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

Michigan Technological University

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

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Section I: Introduction

This project's requirements report was published in October of 2011 (Deliverable 1-A), assessment methods were described in November of 2011 (Deliverable 2-A), the sensor selection report was published in May of 2012 (Deliverable 4-A), and the candidate and recommended remote sensing platforms report was published in June of 2012 (Deliverable 5-A). With technology advancing rapidly, it is important to review whether the recommendations and selections of these reports are still valid. For that purpose, PI Colin Brooks recommended writing a new deliverable that would review and update on requirements, sensors, and platforms for unpaved road assessment, based on the UAV-focused recommendation that came out of the first phase of the project. Updated information would help ensure a system more likely to be implemented by agencies and commercial firms.

This report meets this recommendation for an update by reviewing the original requirements and related information, describing an updated inventory-focused rating system, detailing some new cameras, describing platforms, and reviewing recent related research. The recommended platform components reviewed in the performance evaluation report of November 2013 (Deliverable 7-B) and the phase I final report of December 2014 (Deliverable 8-B) are still satisfactory. Some lighter and higher-resolution cameras are available, but the 36-mp Nikon D800 used in the Unsurfaced Road Condition Assessment System (URCAS) is still an excellent choice. The selected Bergen hexacopter still meets project needs, but a heavier-lift octocopter-version provides longer flight time, more redundant flight capabilities, and is still a reasonable cost.

Dr. Tim Colling's new inventory-based assessment system (IBAS) for unpaved roads being tested in Michigan is designed to be used by road asset management agencies when a less data-intensive assessment methodology is needed for network-level assessment. This paper reviews this assessment system and discusses its potential to have its data collected via the existing system. While URCAS would be capable of providing most of the data needed (such as surface width and the presence of potholes), the IBAS is not intended for rapid condition assessment to recommend specific treatments during a road management season, which has been the focus of this project. We recommend continuing to focus on the URCAS capability to provide detailed road condition data usable in management of rapidly changing, dynamic unpaved road environments, rather than switching our focus to network-level assessment at this time. However, understanding that future needs may be focused on less-detailed, larger areas is a potential requirement to note and revisit as technologies develop.

Section II: Review of Deliverable 1A Requirements

This section serves as a review of the project's phase I report that described the requirements for assessing unpaved road distress types and severity. These requirements drove the evaluation and selection of available rating systems, potential sensors, and best platforms. It is included here to provide a single location to document and review the requirements that resulted in a practical prototype that was field tested in 2012 and 2013 and successfully demonstrated to local and state stakeholders in a technical outreach session in South Dakota in 2014.

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

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.). It is available at for download at: http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del1-A_RequirementsDocument_MichiganTechUnpavedRoadsr1.pdf/. 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, after weather events). 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 generally 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 deteriorate 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 2-1). 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 2-2). 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 2-1: Potholes on an unpaved road.

Figure 2-2: 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 typical cameras providing at least 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 2-1). 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 2-1: 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

Section III: Review of Deliverables 2-A, 4-A, and 5-A

This section serves as a review of the phase I reports that described the available and recommended rating systems, sensors, and platforms. Including them here provides a single location to document them as the project moves forward with potentially updated components towards day-to-day implementation. There were also reviewed in the phase I Final Report (see Brooks et al. 2014 at http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del8B_UnpavedRdsAssessment_FinalReport_CaesarCommentsAddressed_Final_v12-05-14.pdf) and in the original deliverable reports.

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

The full report is 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 then-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 only 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. However, it does not provide quantitative measurements of road distress type, severity, density, or location.

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 wider 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 3-1) 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 3-1: 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 can make for a longer collection time period. A longer review of the URCI is included below as the first part of Section IV. It was selected as the project's rating system because it could provide objective, repeatable measurement requirements that meet assessment needs of unpaved road asset managers, with the approval of the project's Technical Advisory Committee.

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 lower.

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 3-2).

Table 3-2: 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 initially tested by a research team from 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. It showed sufficient promise to serve as a technical inspiration for this project.

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, but does require an ultralight to fly the roads in need of surveying.

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

This deliverable is 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 (MP) camera, which is widely available since most commercial sensors contain resolutions of 16 megapixels or more (note: 24 MP or more are common now in 2015). 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 2.25 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 3-3 is contains a subset of sensors that were considered appropriate in May of 2012. 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 3-3: 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 3-4 is a list of lenses that would fit the necessary requirements as defined for phase I of the project.

Table 3-4: 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.

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

This report is available for download at:
http://geodjango.mtri.org/unpaved/media/doc/deliverable_Del5A_PlatformSelectionReport_UnpavedRoads.pdf

The selected platform(s) that would 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 were be considered. As for manned platforms, any ultra-light to single-engine aircraft would likely work. The only limiting factor is cost.

For the UAV platform, the project team determined potential candidates, which are located within Table 3-5. 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. After this report, the Bergen hexacopter was also tested and eventually used for second year data collections as it was more stable, easier to fly, less expensive ($5k vs. $17k), had the same flight time, and could lift the sensor package.

Table 3-5: 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 at the time. Typical data collections are estimated to last between 1 – 2 hours.

Section IV: Review URCI and Inventory Based Assessment System

URCI – the selected rating system

The Unsurfaced Road Condition Index (URCI) was developed by the Department of the Army and was designed to help in decision making to prioritize maintenance activities on roads that are located on military facilities. Since its development, the URCI has been adapted for wide use in local and state government agencies for asphalt and concrete pavement assessments. During an assessment, a road is divided into segments, which are the basis for assigning an overall road condition rating. Ratings are assigned based on visual and physical measurements of seven specific characteristics (Table 3-6) and distress features, which are classified into severity bins (low, medium, and high). Visual inspections should take place approximately four times per year and can occur while driving at slow speeds (25 mph). Physical measurements should include handheld equipment and straight edges to measure depths of distress features. The URCI was selected for this analysis due to its advantages over other road condition assessment methods including an objective and repeatable distress identification system that quantifies extents and severities of distress features. For example, it contains a clear set of measurement criteria of each of the distress features described in Table 3-6, and is relevant to a wide variety of unpaved roads in the United States.

Table 3-6: 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.

