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Implementation Assessment of Unpaved Road Condition with High-Resolution Aerial Remote Sensing

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www.mtri.org/unpaved
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Transportation Asset Management Council – MI Transportation Reporting Portal | Michigan Tech Research Institute | Road Commission for Oakland County | SEMCOG Southeast Michigan Council of Governments

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Characterization of Unpaved Road Conditions through the Use of Remote Sensing

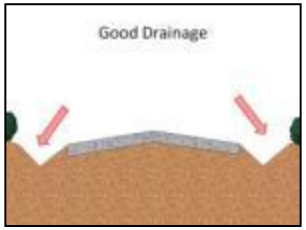
Goal of the Project: *Extend available Commercial Remote Sensing & Spatial Information (CRS&SI) tools to enhance & develop an unpaved road assessment system by developing a sensor for, & demonstrating the utility of remote sensing platform(s) for unpaved road assessment.*

- Commercially viable in that it can measure inventory and distress data at a *rate and cost competitive with traditional methods*
- *Rapid ID & characterization* of unpaved roads
- Inventory level with *meaningful metrics*
- Develop a sensor for, & demonstrate the utility of remote sensing platform(s) for unpaved road assessment
- Platform could be a typical manned fixed-wing aircraft, UAV, or both; depends on relative strengths & weaknesses in meeting user community requirements
- Simplify mission planning, control of sensor system, & data processing fitting for a commercial entity or large transportation agency
- *Demonstrate prototype* system(s) to stakeholders for potential implementation developed through best engineering practices
- Develop a decision support system to aid the user in asset management and planning

Road Characteristics

- Unpaved roads have common characteristics
  - Surface type
  - Surface width
    - Collected every 10', with a precision of +/- 4”
  - Cross Section (Loss of Crown)
    - Facilitates drainage, typically 2% - 4% (up to 6%) vertical change, sloping away from the centerline to the edge
    - Measure the profile every 10' along the road direction, able to detect a 1% change across a 9'-wide lane
  - Potholes
    - <1', 1'-2', 2'-3', >3‘ width bins
    - <2”, 2”-4”, >4” depth bins
  - Ruts
    - Detect features >5”, >10' in length, precision +/-2”
  - Corrugations (washboarding)
    - Classify by depth to a precision of +/-1”
      - <1”, 1”-3”, >3”
    - Report total area of the reporting segment affected
  - Roadside Drainage
    - System should be able to measure ditch bottom relative to road surface within +/-2”, if >6”
    - Detect the presence of water, elevation +/-2”, width +/-4”
  - Float aggregate (berms)

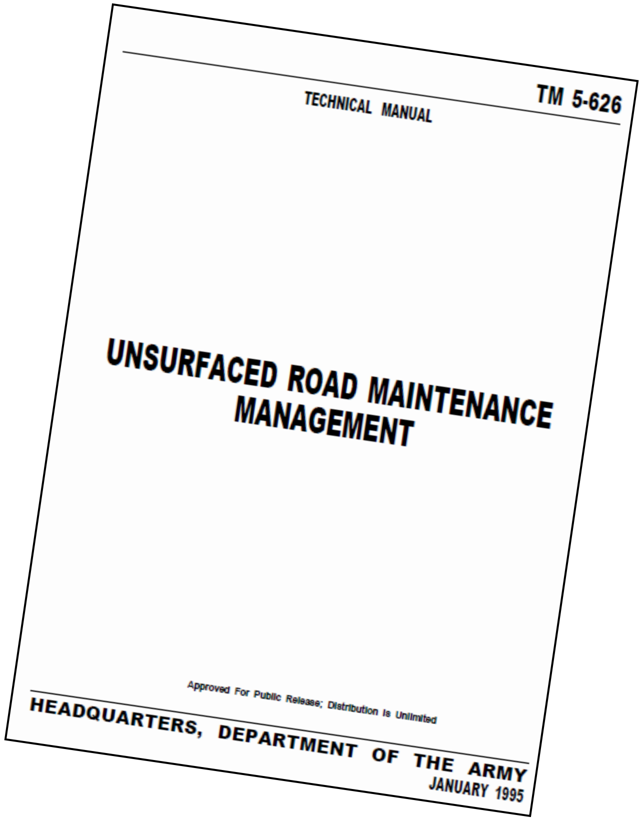
Washboard



Float Aggregate

Combined Methods: Dept. Army Unsurfaced Road Condition Index (URCI)

- Representative Sample Segments (approx. 100’ long; 2 per ~mile for representative sample – pg. 2-3 in TM 5-626)
- 2 Part Rating System
  - Density
    - Percentage of the sample area
  - Severity
    - Low
    - Medium
    - High
- Good candidate method to focus on because it offered a clear set of measurement requirements, the realistic possibility of collecting most of the condition indicator parameters, and the potential applicability to a wide variety of U.S. unpaved roads.
- Endorsed by TAC as effective rating system


TECHNICAL MANUAL TM 5-626

UNSURFACED ROAD MAINTENANCE MANAGEMENT

Approved For Public Release; Distribution Is Unlimited

HEADQUARTERS, DEPARTMENT OF THE ARMY
JANUARY 1995

Combined Methods: Dept. Army Unsurfaced Road Condition Index

- Decision matrix from distress criteria (Eaton 1987a)

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

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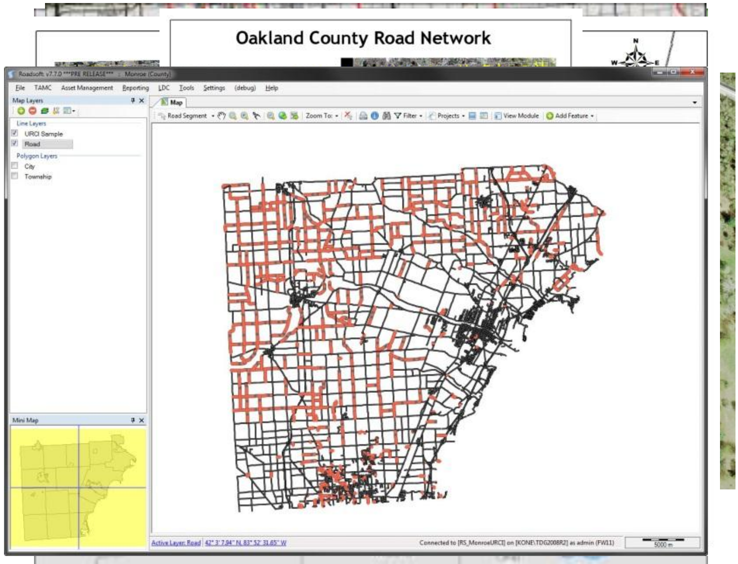
Summary of requirements

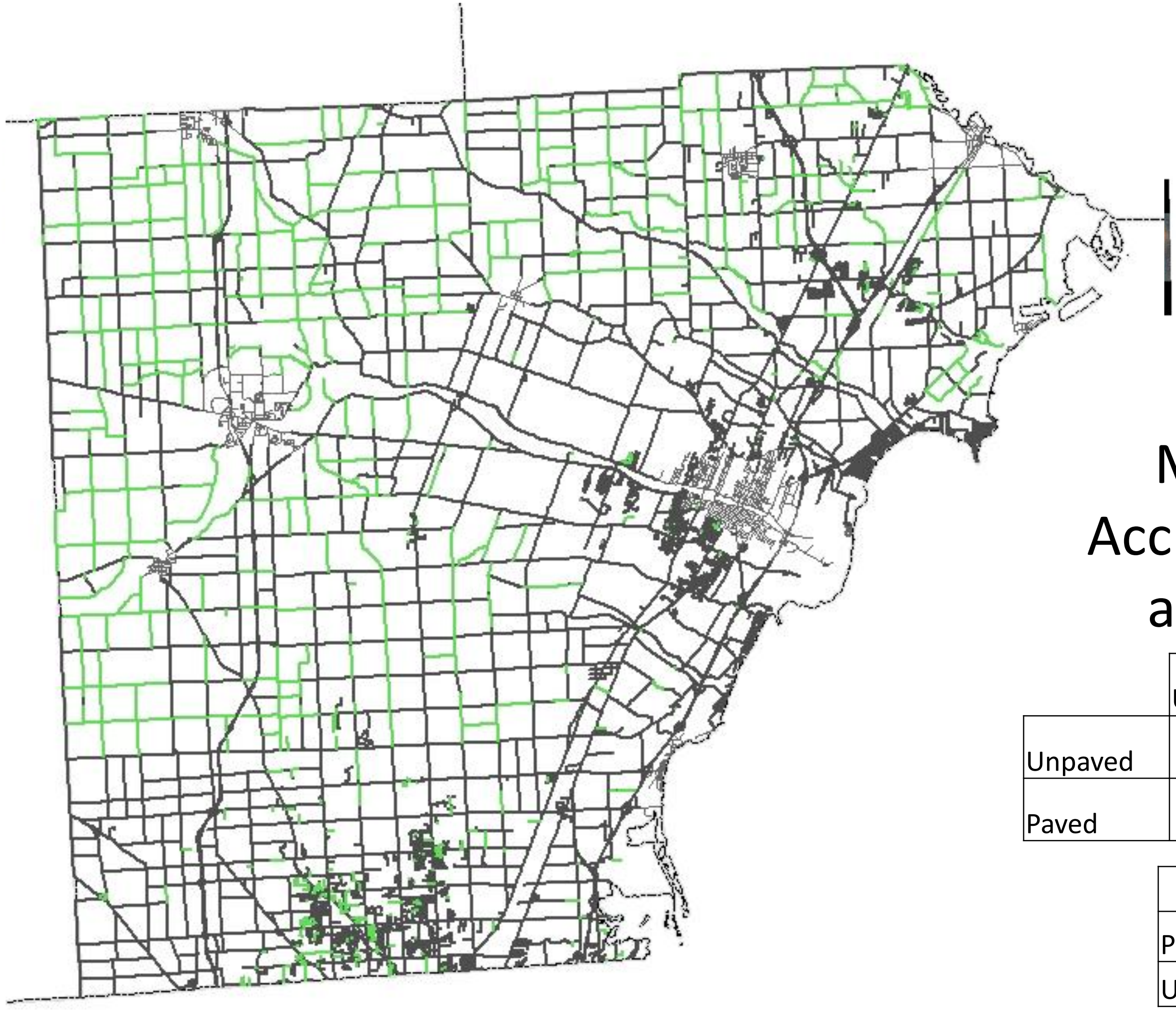
Number	Name	Type	Definition
1	Data Collection Rate	Sensor	The systems must collect data at a rate that is competitive with current practice (to be determined, TBD)
2	Data Output Rate	System	Processed outputs from the system will be available no later than 5 days after collection
3	Sensor Operation	Sensor	“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

Inventory: Surface Type

- How many miles of unpaved road are there? Not all counties have this.
- Need to able to determine this inventory
- c. 43,000 (1984 estimate) – but no up-to-date, accurate state inventory exists
- c. 800 miles in Oakland County estimate
- We are extracting this from recent, high-resolution aerial imagery, focusing on unincorporated areas – attribute existing state Framework roads layer
- Completed Oakland, Monroe, Livingston, St. Clair, Macomb, Washtenaw, Counties; shared with SEMCOG, adding to RoadSoft GIS asset management tool
- 87%-94% accuracy
- Ex: Livingston Co.: 894 miles unpaved
  - 1289 miles unpaved



