalize federal regulations in the next 18 months making it commercially practical throughout the country.

"Where we found the most interest is from administrators responsible for large amounts of unpaved roads, easy to see from the air and vital to the local infrastructure," Brooks explained. "South Dakota has counties where nearly the entire road network is unpaved. This offers a more rapid and affordable way to be proactive rather than reactive. They can make this part of [their] standard assessment basis, either by acquiring the equipment to gather the data themselves, or by having it provided as a service. We plan to be flexible and provide either means."

The remote-sensing platform has been verified in seven sites and counting in Michigan, Iowa and Nebraska, with testing this spring in South Dakota, giving a whole new meaning to being a flyover state.

"We are interested in this kind of opportunity to reach our work out to a larger audience," said Brooks. "We are very excited in its capabilities and think that rapid UAV-based mapping of unpaved roads is a good place for this new technology to be applied in the nearer term. We also think that these methods could be applied to paved roads and bridges, especially as technology develops, prices drop, and people feel more comfortable with UAV-type infrastructure assessment tools."

Photo courtesy of Metropolitan Transportation Authority.
Photographer: Patrick Cashin.

SECOND AVENUE SUBWAY

Celebrating the 110th anniversary of its first underground service, the New York City Subway is the busiest rapid transit rail system in the United States, and the daily, 24-hour lifeblood of the Big Apple. Yet it's been more than 50 years since the subway system has seen an expansion as large as the current Second Avenue Subway project to extend the East Side's Q Line along Second Avenue while adding new stations to the city's more than 420 already online.

When completed in December 2016, the $4.45 billion Phase I will open two miles (3.2 km) of tunnel served by three new stations. Controlled blasting operations began in November 2009 at 96th Street, with a final blast completing excavation in November 2013.

The goal of the project is to relieve overcrowding by as much as 13 percent (or 23,500 fewer weekday riders) along the Lexington Avenue line, improving travel for approximately 200,000 daily commuters by reducing delays and providing broader access to mass transit for travelers in Manhattan's far East Side.

Overall, the expansion project will cost more than $17 billion and run 8.5 miles (13.7 km), from 125th Street to Hanover Square. All told, 16 new stations will be built to serve communities in Harlem, the Upper East Side, East Midtown, Gramercy Park, East Village, the Lower East Side, Chinatown and Lower Manhattan.

Sometimes referred to as "The Line That Time Forgot," the Second Avenue Subway has been on the books since 1929, with occasional construction taking place despite interruptions in funding and emphasis throughout the city's and nation's history.

This most recent financially secure construction plan took hold with a 2007 tunneling contract awarded by the Metropolitan Transportation Authority (MTA) to the Schiavone/Shea/Skanska (S3) consortium, with Parsons Brinckerhoff serving as construction manager.

Phase I's heavy civil/structural work included building demolitions, underpinning, station excavation, slurry wall construction, and concrete placement of the station invert slab of the main station, entrances, and ancillary facilities. Relocating utilities alone involved approximately 82,000 linear feet of Con Edison primary and secondary electric cables, some 4,500 linear feet of Verizon fiber optic cables, extensive relocation of low and high pressure Con Ed gas mains, and relocation or protection of existing water and sewer mains.

Geological and geographical realities in Manhattan led to the choice of cut and cover excavation, which entailed the transport and disposal of approximately 400,000 tons of soil and 40,000 tons of rock and concrete debris translating to about 22,000 truckload runs to various disposal facilities throughout New York, New Jersey and Pennsylvania.

Given the totality of such massively orchestrated efforts, it's no spin for the MTA's Michael Horodniceanu, president of its capital construction projects, to describe it as a monumental accomplishment. "It could not have been done without the hard work and dedication of a very motivated team," Horodniceanu said.

Photo courtesy of Stantec.

GRASSY CREEK BRIDGE

When completed in June 2015, the Grassy Creek Bridge will be Virginia's tallest, with a vertical clearance of 250 feet above the creek in a rural project area with more than 400 feet of vertical elevation differential overall.

Begun in August 2009, the Virginia Department of Transportation (VDOT)'s Route 460 Connector Phase I design-build project brought together the talents of Stantec (as prime designer), Jansen Spaans Engineering (for bridge design) and Bizzack Construction (as prime contractor) with CJ Mahan Construction Co. and RS&H CS. Their Grassy Creek Bridge features twin 1,700-foot-long, cast-in-place segmental bridges, each with a deck width of 43-feet, carrying two lanes of traffic in both directions. Ultimately, it will link federally designated corridors of Virginia and Kentucky in the Appalachian Development Highway System.

The locale presented all kinds of challenges, be it the geography and geology, electrical power or manpower all factoring into the overall $105 million budget. The roadway and bridge approaches needed plenty of both conventional and shape-charge blasting due to the site's soil and rock conditions.

Bridge foundations also had to compensate for the complicated and unstable terrain, which influenced much of the bridge's design and construction. Limited housing options meant that most of the highly-specialized management and labor talent had to commute from neighboring West Virginia, Kentucky, Tennessee and Ohio.

Not only was specialized equipment needed for the cast-in-place segmental construction process, blasting for site preparation, post-tensioning and grouting of steel tendons, but the required power demanded an adept solution too. The team devised and deployed a novel combination of tower cranes to string the power over the top of what otherwise would have required preliminary clearing and construction.