Introduction to the Inventory Based Assessment System for Unpaved Roads

Pavement condition assessment systems can serve two general purposes, providing project level and network level guidance. Condition ratings can be used at a project level to determine when specific maintenance activity on a specific section of road should be conducted. The U.S. Army Corps of Engineers Unsurfaced Road Condition Index (URCI) system, for example, was developed so that road owners could infer specific classes of treatments that would be appropriate based on a road's current rating (Eaton, 1987; Eaton 1987a; Department of the Army, 1995). For example, a gravel road that has moderate severity potholes under the URCI rating system would be a candidate for surface grading and the addition of crushed gravel (Department of the Army, 1995).

Pavement condition assessment systems can also be used as a network-level measure that provides a method to assess the overall health of the road network from year to year. Network-level measures are important for efficient road management because they provide an easy method for determining the correct level of investment to maintain a road network's condition. A simple network-level metric that is commonly used is the percentage of road miles that are rated above a specific threshold rating. For example, this could be the percentage of roads rated with a URCI index rating of 55 or more.

Many condition assessment systems exist for unpaved roads, with measurement methods ranging from basic to complicated (see Deliverable 2-A, the state-of-the-practice report. However there is a lack of low cost, stable, assessment systems for network level measurement of unpaved roads. This need prompted the Michigan Transportation Asset Management Council (TAMC) to engage researchers at Michigan Technological University to develop an unpaved road assessment system to meet their needs. In 2014 Colling and Watkins proposed the background work which developed the Inventory Based Assessment System. In 2015, the Inventory Based Assessment System (IBAS) will be piloted and refined for state wide adoption in Michigan. Interested has been expressed in considering this system for collection by remote sensing as part of the project's outreach and implementation phase (Phase II).

The Shortcomings of Existing Unpaved Road Assessment Systems

Many project level condition assessment systems exist for unpaved roads, with measurement methods ranging from basic to complicated (Brooks et al. 2011). These existing systems are primarily targeted at providing project level guidance, and do not provide a reliable, stable, network-level assessment for the scale necessary for agency wide, regional, or state wide management purposes. The shortcomings of the existing unpaved road condition assessment systems primarily stems from their almost singular focus on surface distresses to drive the rating system. This focus results in the following issues:

1) Surface distresses are rapidly transient in unpaved roads, and as such:
    (a) Require frequent collection to remain current.
    (b) Are unstable as a long term network-level measure.
2) Do not consider features beyond the pavement which have a major impact on road users.
3) The rating is not directly related to the loss or gain in value of the asset.

Most of the unpaved road assessment systems that are widely used were developed as modifications of paved road assessment systems. These systems focus on measuring the extent and severity of surface distresses. These systems work sufficiently well for paved roads because surface distresses change slowly and require a significant effort to repair, making the distresses relatively static over the course of a year. This slow rate of change on paved roads allows a single rating event every one to two years to provide a sufficient level of data for management purposes.

Unpaved roads can have significant changes in surface condition over a matter of days or weeks (Skorseth and Selim, 2000), thus limiting the effectiveness of surface distress driven condition assessment systems both at a network and project level. Rapid changes in the surface condition of unpaved roads cause condition data to quickly become outdated. Similarly, rating systems based on surface conditions are difficult to apply as a network-level measure since the condition of any road in the system may be highly variable during the year as distresses appear and short term maintenance activity, such as grading, are completed. This results in a network-level metric that can vary greatly from week to week depending on when ratings are collected.

A focus almost exclusively on surface distress is valid for paved roads since surface condition is a primary factor that impacts both use of a paved road by motorists and is directly related to the life of the most expensive layer of the pavement (surfacing) that typically drives major improvement work in a paved road network. Unpaved roads, however, can have many other factors that impact their use that are not related to surface condition. Unpaved roads are highly variable in their design, construction, use and upkeep when compared with paved roads. Many unpaved roads do not contain basic inventory elements common to most paved roads, which further can make the exclusive focus on surface condition problematic. These inventory items include sufficient ditches and culverts, minimum lane widths, shoulders, sufficient structural gravel to support loads, etc. Differences in inventory elements can adversely impact the condition of the road and may have more impact on users than poor surface conditions. For example, road users may consider potholes or ruts on an unpaved road a secondary inconvenience if the unpaved road is only nine feet wide, because the limited surface width will not allow the operation of two way vehicle traffic at any significant speed. In this case surface condition may be irrelevant to users. Similarly an unpaved road without proper drainage is likely to perform poorly for any traffic volume regardless of the current surface condition (Skorseth and Selim, 2000).

Poor unpaved road surface condition does not always relate to the life of the surfacing layer, and more typically may be rectified by low-cost grading, and as such is not automatically indicative of a loss in value of the road as is the case with paved roads.

Premise of Inventory-Based Assessment

The Michigan Inventory-based condition assessment system for unpaved roads compares existing roads to a baseline road state, and assesses "points" based on how closely the road in question compares with the base line state. This baseline condition for inventory features is set using characteristics that are considered acceptable for the majority of road users. The baseline condition is in effect a “zero point” in the system. Roads are assessed based on how they compare to the baseline condition in three inventory feature categories (width, drainage and structure). Deficiencies in any of the inventory features will result in a road being rated lower than those that meet all baseline conditions. The level of effort to bring the unpaved road up to the baseline state as measured by construction dollars forms the basis of the point system. This rating system is different than surface distress based systems because it is driven by characteristics which do not change quickly; as a result it will produce a stable network-level metric for measuring investment in the road network that can be collected cost effectively. It is not the intent of this assessment system to collect or provide project-level guidance for unpaved roads, but rather to provide guidance at the network level.

Inventory features proposed in this system do not change rapidly, require a significant construction or maintenance effort to improve, and are apparent enough to be evaluated from a moving vehicle without the need for fine measurement. Once initial ratings are established this system only requires updates when a construction or rehabilitation activity occurs or when a lack of maintenance causes loss or degradation of a road feature. Monitoring inventory features over time at a network level provides a measure that can track the impact of investments on the unpaved road network. This system is intended to be a coarse measure of road utility that can be collected quickly and that is inexpensive to maintain.