Unpaved Road Detection Results

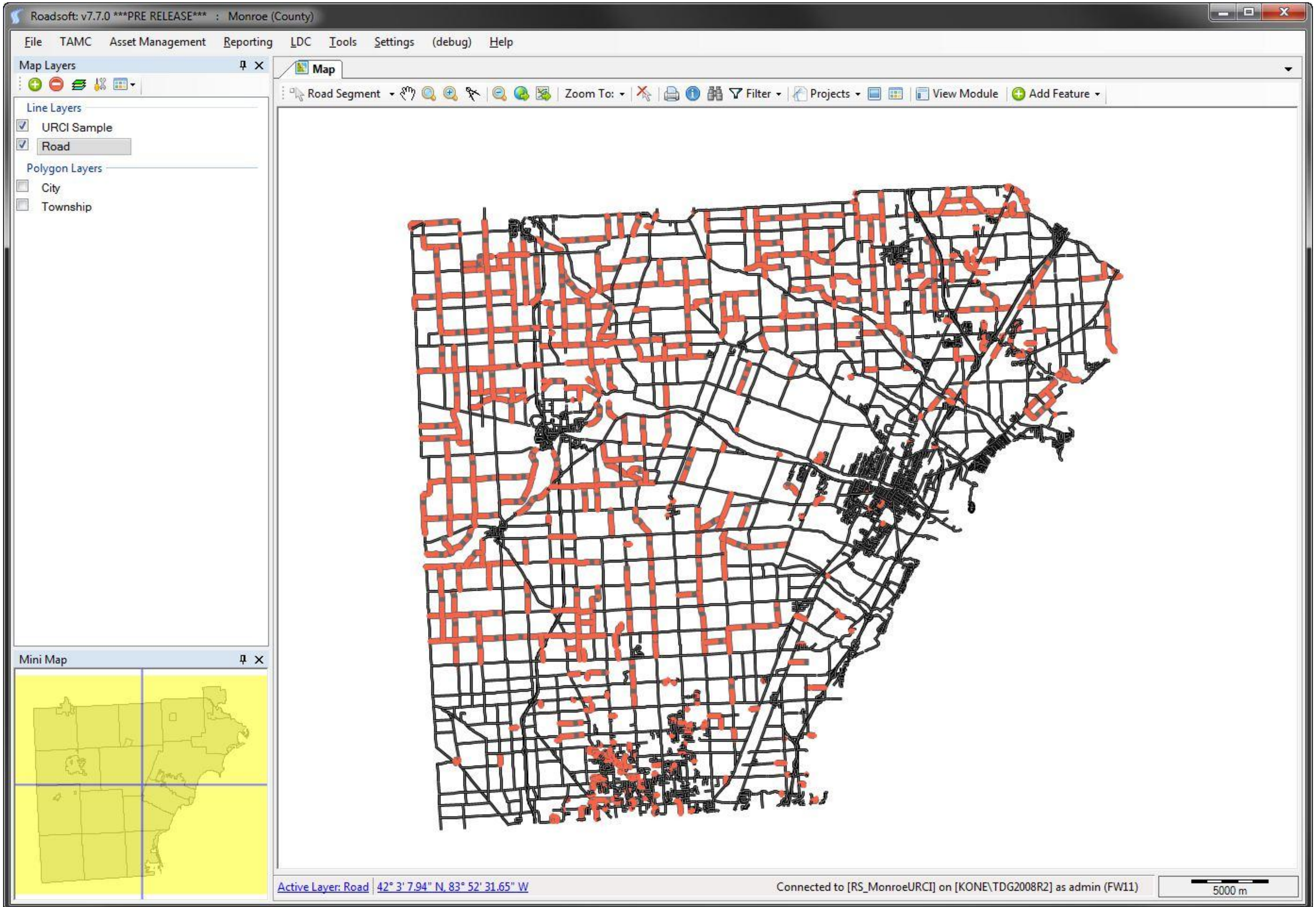


Monroe County
Accuracy Assessment
at 30% coverage

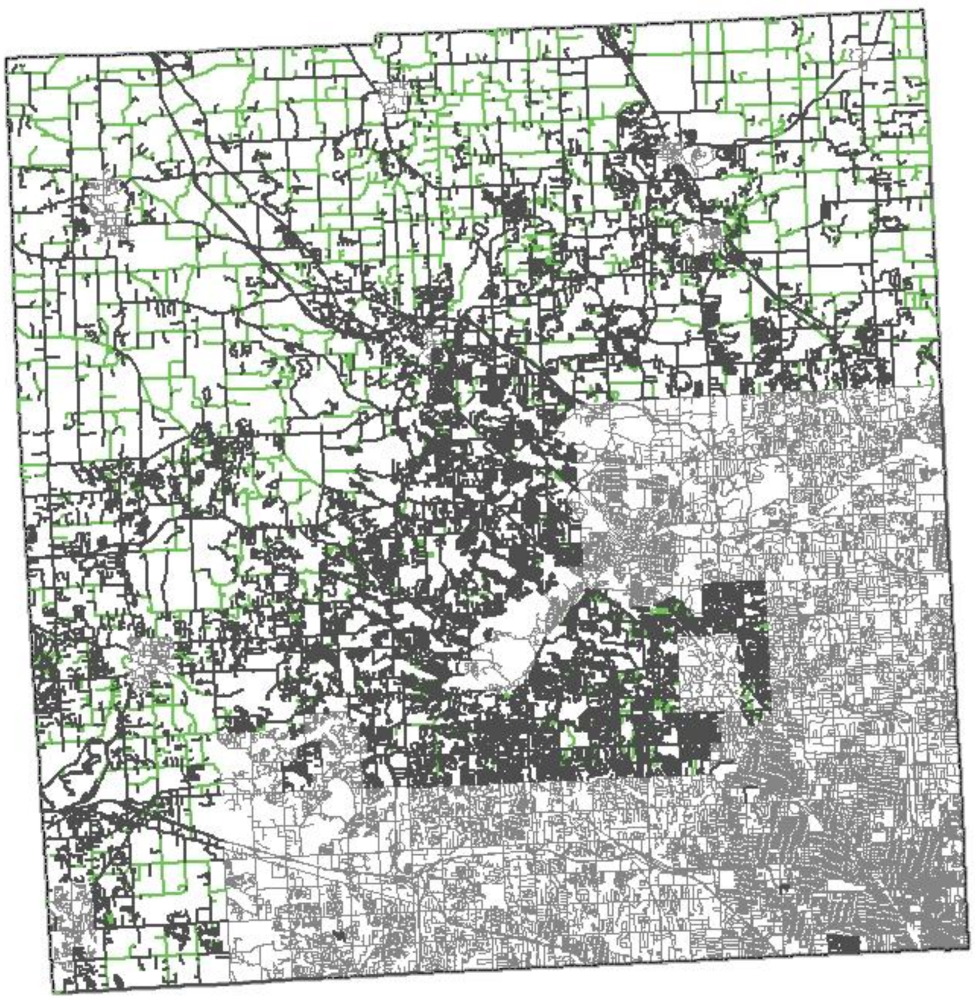
	Users	Producers	Overall
Unpaved	93.9%	77.5%	94.3%
Paved	94.3%	98.7%	

