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.

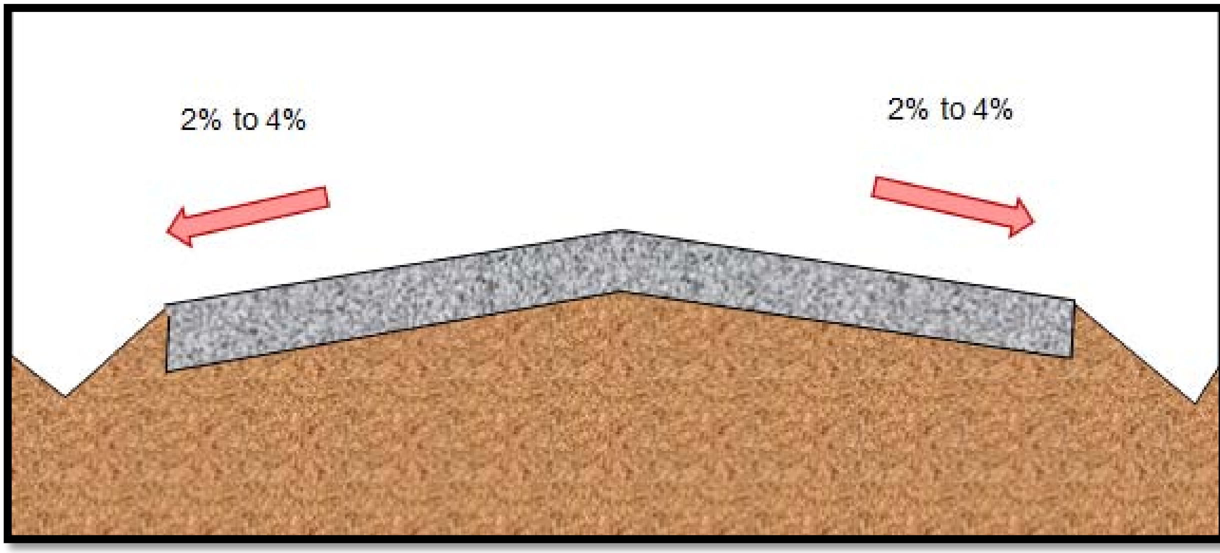

Figure 2: Road cross section illustrating an example of a typical cross slope.

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.

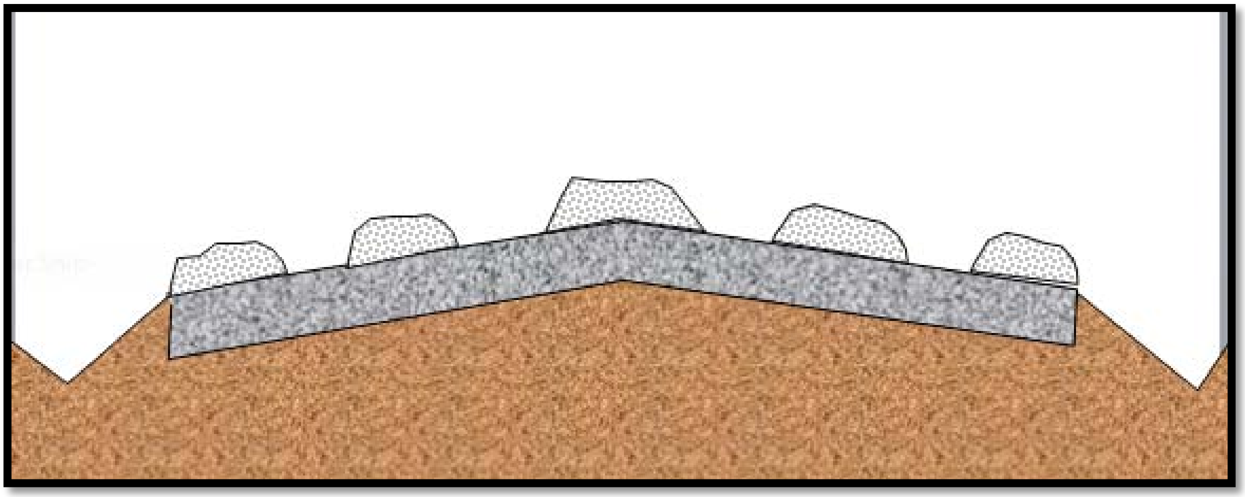

Figure 6: Typical location of float aggregate berms.

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. 11^{o} 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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