Thus, work proceeded from both of the 250-foot pier columns in a cantilevered construction operation with four spots working simultaneously and sufficiently to have all phases of construction going, be it advancing traveler forms, tying reinforcing bars, casting concrete and then curing it—"the full life cycle of concrete construction happening concurrently," as Tony Hunley of Stantec's lead design team described it. All of it is captured in what's another unusual feature for the region—an onsite, time-lapse camera recording images every 10 minutes to track the progress of the project from start to finish via VDOT's website, at www.VirginiaDOT.org/460connector.

Sounding the Refrain

As described, these projects proceed in each of their manners and in all of their methods to solve vitally pressing and respectively challenging transportation problems. Their accomplishments have been realized in new ways once unimaginable. Whether in terms of engineering, economics or politics, they've prevailed through time-proven principles of ideas, designs, dedication and drive. And as anyone from Sesame Street or Main Street might tell them on Wall Street, those are the principles to carry you over, under, around and through.

J.J. McCoy, a former staff writer for the "Washington Post," is a Washington based freelance journalist who often covers transportation and technology: [illegible]@hotmail.com.

Editor's Note: Future innovation stories will focus on airport and port construction projects.

THE URBAN TRANSPORTATION MONITOR

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Environmental Reviews Streamlined for Some Transportation Projects

New Federal Rule Took Effect February 12

A new rule is in effect that's designed to help streamline environmental reviews for transit and highway projects.

As published in the Federal Register, the final rule "amends the Federal Highway Administration (FHWA) and Federal Transit Administration (FTA) joint procedures that implement the National Environmental Policy Act (NEPA)." It amends the procedures "by adding new categorical exclusions (CE) for projects within an existing operational right-of-way and projects receiving limited Federal funding."

The changes are required by the 2012 transportation authorization bill, known as the Moving Ahead for Progress in the 21st Century Act (MAP-21). Both the FTA and FHWA anticipate the new rule will speed delivery of transit and highway projects that fall into two categories: those to be built within an existing right-of-way where transportation already exists and those that receive less than $5 million in federal funding or with a total estimated cost of not more than $30 million and Federal funds comprising less than 15 percent of the total estimated project cost, respectively.

In announcing the rule, the U.S. Department of Transportation said it will encourage "project sponsors and state and regional transportation authorities to build highway and transit projects with fewer impacts to reap the benefits of the quicker, simpler process, which requires less documentation for qualified projects." FTA Administrator Peter Rogoff says "these common sense changes" may shave more than a year off the environmental review process while helping to "balance responsible environmental stewardship with delivering transportation solutions to communities more quickly."

FHWA Deputy Administrator Greg Nadeau adds that the change in Environmental Impact and Related Procedures

Please turn to Page 5

Inside

Researchers Studying Ways to use Drones for Transportation Operations and Planning

Unmanned Aerial Vehicles Show Potential for Improving Safety and Saving Money

Researchers in Michigan are hoping to help transportation agencies "hit the ground running" when the commercial market for unmanned aerial vehicles (UAVs) opens next year. The Michigan Tech Research Institute (MTRI) is looking into ways these UAVs, more commonly known as drones, can be used for transportation planning and operations.

For now, UAV use is limited to government agencies, including public universities, but that will likely be changing next September when the Federal Aviation Administration (FAA) is expected to issue new regulations allowing commercial use of UAVs. They hold potential for use in a wide range of ways for transportation, from assessing the condition of roads and infrastructure to providing aerial traffic information during major sporting events.

MTRI Senior Research Scientist Colin Brooks says researchers are currently working on a $2.4 million project for the

Please turn to Page 6

A Bergen hexacopter drone used by the Michigan Tech Research Institute (MTRI). (Photo: Courtesy of MTRI)

Appendix E. XML Field Descriptions in the DSS from RSPS

Field	Type	Size	Description	Comments
InspectionDate	D	8	Inspection Date	Date the inspection was conducted
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Length Units	N		Sample Length	The length of the sample unit
Area Units	N		Area of Sample	The area of the sample unit
GPSLatitudeBegin	F		Latitude of Beginning Point	Coordinate value for latitude of Beginning
GPSLongitudeBegin	F		Longitude of Beginning Point	Coordinate value for longitude of Beginning
GPSLatitudeEnd	F		Latitude of the Ending Point	Coordinate value for latitude of Ending
GPSLongitudeEnd	F		Longitude of the Ending Point	Coordinate value for longitude of Ending
Type Distress	I	2	Indicates the type of distress present: 81 - Improper cross section 82 - Inadequate roadside drainage 83 - Corrugations 84 - Dust 85 - Potholes 86 - Ruts 87 - Loose aggregate	The distress types define the types of distresses observed on the sample unit. Type is used in conjunction with Severity and Quantity to enumerate the types of distresses present on the sample
Severity	C	1	Indicates the severity of the distress: L - Low M - Medium H – High N – No damage	Severity is used in conjunction with Type and Quantity to enumerate the types of distresses present on the sample unit
Quantity	I	5	Indicates the amount of distress present	Quantity is used in conjunction with Type and Severity to enumerate the types of distresses present on the sample unit
Units	C	4	Indicates the measuring unit for the quantity of a distress	

Type:	I – Integer	D – Date (YYYYMMDD)
	C – Character	B – Binary
	N – Numeric	F – Floating

Appendix F. Sample Road Data Imported into the DSS from the RSPS (Lenawee and Livingston Counties)

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