	Mileage
Paved	1390.0
Unpaved	351.9
Total Mileage	1741.9

Integration of unpaved road inventory results with RoadSoft GIS



Unpaved Road Detection Results

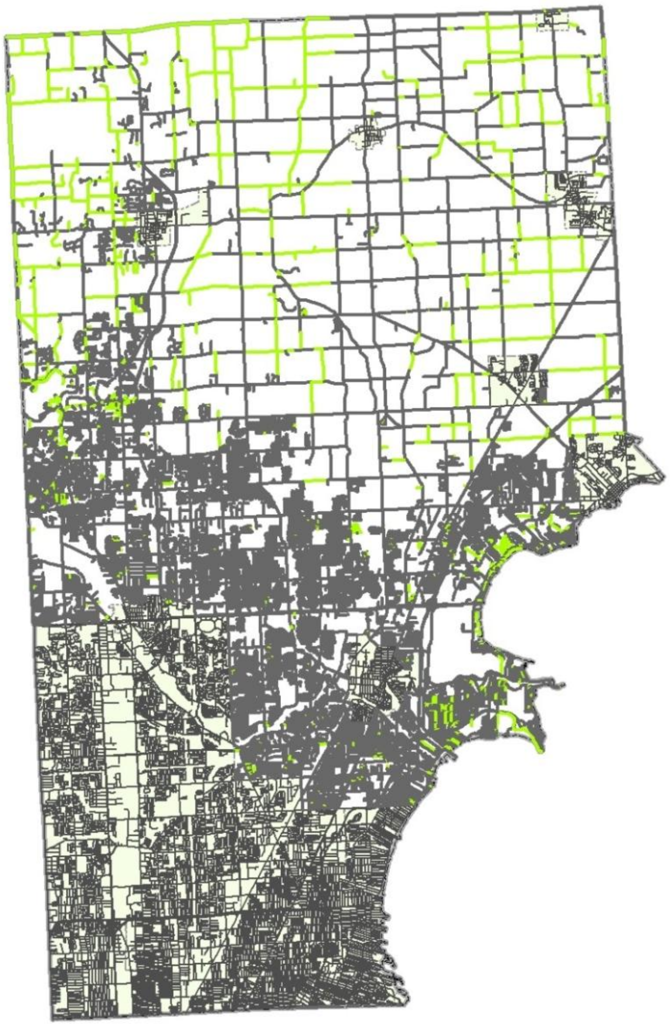


Oakland County
Accuracy Assessment
at 25% coverage

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

	Mileage
Paved	2948.2
Unpaved	693.9
Total Mileage	3642.1

Unpaved Road Detection Results

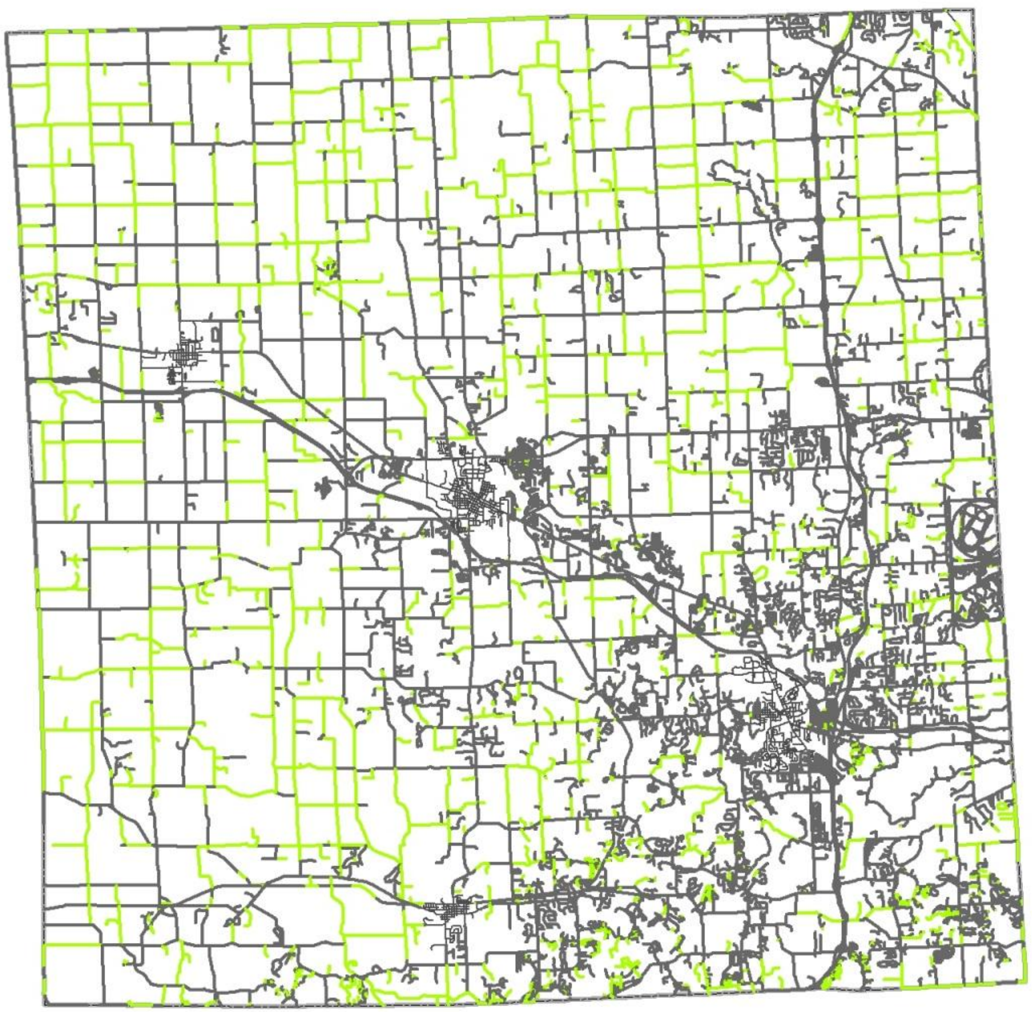


Macomb County
Accuracy Assessment
20% coverage

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

	Mileage
Paved	1847.0
Unpaved	319.4
Total Mileage	2166.4

Unpaved Road Detection Results



Livingston County
Accuracy Assessment
25% coverage

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

	Mileage
Paved	1289.4
Unpaved	894.1
Total Mileage	2183.5

Selected sensor: Nikon D800

- Nikon D800 – full-sized (FX) sensor, 36.3 Mp, 4 fps - $3,000
- More than meets all our requirements
- Weight prime lens, weights ~1.5 kg

Body type	
Body type	Mid-size SLR
Body material	Magnesium alloy
Sensor	
Max resolution (px)	7360 x 4912
Effective pixels	36.3 megapixels
Sensor photo detectors	36.8 megapixels
Other resolutions	6144 x 4912, 6144 x 4080, 5520 x 3680, 4800 x 3200, 4608 x 3680, 4608 x 3056, 3680 x 2456, 3600 x 2400, 3072 x 2456, 3072 x 2040, 2400 x 1600
Image ratio w:h	5:4, 3:2
Sensor size	Full frame (35.9 x 24 mm)
Sensor type	CMOS
Processor	Expeed 3
Color space	sRGB, Adobe RGB
Color filter array	Primary Color Filter
Image	
ISO	100 - 6400 in 1, 1/2 or 1/3 EV steps (50 - 25600 with boost)
White balance presets	12
Custom white balance	Yes (5)
Image stabilization	No
Uncompressed format	.NEF (RAW)
JPEG quality levels	Fine, Normal, Basic
File format	• NEF (RAW): 12 or 14 bit, lossless compressed, compressed or uncompressed • TIFF (RGB) • JPEG
Optics & Focus	
Autofocus	• Phase Detect • Multi-area • Selective single-point • Tracking • Single • Continuous • Face Detection • Live View

Platforms

- Bergen Helicopter
  - Total flight time: 16 minutes (not including 2 minute reserve); flight time for a 200 meter section ~ 4 minutes.
  - Flown at 2 m/s at 25 and 30 meters
  - 50mm prime lens


- Cessna 172 and 152 Aircraft
  - Average air speed: 65 knots (~ 75 mph)
  - Flown at altitudes of 500 and 1000 feet
  - 105 mm prime lens (2012), 70-200mm zoom (2013)


- Bergen Hexacopter
  - Total flight time: up to 30 minutes with small payloads
  - Weight: 4kg unloaded
  - Maximum Payload: 5kg
  - Includes autopilot system, stabilized mount that is independent of platform movement, and first person viewer system (altitude, speed, battery life, etc.)


Initial UAV Collect

- Flight time for a 200 m section: 4 minutes
- During collects helicopter is flown at 2 m/s and at an altitude of 25 m (82') and 30 m (98')

Example flight at http://www.youtube.com/watch?v=KBNQzM7xGQo

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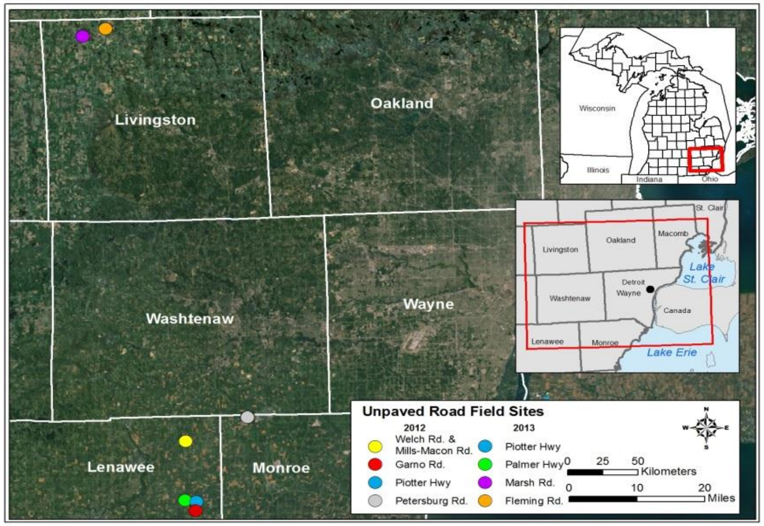
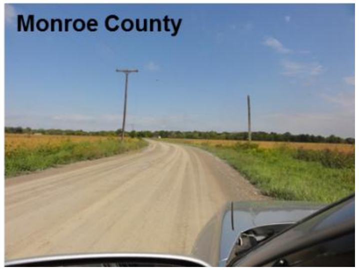
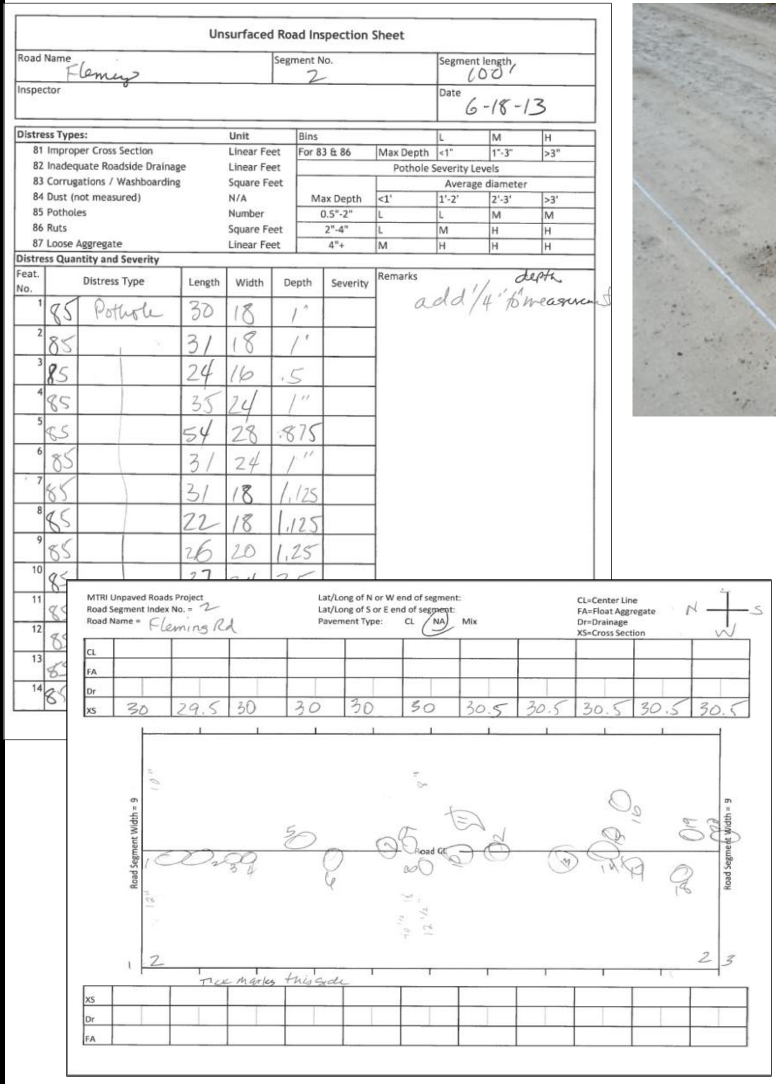
Field site collections





- Five sites were selected in 2012, four sites were selected in 2013 in SE Michigan
  - Assistance of Road Commission Authorities aided in the selection of field sites
  - None of the sites contained all distress features of interest for ground truth assessment, but all were found
  - Road graders often hindered data collection
- Two collections opportunities in Iowa and Nebraska (August 2013)
  - Verified maintained roads (with the potential of being maintained using different materials and methods) in other states could be categorized with the same processing suite as Michigan roads
  - Selections based on Google Earth imagery and proximity to Interstate-80
  - Results indicate that there were no issues in assessing road conditions on these other unpaved roads.