Detailed information relating to the development of the Michigan Inventory Based Rating System is outlined in the report (Colling and Watkins, 2014), available from Dr. Colling via email at tkcollin@mtu.edu,

Assessment Criteria for the Baseline Standard

Surface width, drainage adequacy, and structural sufficiency are the three baseline inventory features measured for the Michigan Inventory Based Rating System. Each criterion is assessed independently and categorized into one of three levels for each feature. Each of the three inventory features are assessed continuously during inspection for the entire road system. The three inventory feature ranges are:

- *Good* – meets the baseline standard for this item
- *Fair* – minor maintenance or rehabilitation work needed to meet the baseline standard for this item
- *Poor* – major rehabilitation or construction work needed to meet the baseline standard for this item

Good – Fair – Poor ratings for inventory features are used to assign a point value that is added for each of the three features. Point values are based on average costs to bring a road up to baseline standards. The combined point totals for each of the three inventory features are rounded to the nearest whole number to form a 1 to 9 scale, with nine being the best condition and one being the worst. This point scale also includes a rating of 10 which is reserved for newly constructed roads during their first year of operation, however this rating is not assessed by condition, but rather construction history.

Table 5-1: Point Values for Inventory-Based Rating System

Inventory Rating Feature	Point Value
Surface Width - Good	4.66
Surface Width – Fair	3.41
Surface Width - Poor	0.52
Drainage Adequacy - Good	1.86
Drainage Adequacy - Fair	1.46
Drainage Adequacy - Poor	0.21
Structural Adequacy - Good	2.48
Structural Adequacy - Fair	1.46
Structural Adequacy - Poor	0.27

Surface Width

The surface width is assessed by estimating the approximate width of the traveled portion of the road down to the nearest foot which includes travel lanes and any shoulder that is suitable for travel. The criteria for assigning levels for this feature are:

- *Good* – Surface width of 22 feet or greater.
- *Fair* – Surface width between 16 to 21 feet.
- *Poor* – Surface width of 15 feet or less.

Collection of this feature via remote sensing would require the system to measure surface width to the unpaved road to the nearest foot, which is well within the sub-inch capabilities demonstrated in Phase I of the project.

Drainage Adequacy

Drainage adequacy is assessed by determining the presence or absence of a secondary ditch (high shoulder) that has the capacity to retain surface water, and by estimating the difference in elevation between the ditch flow line or level of standing water in the ditch and the top of the edge of the shoulder. For roads that are constructed in a fill section where water is free to drain away from the roadway to the native soil, but there is no ditch as such, the ditch measurement will be estimated to the elevation where the native soil meets the toe of the fill section.

- *Good* – Two feet vertical or more between the ditch flow line or any standing water (whichever is less) and the top edge of the shoulder, and no secondary ditches are present.
- *Fair* – between two and 0.5 feet of difference in elevation between the ditch flow line or any standing water (whichever is less) and the edge of the shoulder, with or without the presence of secondary ditches; or two feet or more vertical between the ditch flow line or any standing water (whichever is less) and the top edge of the shoulder where secondary ditches are present.
- *Poor* – less than 0.5 feet of difference in elevation between the ditch flow line or any standing water (whichever is less) and the edge of the shoulder. Secondary ditches may or may not be present.

Collection of this feature via remote sensing would require the system to measure drainage using the same methods used for the collection of the “Drainage” criteria for the URCI system as well as checking for the presence of “Loose Aggregate” berms greater than one inch (2.5 cm) in height according to the URCI system.

Structural Adequacy

Structural adequacy is assessed by the presence or of lack of structural distresses (rutting or large potholes) during the previous year that required emergency maintenance to maintain serviceability. If this data are unknown the assessment can be conducted using an estimate of gravel thickness if known. It is not the intent of this inventory feature to require involved testing or exploration of existing conditions. Ratings are to be made on this feature based on local institutional knowledge.

- *Good* – Structural rutting or major (three-feet or larger) potholes did not develop throughout the year and emergency maintenance was not required leaving the road is serviceable throughout the year (when plowed). Alternately the road can be assessed by estimating the thickness of good quality gravel (crushed and dense graded). An estimate thickness of eight inches or more of good gravel would qualify a road for this level.
- *Fair* –Limited rutting and/or some major (three-feet or larger) potholes during the spring or very wet periods. The road is passable throughout the year but emergency maintenance grading was necessary to maintain it during the wet periods. Placement of four inches of good quality gravel would be recommended as a fix. Alternately the road can be assessed by determining the gravel thickness is four to seven inches, thus some additional gravel base material could be added.
- *Poor* – Structural rutting and/or major (three-feet or larger) potholes are apparent during much of the year. The road is passable throughout the year but frequent emergency maintenance is required. Placement of five to eight inches of good quality gravel would be recommended as a fix. Alternately the road can be assessed by determining the gravel thickness is less than four inches, thus significant additional gravel base material should be added.

The existing URCAS can already detect and measure rutting and the presence of three-foot or larger potholes. Measuring gravel thickness is not an existing feature of URCAS or one that is likely to be accomplished with optical remote sensing, except for providing a geo-located digital photo inventory that can be used to visually assess likely gravel thickness and how it may have changed over time.

Example Applications of the Inventory-Based Assessment System

Example 1 is a one-mile road segment that is has significant deficiencies when compared to the base line condition (Figure 1).

Figure 4-1: Unpaved rural road with narrow lane width, no ditches and little or no gravel.

The road description and corresponding assessment conditions for Example 1 are as follows:

- Surface Width: less than 15 feet. Assessment condition: *Poor*.
- Drainage Adequacy: no ditches. Assessment condition: *Poor*.
- Structural Adequacy: little or no gravel, frequently requires emergency maintenance to maintain serviceability during the wet season. Assessment condition: *Poor*.

  Point Scale Rating: 0.52+0.21+0.27 = 1 (*Poor*)

Summary of Applicability of the Inventory Based Assessment System for Unpaved Roads.