Ground Truth



Unsurfaced Road Inspection Sheet

Road Name: Fleming	Segment No.: 2	Segment length: 100'
Inspector:		Date: 6-18-13

Distress Types:	Unit	Bins		L	M	H
81 Improper Cross Section	Linear Feet	For 83 & 86	Max Depth	<1"	1"-3"	>3"
82 Inadequate Roadside Drainage	Linear Feet	Pothole Severity Levels				
83 Corrugations / Washboarding	Square Feet		Average diameter			
84 Dust (not measured)	N/A	Max Depth	<1'	1'-2'	2'-3'	>3'
85 Potholes	Number	0.5"-2"	L	L	M	M
86 Ruts	Square Feet	2"-4"	L	M	H	H
87 Loose Aggregate	Linear Feet	4"+	M	H	H	H

Distress Quantity and Severity

Feat. No.	Distress Type		Length	Width	Depth	Severity	Remarks
1	85	Pothole	30	18	1"		add 1/4" depth to measurement
2	85		31	18	1"		
3	85		24	16	.5		
4	85		35	24	1"		
5	85		54	28	.875		
6	85		31	24	1"		
7	85		31	18	1.125		
8	85		22	18	1.125		
9	85		26	20	1.25		
10	85		[illegible]	[illegible]	[illegible]		
11	85						
12	85						
13	85						
14	85						

MTRI Unpaved Roads Project
Road Segment Index No. = 2
Road Name = Fleming Rd

Lat/Long of N or W end of segment:
Lat/Long of S or E end of segment:
Pavement Type: CL NA Mix

CL=Center Line
FA=Float Aggregate
Dr=Drainage
XS=Cross Section

N S W

CL											
FA											
Dr											
XS	30	29.5	30	30	30	30	30.5	30.5	30.5	30.5	30.5

Road Segment Width = 9

Road CL

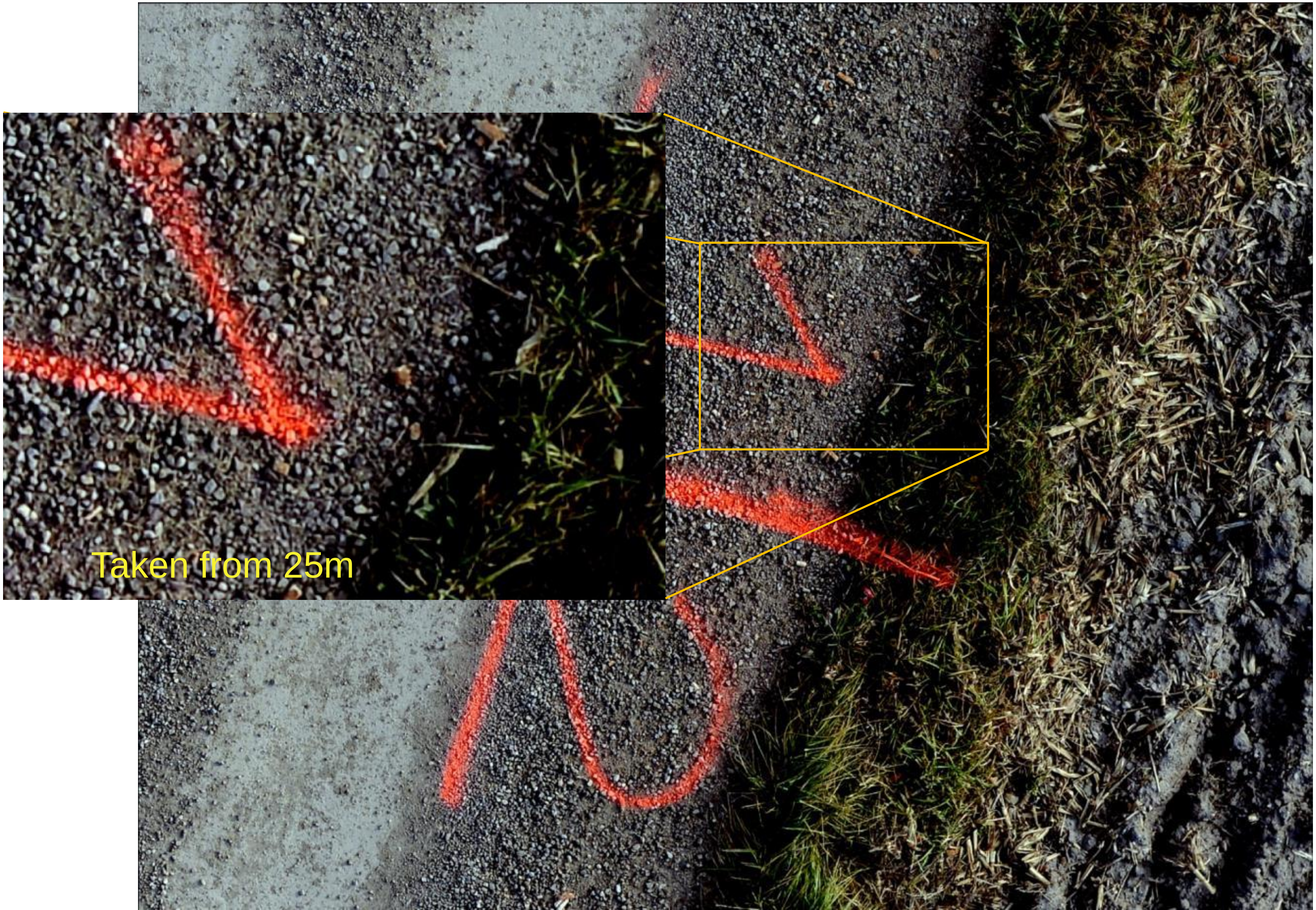
Road Segment Width = 9

Tick marks this side

XS											
Dr											
FA											

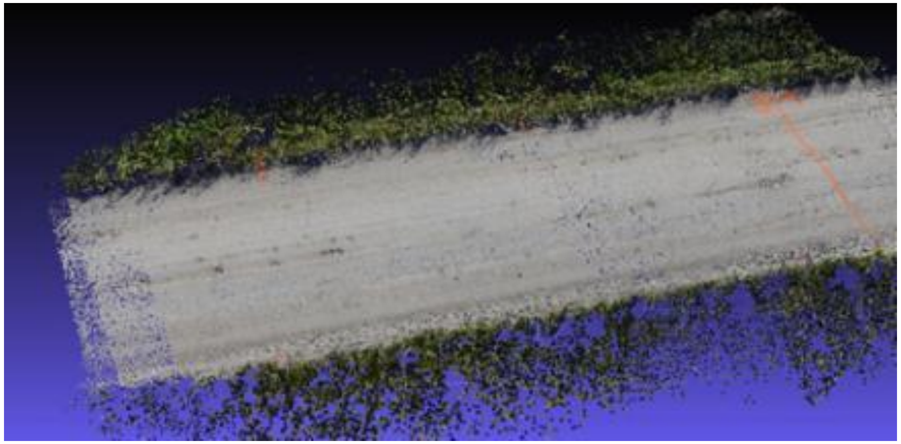
Helicopter Data – Garno Rd.
25m Altitude

Performance – Collected Imagery

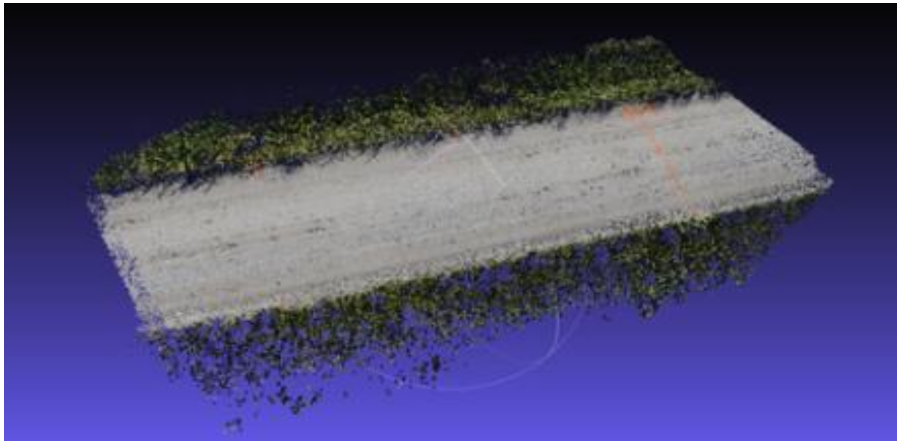


Aerial Data – Piotter Rd.
500 ft Altitude

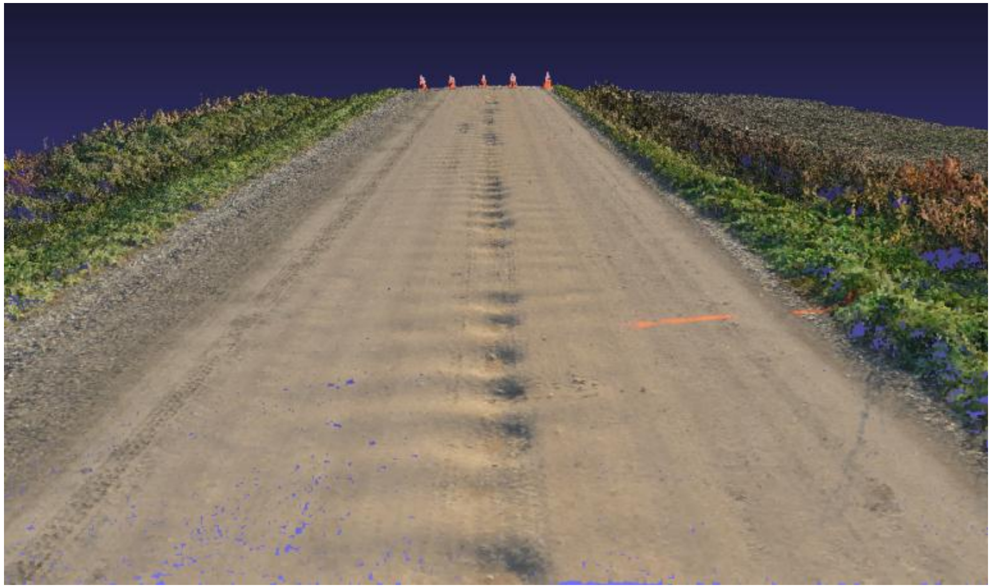
3D Reconstruction (Helicopter)