The new IBAS for Unpaved Roads being developed by Dr. Colling under Michigan TAMC funding has three main attributes that need to be recorded to develop the overall rating. These include quantitative estimates of surface width, drainage adequacy, and structural adequacy. The existing URCAS system can clearly measure surface width well within the 1-foot (30 cm) accuracy needed. It can measure the distance between the flow line or level of standing water and the top edge of the road shoulder within the nearest inch (+/- 2.5cm), assuming that vegetation is not obscuring the drainage ditch areas. For structural adequacy assessment, it cannot objectively measure gravel thickness, but it can provide density and severity of rutting and potholes. However, the IBAS for Unpaved Roads is not intended to require or provide information on rapidly-changing, section-specific distresses like the Unsurfaced Road Condition Index (URCI) is designed to do. As noted, it is a network-level assessment tool, not one for recommending specific maintenance activities on individual road sections.

While it would be possible to use URCAS to meet most of the data needs of IBAS, the strength of existing system is in providing the detailed data needed to recommend specific treatments for road managers. For these reasons, we are recommending to continue using the URCI to provide detailed road management data able to reflect rapidly changing conditions. In the future, especially as UAVs improve their capability to fly longer, pre-programmed distances, and that it is possible to obtain permission to do so, it would be worth revisitng the usefulness of URCAS to collect IBAS-type network-level data.

Section V: Summary of Updated Requirements

The requirements were defined at the beginning of the project with Deliverable 1-A. These requirements establish the minimum size of distress that needs to be detected as well as requirements of the system for collecting the data. As the project has progressed over the first three years, the basic requirements have not changed. However, when deployed, cameras with at least 24 MP are readily accessible, relatively inexpensive (less than $3,000) and provide high-resolution data beyond the minimum requirements. The Deliverable 1-A requirements are listed below.

Number	Name	Type	Definition
1	Data Collection Rate	Sensor	The systems must collect data at a rate that is competitive with current practice (to be determined, TBD)
2	Data Output Rate	System	Processed outputs from the system will be available no later than 5 days after collection
3	Sensor Operation	Sensor	“easy”, little training required
4	Platform Operation	Platform	Training needed TBD, based on platform choice
5	Reporting Segment	System	<100ft x 70ft, with location precision of 10ft. Map position accuracy +/- 40ft
6	Sample locations	System	Specified by the user a map waypoints
7	Inventory	System	A classified inventory of road types is required prior to system operation. This will consist of 3 classes: Paved, Gravel, Unimproved Earth
8	Surface Width	System	This is part of the inventory, and may also be estimated by the system measured every 10ft, precision of +/- 4”
9	Cross Section	Distress	Estimate every 10ft, able to detect 1” elevation change in 9’, from center to edge.
10	Potholes	Distress	Detect hole width >6”, precision +/-4”, hole depth >4”, precision +/-2”. Report in 4 classes: <1’, 1’-2’, 2’-3’, >3’
11	Ruts	Distress	Detect >5” wide x 10’ long, precision +/-2”
12	Corrugations	Distress	Detect spacing perpendicular to direction of travel >8” - <40”, amplitude >1”. Report 3 classes: <1”, 1”-3”, >3”. Report total surface area of the reporting segment exhibiting these features
13	Roadside Drainage	Distress	Detect depth >6” from pavement bottom, precision +/-2”, every 10ft. Sense presence of standing water, elevation precision +/-2”, width precision +/-4”
14	Loose Aggregate	Distress	Detect berms in less-traveled part of lane, elevation precision +/-2”, width +/-4”
15	Dust	Distress	Optional – measure opacity and settling time of plume generated by pilot vehicle
16	Flight Altitude	Platform	~400’ (max)
17	Field-of- View	Sensor	11 degrees
18	Resolution	Sensor	0.5”, (4 MP pixels for this geometry)
19	Image Capture Speed	Sensor	2.25 frames per second

As noted in Deliverable 7-B (pg. 43 of the Performance Evaluation Report, Brooks et al. 2013) and reviewed in the Phase I Final Report, practical operational data collection parameters were established through the project’s field testing. These were described as follows.

The following data collection parameters would meet all system performance requirements for a deployable system ready for implementation and outreach:

- 24 MP to 36 MP 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
- 2 m/s (maximum) forward speed (4.5 mph)
- 2 fps (minimum) image capture rate (obtained with a simple intervalometer)
- 64GB high-speed storage medium

Note that except for the sensor requirement (met with a 36 MP Nikon D800 in Phase I), these are not different from the original requirements established in 2011. The objective measurement requirements of the Inventory Based Assessment System do not exceed these parameters. Therefore, we are not recommending any changes to requirements, except using a camera with at least 24 MP resolution.

Section VI: Review of Existing and Potential New Optical Sensors

During the first phase of the unpaved roads project, requirements were defined for the required sensor. It was determined that while a 4 MP camera could meet needs, a higher-resolution camera (at least 24 MP) would be used as part of data collection parameters to exceed minimal system performance requirements. Since the initial sensor selection, the underlying requirements have remained the same. As stated in Deliverable 4-A (Sensor Selection report), a camera with the largest possible sensor array at a reasonable weight would enable for the collection of high resolution imagery while maintaining a shorter focal length lens. This shorter lens requirement keeps the total sensor weight down for longer flight times for the UAV platform.

Nikon D800/D810

The Nikon D800 is the camera that was chosen as the sensor to be used during the first phase of this project. This was done because it has a full frame ("FX") sensor with the highest digital single lens reflex (DSLR) camera resolution (36.3MP) at that time. It is capable of being remotely triggered as well as having an internal interval timer to continuously capture imagery at user defined rate. Through testing of the camera it was determined that the interval timer on the camera allowed for a maximum frame rate of 1 fps while an external controller enabled up to 2 fps. While the camera is rated from up to 4 fps continuous shooting, the camera ran into buffer issues when collecting unpaved road data at 3 to 4 fps.

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

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

Nikon D900 and Canon 5Ds

The Nikon D900 is the likely next generation of Nikon DSLRs with a resolution of at least 40MP. It is expected to be similar to the D800s that have been used on this project but with more pixels on the same size sensor allowing for a higher resolution. Currently, Nikon has not made a formal announcement on this camera.

Canon has recently announced the EOS 5Ds which will be a DSLR with a 50.6MP sensor (http://www.dpreview.com/previews/canon-eos-5ds-sr). This camera will be capable of continuous frame rates of up to 5 fps and will be 55g lighter than the Nikon D800. The increased resolution of the sensor would also allow for a shorter focal length prime lens which would lead to further weight reductions. B and H Photo and Video, a well-known national-level camera store, has an initial price of $3,899 with a release date of June 2015.

Sony α7R

The Sony α7R is a full frame mirrorless camera with the same 36.3MP resolution as the Nikon D800. A DSLR like the Nikon D800 has a mirror behind the lens that changes the direction of incoming light between the viewfinder and the sensor when a picture is taken. By removing this mirror, the α7R camera body is only 407g while the D800 is 900g. A longer UAV flight time could be achieved by this weight reduction. Another advantage of a mirrorless camera is durability. Since there are fewer moving parts the camera should have increased reliability and durability. Two of these cameras are undergoing testing for another OST-R project, “Sustainable Geotechnical Asset Management along the Transportation Infrastructure Environment using Remote Sensing” (http://www.mtri.org/geoasset). Due to the lighter weight, we anticipate this camera being a viable solution.

Other Similar Cameras meeting the Requirements

There are a variety of camera options that have a high resolution sensor that would be suitable as shown in table 6-1. With advances in camera technology, more cameras have become available with sensors of 30MP or more. Currently the highest resolution camera listed is the Pentax 645Z with a 51.4MP sensor, but it is also one of the more expensive cameras. The Nikon D800 was selected during the first phase as it had a high resolution sensor, was cost effective, and it had a wide range of lens options. The current list of cameras range in price from $1,500 - $25,400. The Nikon D800's replacement, the D810, costs a typical $3,297 which is similar in cost and weight with the same resolution.

For increased flight time of the UAV platform, a lighter camera is preferred. Form the table 6-1 the Sony α7R is the lightest at 407g for the body only while the Pentax 645Z is the heaviest at 1550g. The Nikon D800 falls in the middle of the range at 1000g.

Table 6-1: High resolution cameras that could be used for Unpaved Roads data collections.

Manufacturer	Model	MP	Price (USD)	Max FPS	Sensor Width	Sensor Height	Remote	Weight (Body g)
Canon	5Ds	50.6	-	5	-	-	Yes	930 (est.)
Leica	S (Type 007)	37.5	$25,400.00	3.5	7500	5000	Yes	1260
Leica	S-E (Type 006)	37.5	$16,900.00	1.5	7500	5000	Yes	1260
Nikon	D800	36.3	$2,999.95	4	7360	4912	Yes	1000
Nikon	D810	36.3	$3,296.95	5	7360	4912	Yes	980
Pentax	645D	40	$4,999.95	1.1	7264	5440	No	1479
Pentax	645Z	51.4	$8,499.95	3	8256	6192	Yes	1550
Samsung	NX1	28.2	$1,499.99	-	6480	4320	Yes	550
Sigma	SD1	46	$1,999.00	5	14400	9600	Yes	700
Sony	α7R	36.3	$2,298.00	4	7360	4912	Yes	407

Based on these data, we are recommending continuing using the Nikon D800/D810 line with the Bergen hexacopter. The Sony α7R also is suitable, lighter-weight, and less expensive camera system that meets requirements that should be considered by implementers of URCAS.

Section VII: Review of Existing and Potential New Platforms

It has been shown that multirotor systems are the clear choice for the road measurement application, both from safety issues as well as performance (Roussi and Brooks 2012b, Brooks et al. 2013, Brooks et al. 2014, Dobson et al. 2013, Dobson et al. 2014). Within that category, there are a number of possible configurations, shown in Figure 7-1.

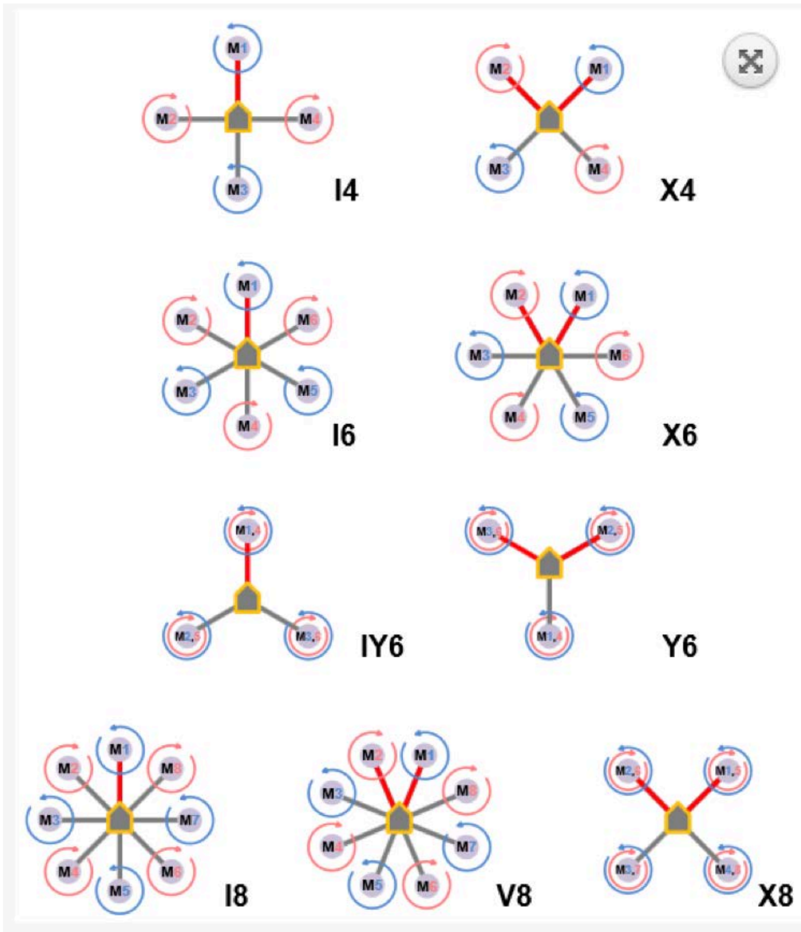

Figure 7-1: Possible Multirotor prop configurations

We have previously recommended that 4-rotor systems not be used, since the loss of a rotor would result in complete loss of flight-control, and probable loss of the camera on impact. 6-rotor systems have sufficient redundancy that loss of a single rotor, while resulting in unusual flight dynamics, can still be landed safely. The Bergen hexacopter adopted in 2013 for use in Phase I is an example of such a system. The ultimate in stability and redundancy is the 8-rotor system (either 8 arms (V8), or the 4-arm version with coaxial props (X8)). The loss of a single prop or motor is not even noticeable during flight, allowing one to complete the mission, even with mechanical failures.