Initial point cloud

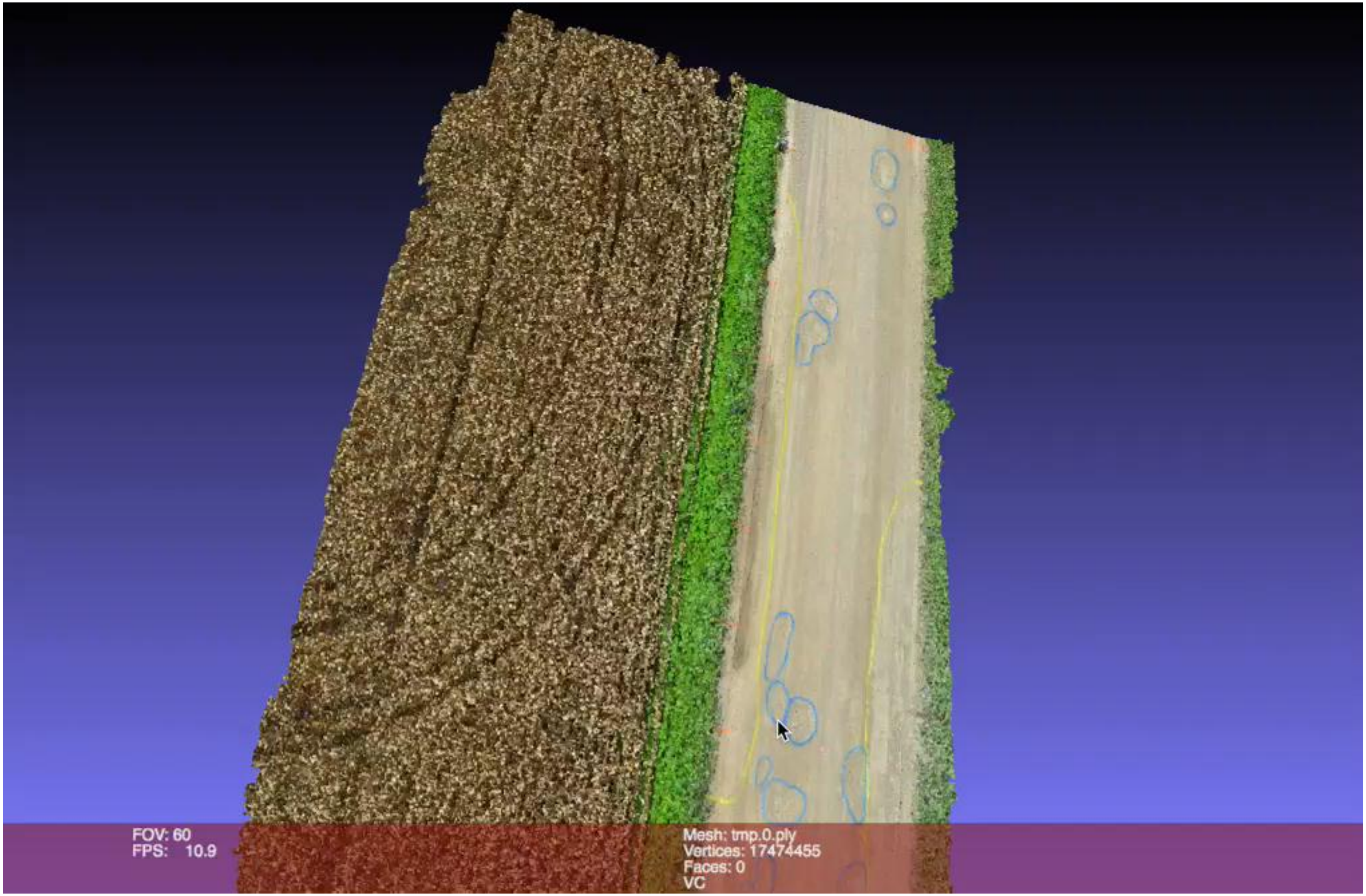


Densified point cloud



3D surface from point cloud

3D of Piotter Rd (Hexacopter, 27 images)

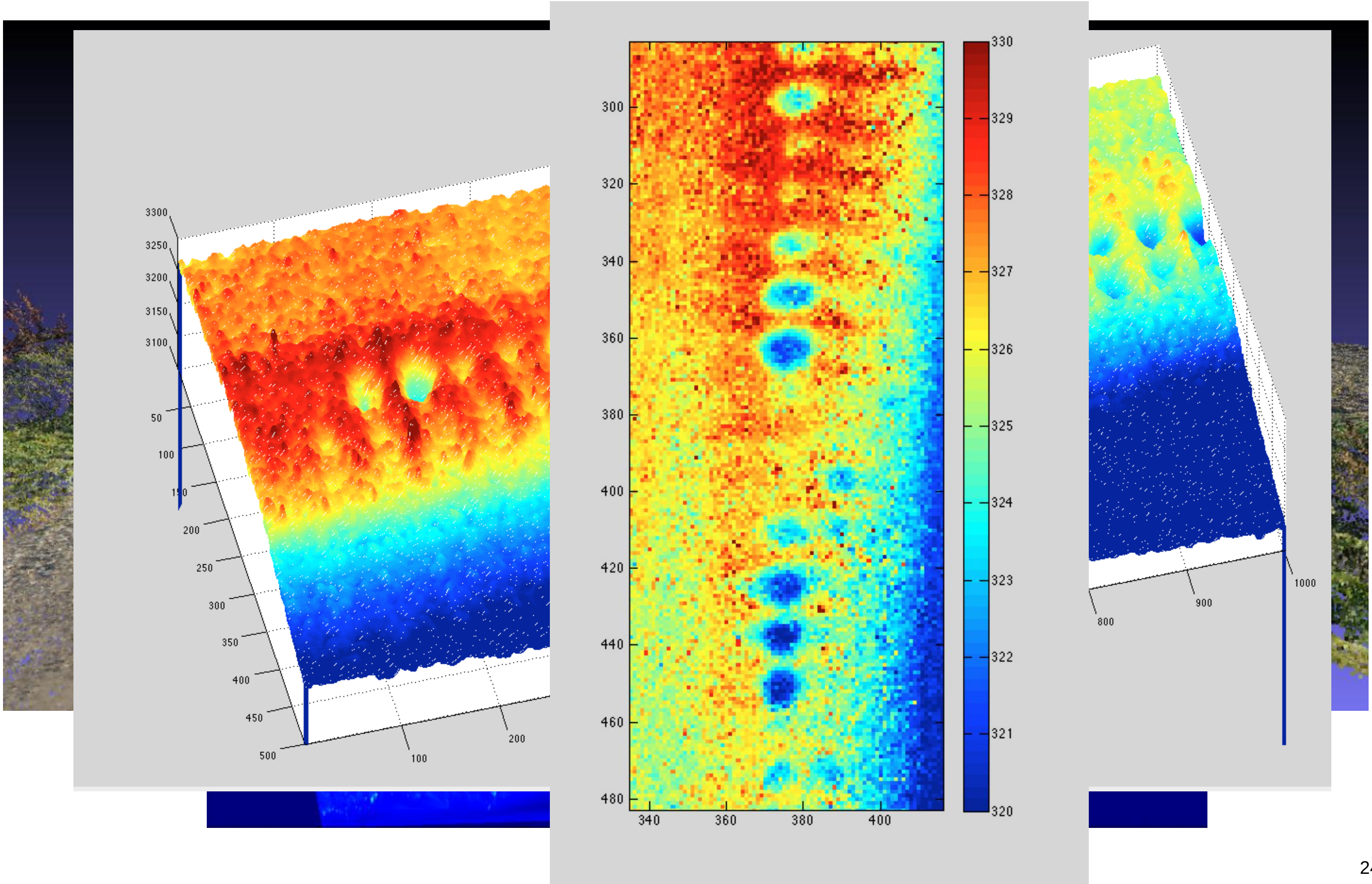


3D of an Iowa Road (Hexacopter, 18 images)

3D data examples

Important to categorizing distresses by severity

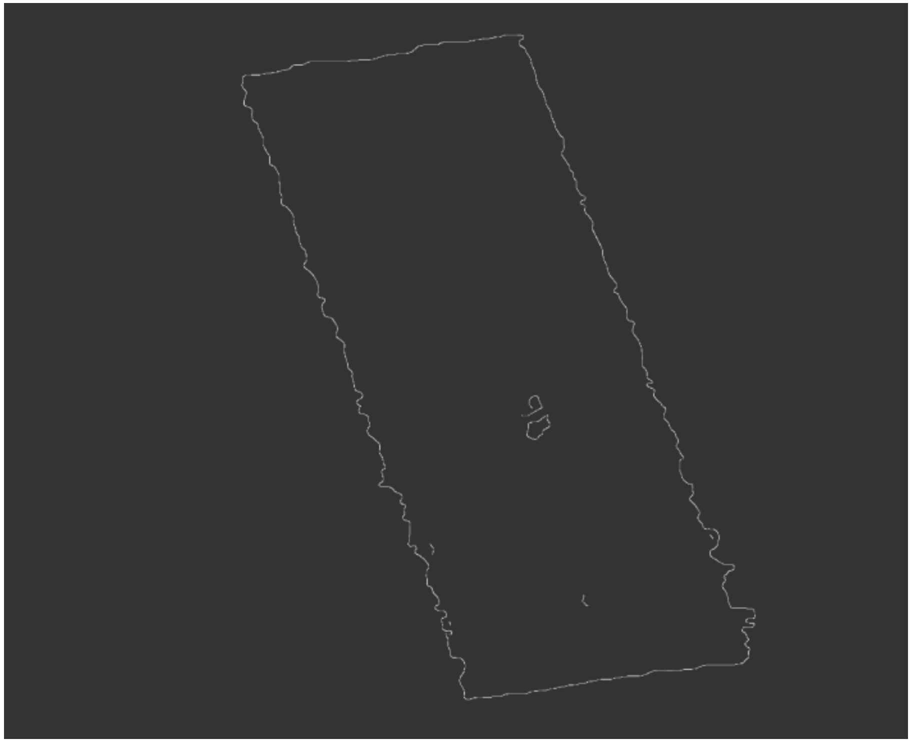
Obtaining 0.9 cm ground sample distance



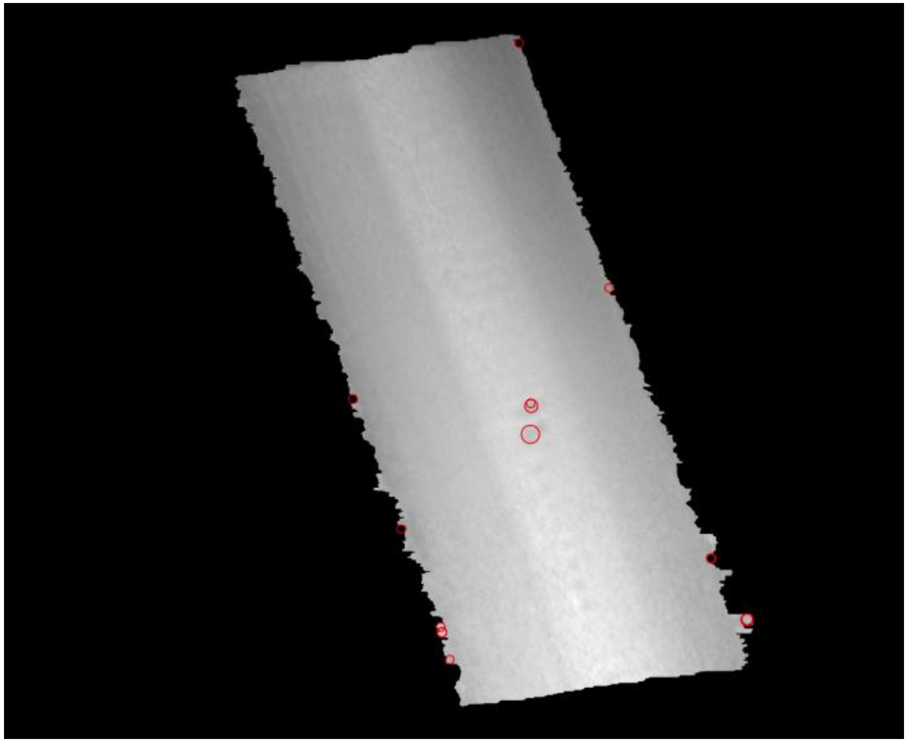
Distress Detection – Potholes

- Canny Edge detection used to locate edges
- Hough Circle Transform is used to locate potholes

Edge Detection

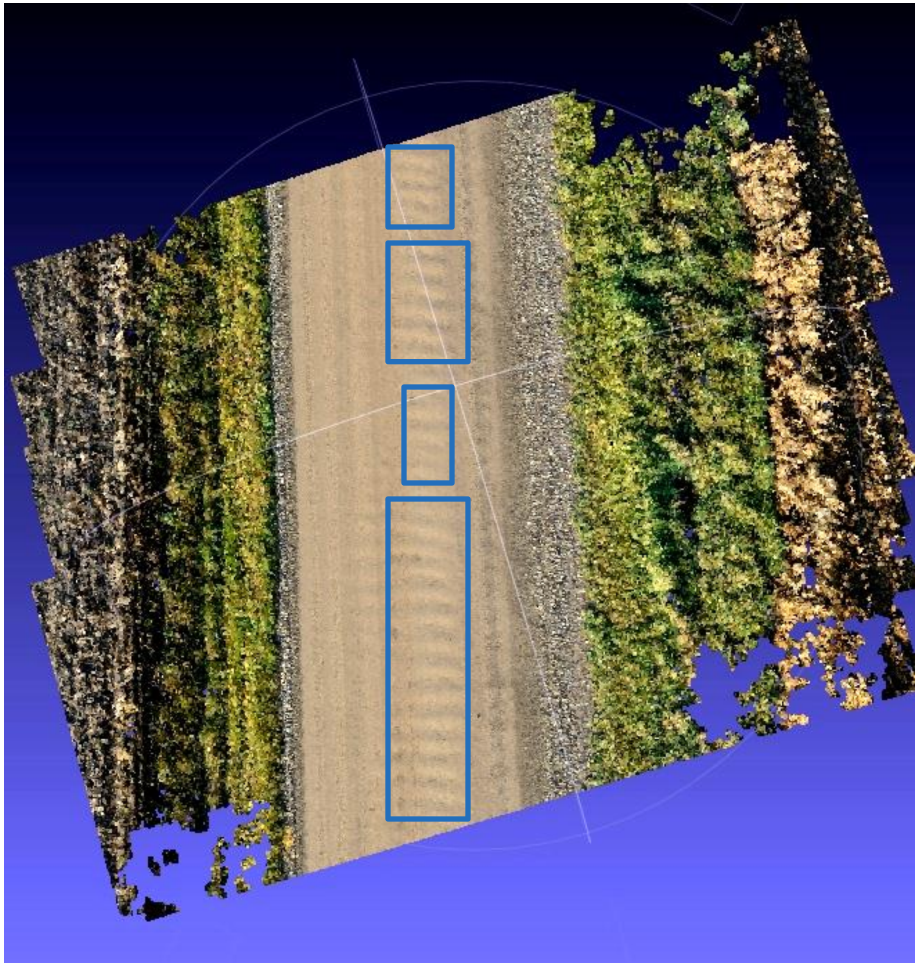


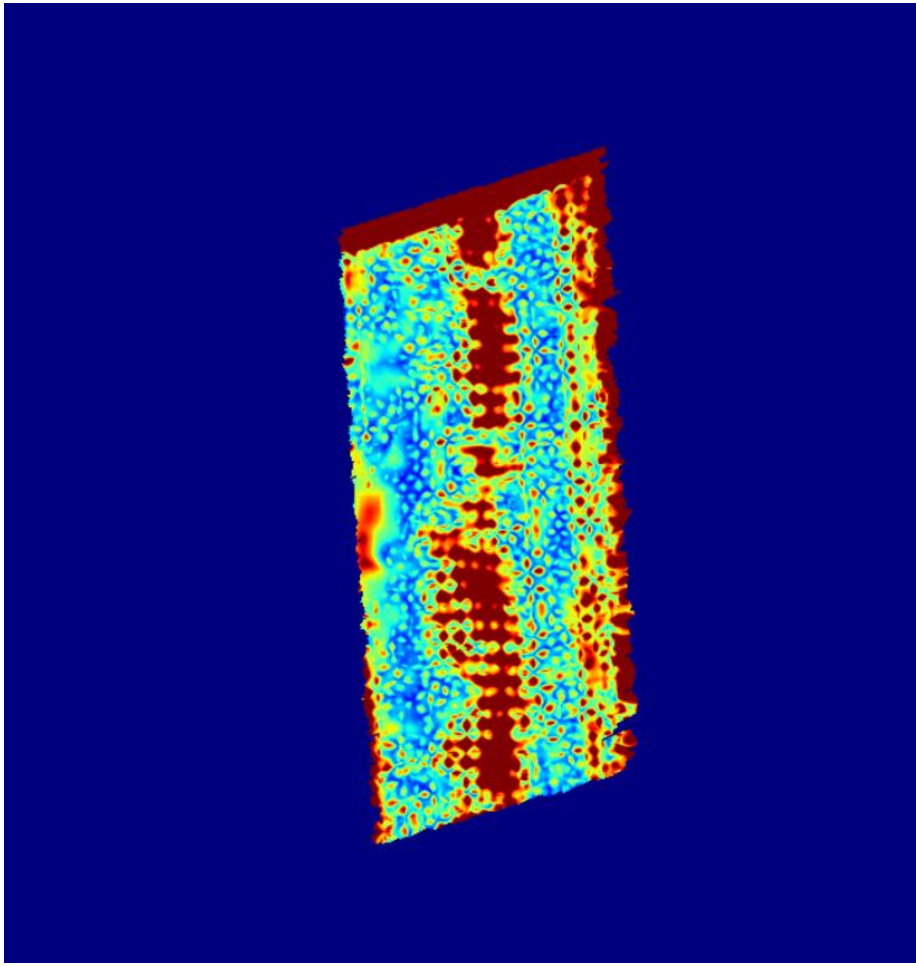
Identified circles



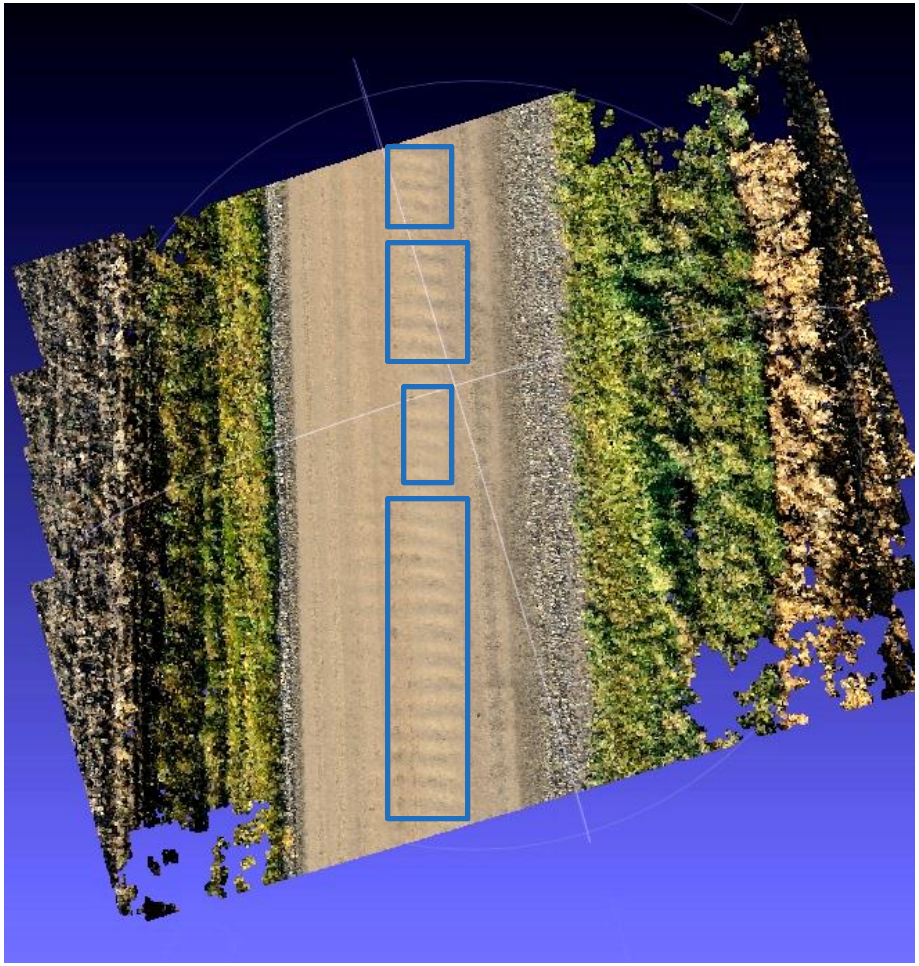
Note: Circles near edges ignored.

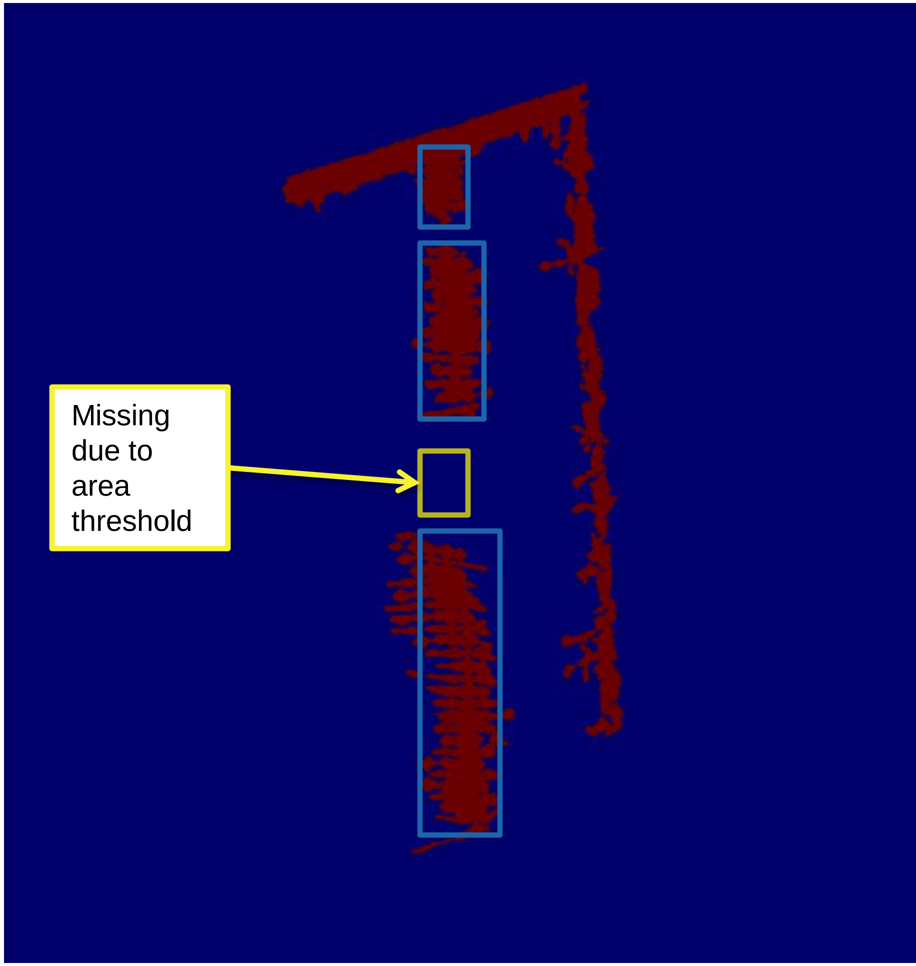
Distress Detection – Washboarding





Distress Detection – Washboarding





Ground Truth Corrugation Area:
19.6 sq. m

Computed Corrugation Area:
17.2 sq. m

Algorithm Performance Summary

- In summary, the following data collection parameters will meet all system performance requirements:
  - 24M-36M-pixel sensor
  - 50mm, f/1.4 lens set at f/2.8
  - 1/250s (maximum) shutter speed (shorter is better)
  - ISO set as needed for proper exposure given ambient lighting
  - Distance of 20m-30m from surface
  - 2m/s (maximum) forward speed
  - 2fps (minimum) image capture rate (obtained with a simple intervalometer)
  - 64GB high-speed storage medium
- Results from this system - User feedback: results appearing useful, implementation needed
  - The Asset Management Council of Michigan, Southeastern Michigan Council of Governments, Road Commission for Oakland County; sharing results with South Dakota DOT