Table 7-1 summarizes the various factors in each configuration. Note that as the number of rotors increases, so does the payload and flight-time.

Table 7-1: Pros and cons of multirotor systems (from http://www.coptercraft.com/multirotor-frame-configurations/)

Multi-Rotor Configurations

TYPE	ENGINES	COAXIAL	PRO'S	CON'S	EXAMPLE CAMERA PAYLOAD
I4	4	No	Simple & Cheap	No Redundancy	GoPro 3
X4	4	No	Simple & Cheap	No Redundancy	GoPro 3
I6	6	No	Limited Redundancy & Larger Payload Capacity	Larger footprint & Pricier	GH2/Nex7
X6	6	No	Limited Redundancy & Larger Payload Capacity	Larger footprint & Pricier	GH2/Nex7
Y6	6	Yes	Small + High stability and Wind Resistance	Poor Efficiency & Complex Mechanics	GH2/Nex7
IY6	6	Yes	Small + High stability and Wind Resistance	Poor Efficiency & Complex Mechanics	GH2/Nex7
I8	8	No	True Redundancy & Horsepower	Large and Expensive	5D/Epic/C300
V8	8	No	True Redundancy & Horsepower	Large and Expensive	5D/Epic/C300
X8	8	Yes	Very High Lift Capacity & Wind Resistance	Inefficient	C500/FS700/Dual Epics

It should be noted that the coaxial systems are ~5% less efficient that the 8-motor systems, but this is offset by an increase in stability and quiet operation. This loss can almost be recovered by careful tuning of the prop sizes, tailoring them to the particular payload. In practice, there is no disadvantage to using a coaxial configuration.

Bergen Hexacopter

The system that has been used by us for road characterization is the Bergen folding hexacopter (Figure 7-2). This system is still a viable candidate, and has been updated with more powerful motors, and larger props, allowing for longer sustained flights with a given payload than earlier versions. This is still a good choice, especially at its current $5,400 price point (hexacopter + one set of spare batteries). However, there are other options that may have advantages.

Figure 7-2: Existing hexacopter system from Bergen used to evaluate unpaved road condition in 2013 and 2014.

Bergen Octocopter

A new offering from Bergen is the Folding Octocopter, in the “Quad-8” (coaxial or X8) configuration, shown in Figure 7-3.

Figure 7-3: Bergen "Quad-8" Folding Octocopter, $8600 as shown

It utilizes four 6s 8000 Mah Batteries, but can use four 10,000 mah batteries for increased flight time. The aircraft weighs 11kg with the 4 batteries on board, ready to fly (RTF).

Performance tests have been made by its Michigan manufacturer with 18”X5.5” (45.7 cm X 14.0 cm) props on top and bottom. Tests are underway to use smaller props on the top, since simulations have shown increased performance in this configuration. With 8000 Mah batteries, carrying a 2.75kg payload, a 10-minute flight in a hover used 31% of the battery power (10,093 Mah) or ~2520 mah out of each battery. This scales to an expected 25-30 min hover time with payload (keeping 15% battery capacity in reserve).

A test in constant forward flight (setting up a square waypoint mission) of 10 minutes used 40% of the total battery (12,914 Mah) or ~3225 mah of each battery, scaling to approximately 20 minutes of forward flight with its payload capability. This Quad-8 or X8 configuration offers the same or better flight time with higher payload capacity and better rotor redundancy for safer flight vs. the existing hexacopter system.

Other Similar Platforms

Since the original choice of aircraft, the number available that meet our requirements has expanded greatly. There are many new systems available, ranging in price from $24,000 to as low as $6,000. Without dedicated funding for flight-testing them, it is impossible to rank them effectively at this time. However, it is useful to know that other systems are becoming available. All the systems listed meet the payload and flight-time requirements for our system. Only three are easily folded for transport and quick deployment (the Bergen, Harris, and Autonomous Avionics). These are all in the $8000-$9000 price range. The higher-priced systems all seem targeted toward the film industry, which is well-known to be able to pay plenty for their equipment.

Other platforms that could be used:

- http://www.uavrotorking.com/product/superjib/ $23,900
- http://www.dronera.no/product/dronera-8hl-heavy-lift-rtf/ $21,000, quick-release, but not foldable
- http://www.coptercraft.com/shop/photohigher-halo-8-rtf-2/ $15K
- http://www.quadrocopter.com/CineStar-8-MK-Heavy-Lift-RTF_p_1156.html $8K
- http://www.versadrones.com/#!heavy-lift-octocopter/c20vl $20K
- http://harrisaerial.com/product/h18-octocopter-rtf-uav/ $9K, foldable
- http://autonomousavionics.com/products/carboncore-cortex-heavy-lift-by-autonomous-avionics $6K (with gimbal), foldable

We continue to recommend Bergen equipment; the performance, the price, and outstanding customer support, make this an excellent choice for a commercially-ready, deployed unpaved road condition assessment system. Companies deploying this project’s system may choose another system, but we have recommended a practical, low-cost, readily available system for the implementation and outreach phase of this project.

Section VIII: Review of Related Research

Deliverable 2-A (State of the Practice – Brooks et al. 2011) reviewed some example projects using remote sensing for unpaved road assessment, such as the original South Dakota State University project led by Dr. Chunsun Zhang that used a UAV and a South African evaluating unpaved roads using an ultralight. Other described studies focused on sensors (accelerometers and GPS) rather than a deployable system that combined Since that report, there appears to have been very little research being done on using remote sensing to asses unpaved road condition, despite strong interest in this capability from our representative Technical Advisory Committee and the attendees of the 2014 technical demonstration in South Dakota. It is possible that impending new UAV regulations from the FAA are making research groups cautious, or they are focusing on areas described as potentially lucrative, such as UAV based sensing of farming (see Jenkins and Vasigh, 2013) .