Algorithm Performance Summary

- ## Pothole:

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

- ## Crown Damage:

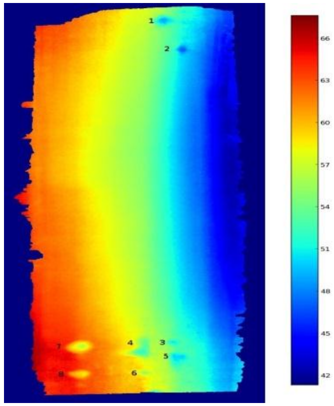
	Width (cm)	Crown A (cm)	Crown B (cm)	Grade A	Grade B	Min Grade	Damage
1	535	-8.1	10.9	-3.02%	4.07%	-3.02%	H
2	537	-7.4	11.5	-2.75%	4.28%	-2.75%	H
3	545	-7.5	12	-2.75%	4.40%	-2.75%	H
4	519	-7.1	13.1	-2.73%	5.04%	-2.73%	H
5	550	-7.3	12.9	-2.65%	4.69%	-2.65%	H
6	539	-7.5	13	-2.78%	4.82%	-2.78%	H
7	537	-6.4	13	-2.38%	4.84%	-2.38%	H
8	530	-6.1	12.6	-2.30%	4.75%	-2.30%	H
9	525	-5.2	12.6	-1.98%	4.80%	-1.98%	M
10	520	-7.2	11.7	-2.76%	4.50%	-2.76%	H

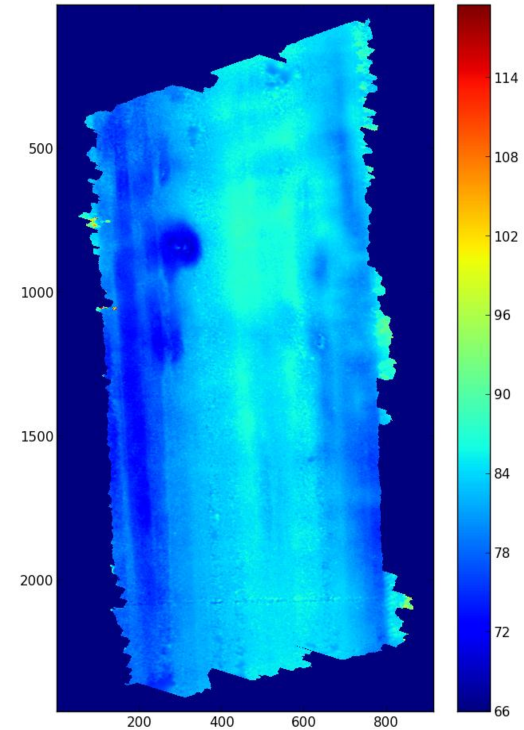
- ## Rut Detection:

Probability of Detection	Probability of False Alarm
67%	19%

- ## Corrugation Detection:

Probability of Detection	Probability of False Alarm
100%	38.5%

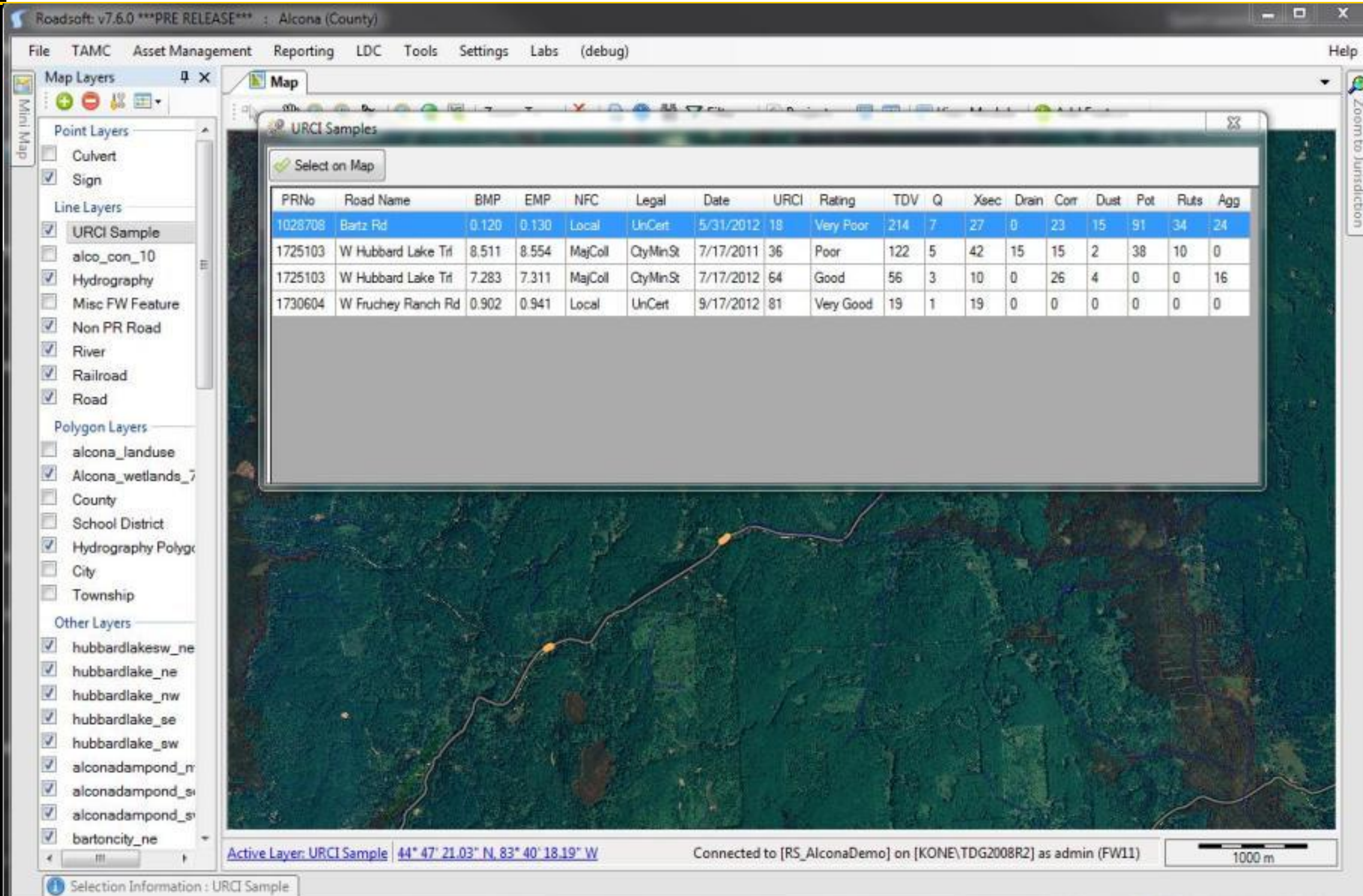




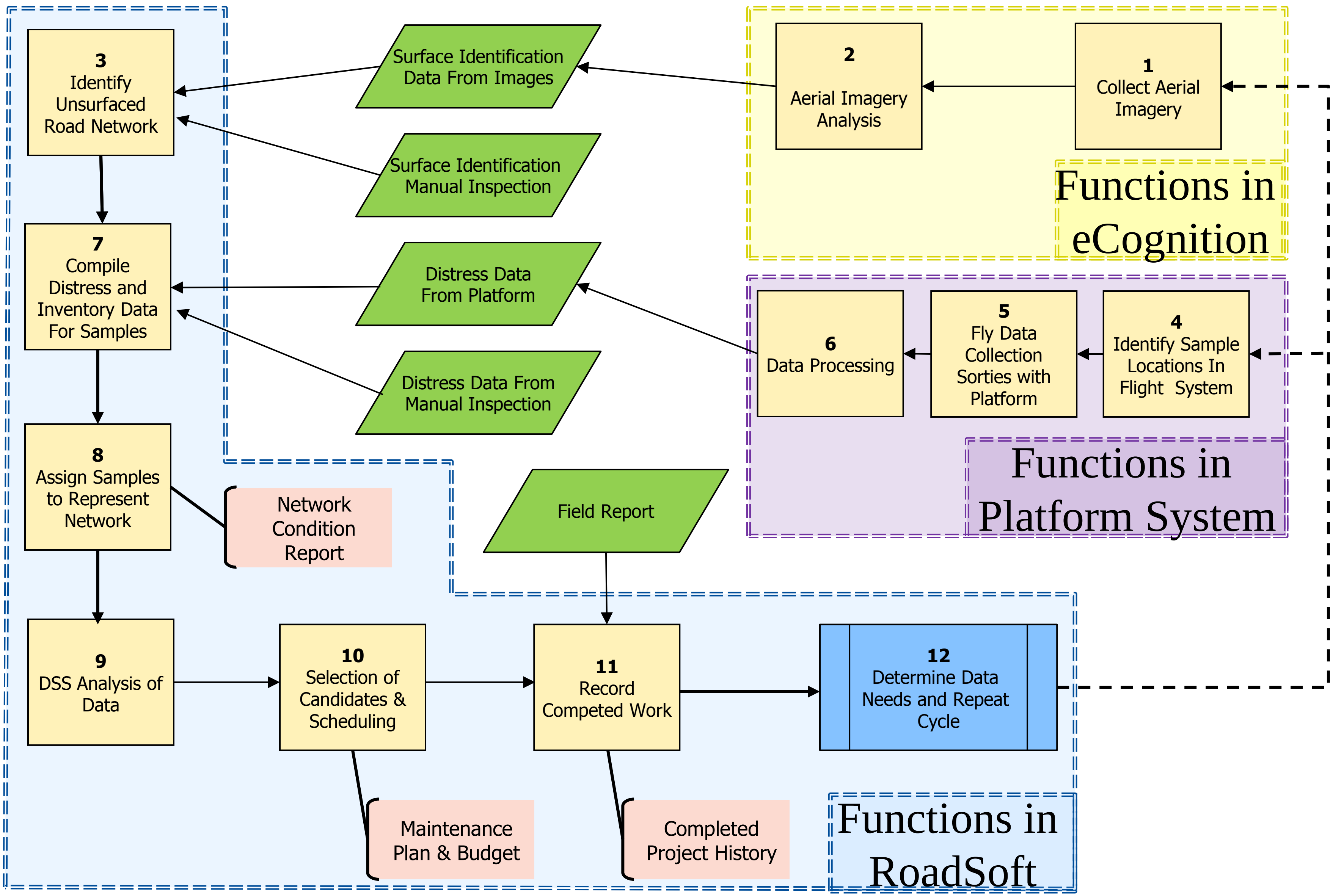
Aerial Sensor Performance

- Algorithm performance, and the ability to meet the stringent requirements on resolution, depends on the ability to collect data that has enough angular diversity to be able to reconstruct three dimensions from two dimensions.
  - As the distance from the ground increases, the solid angle that any object subtends decreases, and at some point, becomes too small for high-resolution reconstruction.
  - Data taken from an altitude of 500 feet do not meet the system requirements in resolution. That is, the reconstructed pixels have been found to be “too large”. This is due to the lack of sufficient angular diversity.
- Solutions:
  - More data are collected with the camera points at the same point on the ground, but at oblique (as well as nadir) views.
  - Several passes over the same location can be made, with the camera at different angles.
  - Much higher resolution sensors, with a wider-angle lens than the 200mm currently used, would allow data to be taken in a single pass.
- Use of a sensor at altitudes above 400 feet is not practical at this time, only sensors flown at altitudes below 100m will meet all the performance (i.e. resolution) and cost-effectiveness requirements.