An exception to this is research is from North Dakota State University where Raj Bridgelall and Bruce Rafert investigated using hyperspectral imagery for assessing transportation systems as part of the Upper Great Plains Transportation Institute (http://www.ugpti.org/). Their paper, "Hyperspectral Imaging Utility for Transportation Systems", is currently in review with SPIE (the international society for optics and photonics). They determined that hyperspectral imagery could be used for condition assessment and remotely mapping the location of paved vs. unpaved roads. In personal communications, Dr. Rafert has indicated a strong interest in deploying hyperspectral sensors for road condition assessment, and his research with Dr. Bridgelall should be monitored for further relevant developments.

Section IX: Conclusions

This report documents the project's previous efforts on establishing requirements, and how these led to the selector platform and sensor. A new Inventory Based Assessment System (IBAS) for Unpaved Roads being developed by Associate PI Dr. Tim Colling, P.E., is described. The existing version URCAS would be capable of collecting most the data needed for the IBAS data needs, such as road width, drainage ditch assessment (assuming there is not too much vegetation), and presence of ruts and large potholes. For example, IBAS needs road width data within the nearest foot (30cm), drainage ditches measured to the nearest inch (2.5 cm), and potholes over 3 feet wide (1m) identified, all of which URCAS can provide. However, it is our conclusion that since IBAS is focused on more network-level assessment, and URCAS is focused more on collecting and analyzing detailed distress data over short (100 ft / 30.5 m) representative segments that can be used for quickly selecting and implementing specific site treatments, it is better for the time being for our UAV-based system to keep focusing on the more detailed Unsurfaced Road Condition Index (URCI) data. It is our opinion that if URCAS can be deployed to cost-effectively collect URCI data, which is more detailed and technically challenging, then it would also be likely to easily modify it to efficiently collect IBAS data at a future time. However, URCAS was designed and optimized to collect the level of data necessary for URCI ratings, and a switch to try to optimize its function to collect IBAS data may result in compromises that would make the system less attractive to commercialization.

The Nikon D800 full-frame camera sensor and the Bergen hexacopter platform selected and tested in the prototype development phase continue to meet data collection requirements. Newer cameras, such as the Nikon D810 and the lighter-weight Sony α7R mirrorless camera would also meet requirements at similar costs. Newer multi-rotor platforms would also meet project needs, including ones with 8-rotor "V8" and "X8"arrangements. The project team continues to recommend the Bergen platform, because of its demonstrated performance, reasonable price, and outstanding customer support. The Bergen "Quad-8" folding octocopter, with an $8,600 cost, provides longer flight time, heavier lift capabilities, and improved safety through rotor redundancy. For these reasons, we conclude that demonstrating the capabilities of the Bergen Quad-8 octocopter is a reasonable component of new outreach and implementation-focused second phase of the project.

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Appendix A: Quantities for Illustrative Projects

Illustrative Project Work for Surface Width, Fair – Road needs 1’ to 6’ of widening.

Assumptions

Project is based on an average of 3 feet of widening.

Assume V ditch is sufficient 2' deep with 4:1 front and back slopes (16' width) and is cleared.

Assume topsoil can be salvaged mulching is not necessary.

Assume widening can be accomplished on one side of the road

Clearing:

3’ * 5280’ per mile =15,840 square feet

15840 sqft /43560 = 0.3636 Acres of clearing per mile for road

0.3636 * $4,290=$1,559 per mile

Earth Excavation

8”/12”/’=0.67’

0.67’* 3’ * 5,280’ = 10,560.5 cubic feet

10,560 cuft /27=391 sqyd excavation for widening, not including ditch move

391*$4.54=$1,775 per mile

Ditch move 3’*8.2’* 5,280’ / 27=4,810 cubic yards

4,810 cuyd * $4.54=$21,842 for ditch move per mile

Agg surface course

0.67’ * 3’ * 5,280’ / 27=391 cubic yards

391 cuyd * $38.72= $15,139 per mile

Topsoil salvage

8.2’ * 2 * 5,280’ / 9 =9,621 square yards

9,621 sqyd * $1.05 = $10,102 per mile

Seeding

9,621 sqyd * 9 / 43,560 = 1.98 Acre, assume 2 acres
2 acre * 220 lb/acer * $2.22= $976 per mile

Total for 3 foot widening $1,559+$1,775+$21,842+$15,139+$10,102+$976 = $51,393 per mile

Total Cost $51,393 per mile

Illustrative Project Work for Surface Width, Poor – Road needs 7 to 15 of widening

Assumptions

Project is based on an average of 11 feet of widening.

Assume V ditch is sufficient 2' deep with 4:1 front and back slopes (16' width) and is cleared.

Assume topsoil can be salvaged and mulching is not necessary.

Clearing

11’ * 5,280’ = 58,080 square feet

58,080 sqft / 43,560 = 1.33 Acres of clearing per mile for road

1.33 acre * $4,290=$5,719 per mile

Earth Excavation

8”/12”/’ = 0.67 feet

0.67’ * 11’ * 5,280’ = 38,721cubic feet

38,721 cuft / 27 = 1,434 cubic yards excavation not including ditch move.

1,434 cuyd * $4.54=$6,510 per mile

Ditch move 11’ * 8.2’ * 5,280’ / 27 = 17,639 cubic yards

17,639 cuyd * $4.54= $80,081 per mile

Agg surface course

0.67’ * 11’ * 5,280’ / 27=1,434 cubic yards

1,434 cuyd * $38.72= $55,524 per mile

Topsoil salvage

8.2’* 2’ * 5,280’ / 9 =9,621 square yards per ditch

9,621 sqyd* 2 * $1.05=$20,204 per mile for 2 ditches

Seeding 9,621* 9 / 43560=1.98 Acre assume 2 acres

2ac * 2 * 220lb / ac * $2.22=$1,953 per mile

Total for 11 foot widening $5,719+$6,510+$80,081+$55,524+$20,204+$1953= $169,992 per mile

Total Cost $169,992 per mile

Illustrative Project Work for Drainage Adequacy, Fair – Ditches need to be cleaned out

Assumptions

Assumes ditches or swales are present and cross drainage is sufficient

Assumes no large trees.

Assume topsoil and seeding / mulching are not necessary.

Ditch cleanout: lower the ditch profile; remove vegetation for positive drainage.

53 stations per mile * $305/ STA = $16,165 per mile

Total Cost $16,165 per mile

Illustrative Project Work for Drainage Adequacy, Poor – Ditches need to be created.

Assumes relatively level earthwork adjacent to road

Assume topsoil can be salvaged.

Assume no wetlands permits necessary.

Does not include pipe work for drives or cross culverts

Assumes 2 foot deep V ditch with 1:4 front and back slopes

Clearing

16’ * 5,280’ = 84,480 square feet

84,480 sqft / 43,560 =1.94 acres - Assume 2 acres of clearing per mile for road

2 acres * 2 ditches * $4,290 acre =$17,160 for two ditches per mile of road

Earth Excavation

8’ * 2’ * 5,280’ /27 = 3,128 cubic yards per ditch - mile

3,128 cuyd * 2 ditches * $4.54= $28,402 for two ditches per mile

Topsoil salvage

8.2’ * 2 * 5280 / 9 = 9,621 square yards per ditch

9,621 sqyd * 2 ditches * $1.05=$ 20,204 for two ditches per mile of road

Seeding

9,621 sqyd * 9sqft/sqyd / 43560= 1.9878 Acre- assume 2 acres per ditch

2 acres * 2 ditches * 220 lb/acre * $2.22= $1,953 for two ditches.

Total Cost $17,160+$28,402+$20,204+$1,953=$67,719 per mile

Illustrative Project Work for Structural Adequacy, Fair – Road needs 2” to 4” of gravel

Assumptions

Assume surface width of 22 feet to cover most cases.

Assume average depth of 3” gravel

3/12’ gravel * 22' wide * 5,280’ long / 27 = 1,075 cubic yards

1,075 cuyd * $38.72= $41,624.0 per mile

Total Cost: $41,624.0 per mile

Illustrative Project Work for Structural Adequacy, Poor – Road needs 5” to 8” of gravel

Assumptions

Assume surface width of 22 feet to cover most cases.

Assume average depth of 6.5” gravel

Assume no subgrade undercutting or other grading

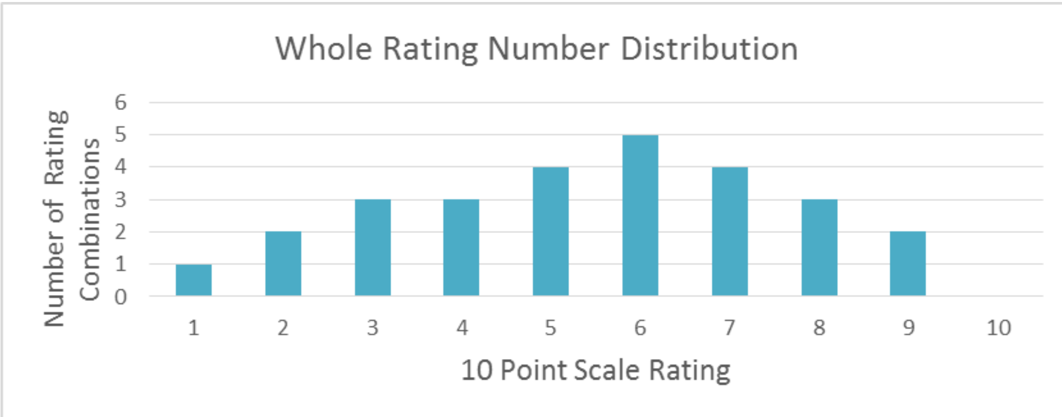
6.5”/12’ gravel * 22' wide * 5,280’ long / 27 = 2,330 cubic yards

2,330 cuyd * $38.72= $90,217 per mile

Total Cost: $90,217 per mile

Appendix B: Total Point Value Combinations

Nine Point Scale Combination Table with Rounded Total Ratings



Rating (Wid., Drain, Struct.)	Width	Drainage	Structure	Total	Rounded Total	Overall Rating
poor, poor, poor	0.52	0.21	0.28	1.00	1	poor
poor, poor, fair	0.52	0.21	1.46	2.19	2	poor
poor, fair, poor	0.52	1.46	0.28	2.26	2	poor
poor, good, poor	0.52	1.86	0.28	2.65	3	poor
poor, poor, good	0.52	0.21	2.48	3.20	3	poor
poor, fair, fair	0.52	1.46	1.46	3.44	3	poor
fair, poor, poor	3.41	0.21	0.28	3.89	4	poor
poor, good, fair	0.52	1.86	1.46	3.84	4	poor
poor, fair, good	0.52	1.46	2.48	4.46	4	poor
fair, poor, fair	3.41	0.21	1.46	5.08	5	fair
poor, good, good	0.52	1.86	2.48	4.85	5	fair
good, poor, poor	4.67	0.21	0.28	5.15	5	fair
fair, fair, poor	3.41	1.46	0.28	5.15	5	fair
fair, good, poor	3.41	1.86	0.28	5.55	6	fair
fair, poor, good	3.41	0.21	2.48	6.09	6	fair
good, poor, fair	4.67	0.21	1.46	6.33	6	fair
fair, fair, fair	3.41	1.46	1.46	6.34	6	fair
good, fair, poor	4.67	1.46	0.28	6.40	6	fair
fair, good, fair	3.41	1.86	1.46	6.73	7	fair
good, good, poor	4.67	1.86	0.28	6.80	7	fair
good, poor, good	4.67	0.21	2.48	7.35	7	fair
fair, fair, good	3.41	1.46	2.48	7.35	7	fair
good, fair, fair	4.67	1.46	1.46	7.59	8	good
fair, good, good	3.41	1.86	2.48	7.75	8	good
good, good, fair	4.67	1.86	1.46	7.98	8	good
good, fair, good	4.67	1.46	2.48	8.61	9	good
good, good, good	4.67	1.86	2.48	9.00	9	good