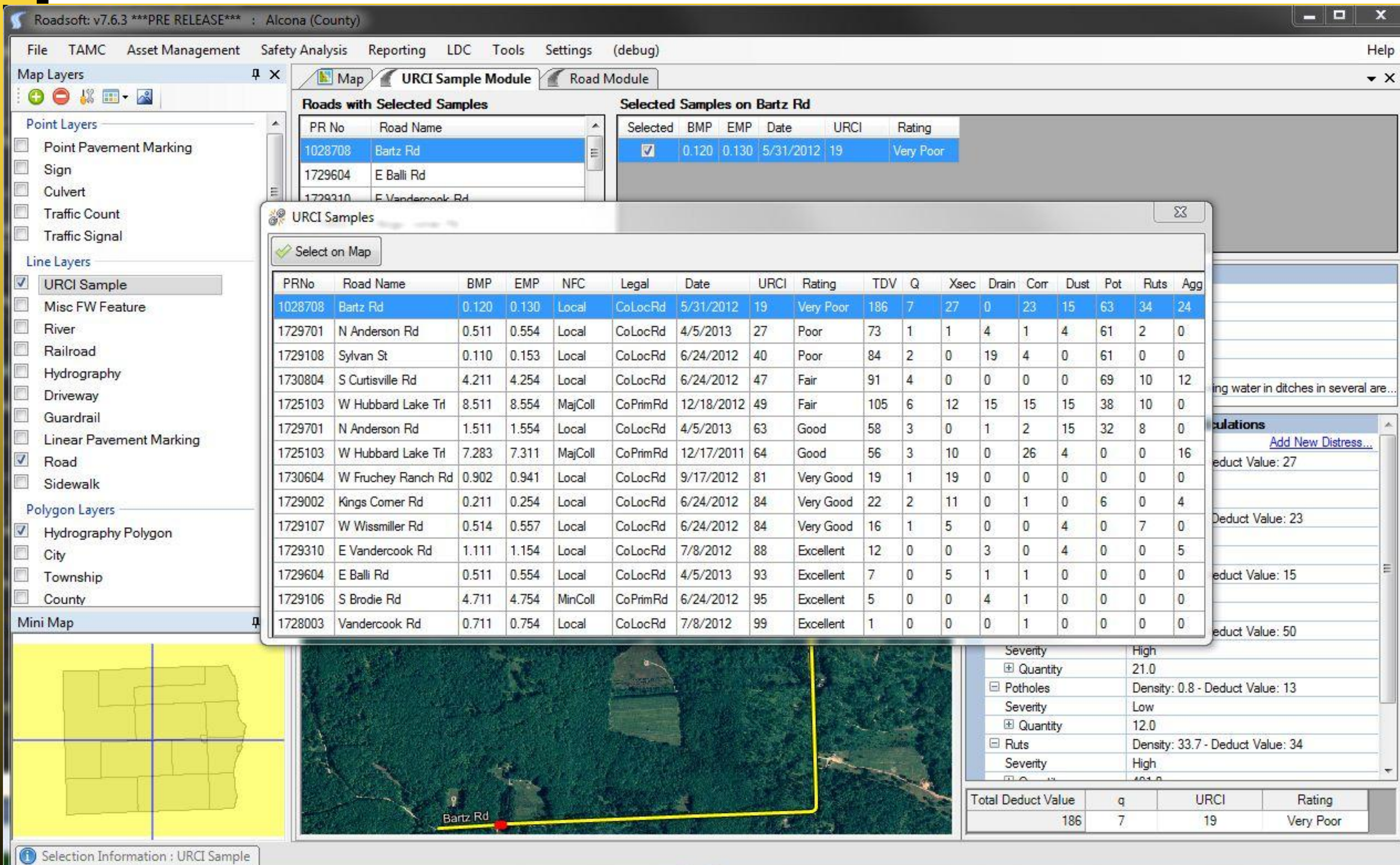
Analyzed data are integrated into RoadSoft GIS Decision Support System



Road Analysis Process Flow – RoadSoft DSS integration



DSS Ranking System



PR No	Road Name
1028708	Bartz Rd
1729604	E Balli Rd

Selected	BMP	EMP	Date	URCI	Rating
☑	0.120	0.130	5/31/2012	19	Very Poor

PRNo	Road Name	BMP	EMP	NFC	Legal	Date	URCI	Rating	TDV	Q	Xsec	Drain	Corr	Dust	Pot	Ruts	Agg
1028708	Bartz Rd	0.120	0.130	Local	CoLocRd	5/31/2012	19	Very Poor	186	7	27	0	23	15	63	34	24
1729701	N Anderson Rd	0.511	0.554	Local	CoLocRd	4/5/2013	27	Poor	73	1	1	4	1	4	61	2	0
1729108	Sylvan St	0.110	0.153	Local	CoLocRd	6/24/2012	40	Poor	84	2	0	19	4	0	61	0	0
1730804	S Curtisville Rd	4.211	4.254	Local	CoLocRd	6/24/2012	47	Fair	91	4	0	0	0	0	69	10	12
1725103	W Hubbard Lake Trl	8.511	8.554	MajColl	CoPrimRd	12/18/2012	49	Fair	105	6	12	15	15	15	38	10	0
1729701	N Anderson Rd	1.511	1.554	Local	CoLocRd	4/5/2013	63	Good	58	3	0	1	2	15	32	8	0
1725103	W Hubbard Lake Trl	7.283	7.311	MajColl	CoPrimRd	12/17/2011	64	Good	56	3	10	0	26	4	0	0	16
1730604	W Fruchey Ranch Rd	0.902	0.941	Local	CoLocRd	9/17/2012	81	Very Good	19	1	19	0	0	0	0	0	0
1729002	Kings Corner Rd	0.211	0.254	Local	CoLocRd	6/24/2012	84	Very Good	22	2	11	0	1	0	6	0	4
1729107	W Wissmiller Rd	0.514	0.557	Local	CoLocRd	6/24/2012	84	Very Good	16	1	5	0	0	4	0	7	0
1729310	E Vandercook Rd	1.111	1.154	Local	CoLocRd	7/8/2012	88	Excellent	12	0	0	3	0	4	0	0	5
1729604	E Balli Rd	0.511	0.554	Local	CoLocRd	4/5/2013	93	Excellent	7	0	5	1	1	0	0	0	0
1729106	S Brodie Rd	4.711	4.754	MinColl	CoPrimRd	6/24/2012	95	Excellent	5	0	0	4	1	0	0	0	0
1728003	Vandercook Rd	0.711	0.754	Local	CoLocRd	7/8/2012	99	Excellent	1	0	0	0	1	0	0	0	0

Total Deduct Value	q	URCI	Rating
186	7	19	Very Poor

Michigan Tech Research Institute

Costs – Manual Characterization

Rating Method	$/sample segment	$/Mile
Wyoming Manual URCI (Huntington 2013)	$80	$160*
Manual URCI Ground Truth Collection moderate distress	$100	$200*
Manual URCI Ground Truth Collection high distress	$140	$280*
Army Cold Regions Automated PCI (Cline et al. 2003)	$34.23	$66.10
Army Cold Regions Manual PCI – low total area (Cline et al. 2003)	$50.84	$101.68
UNH/FHWA: RSMS – high productivity estimate (Goodspeed 2011 2013)	NA	$33.65
UNH/FHWA: RSMS – low productivity estimate (Goodspeed 2011 2013)	NA	$65.65
Wyoming Modifications of the PASER Method (Huntington 2011 2013)	NA	$8.55
Michigan PASER Method (CRAM MDOT n.d.)	NA	$8.05

- Cost assumptions are described in detail in Deliverable 7-B that will be posted to the project website once approved.

Costs – Remote Sensing

- UAS (UAV, high-resolution camera, and good-quality lens):
  - Cost per mile rated $30,590/yr/1575 mi/yr = $19.42/mi rated.
  - HOWEVER…two 100-foot measured segments represent one mile of road, so 5,280 ft/200ft is 26.4. Therefore each mile of measured road represents a road network 26 times larger.
  - Therefore cost is $0.74 per mile, in addition to the cost of vehicle use ($0.55/mi)
    - 8 hours/day, 3 days/week, 21 week season to collect 300 road-miles of data segments
- Manned Fixed Wing:
  - Cost per mile rated $54.47 per mile assessed for up to five sites per mile
  - $10.26 per mile (generous assumption of continuous data collection)
  - $16,340 for same type of analysis as listed above
- Caution must be made for cost comparisons between remote sensing and manual characterization of road conditions due to the resolutions of the outputs; centimeter-by-centimeter analysis of entire road segments is essentially impossible via manual inspection.

Administrative Issues – FAA regulations

- It should be noted that current (as of October 2013) FAA regulations do not adequately address UAS operations for private entities.
  – The FAA document 14 CFR Part 91 (http://www.faa.gov/about/initiatives/uas/reg/media/frnotice_uas.pdf) specifically excludes individuals or companies flying model aircraft for business (commercial) purposes.
  – For public entities (such as the USDOT), the process of operating a UAS involves obtaining a Certificate of Authorization (COA) for a particular mission. Each mission must have its own COA, which effectively prevents the current use of UASs for arbitrary unpaved road assessment. Thus, under current FAA guidelines, there is no way to deploy an unmanned system for this purpose.
  – However, some agencies with COAs have been able to get them reapproved within relatively short time periods (< 1 month).
  – New Dec. 2013 5-year FAA UAV integration RoadMap
- This may change by late 2015, when the FAA has to have established regulations dealing with Unmanned Aerial Systems (UASs) in the National Airspace System (NAS).
- New regulations for small UAVs (SUAS) due by Nov. 2014 – “file & fly” for under 55 lbs SUAS?
- More practical deployment starting in 2015 - commercially

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