Michigan Tech Research Institute

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Road Surface Identification Using AI Models on Remote Sensing Data

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Transportation Asset Management Council 2023 Conference

September 26, 2023

https://www.mtu.edu/mtri/
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Center for Technology & Training

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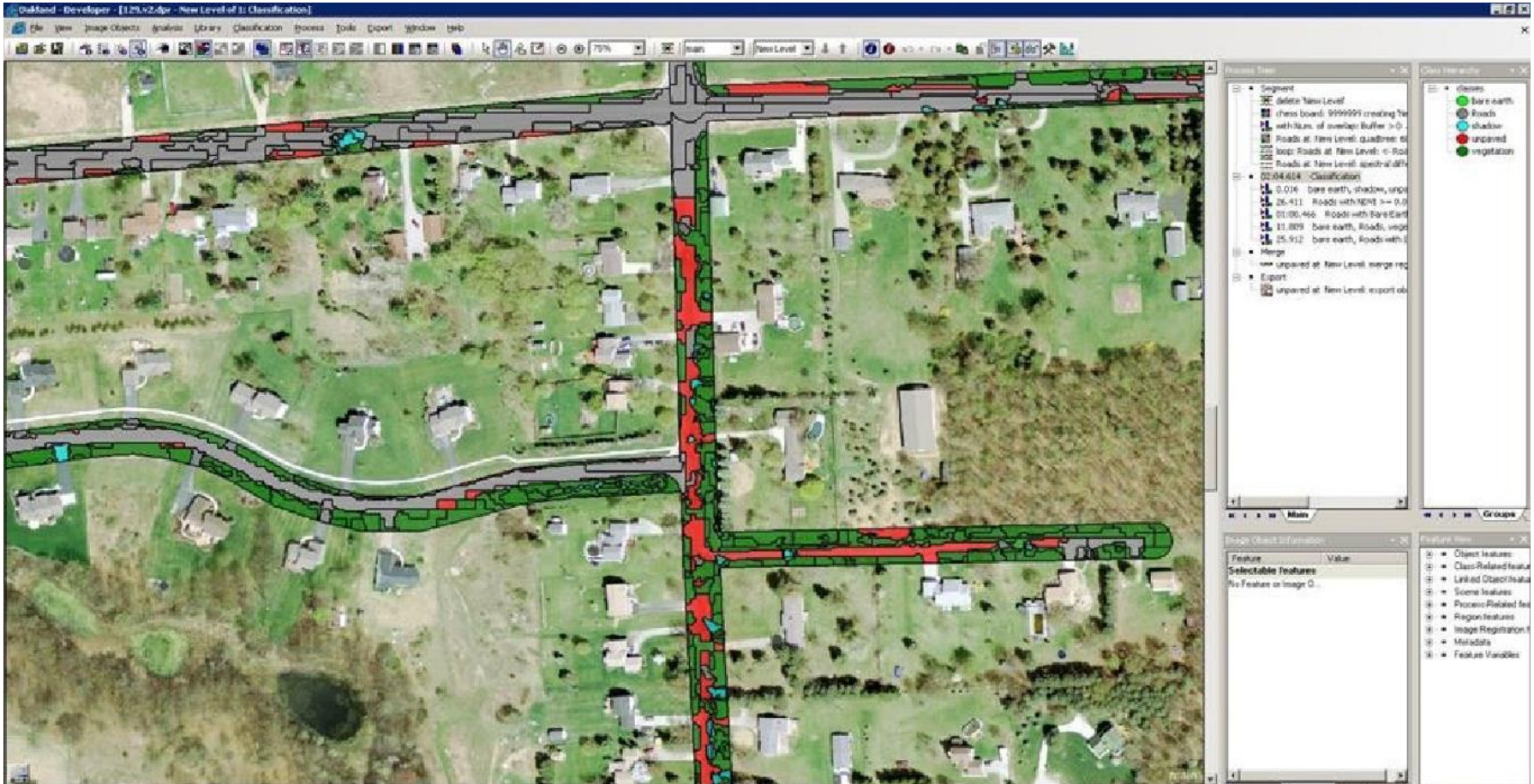
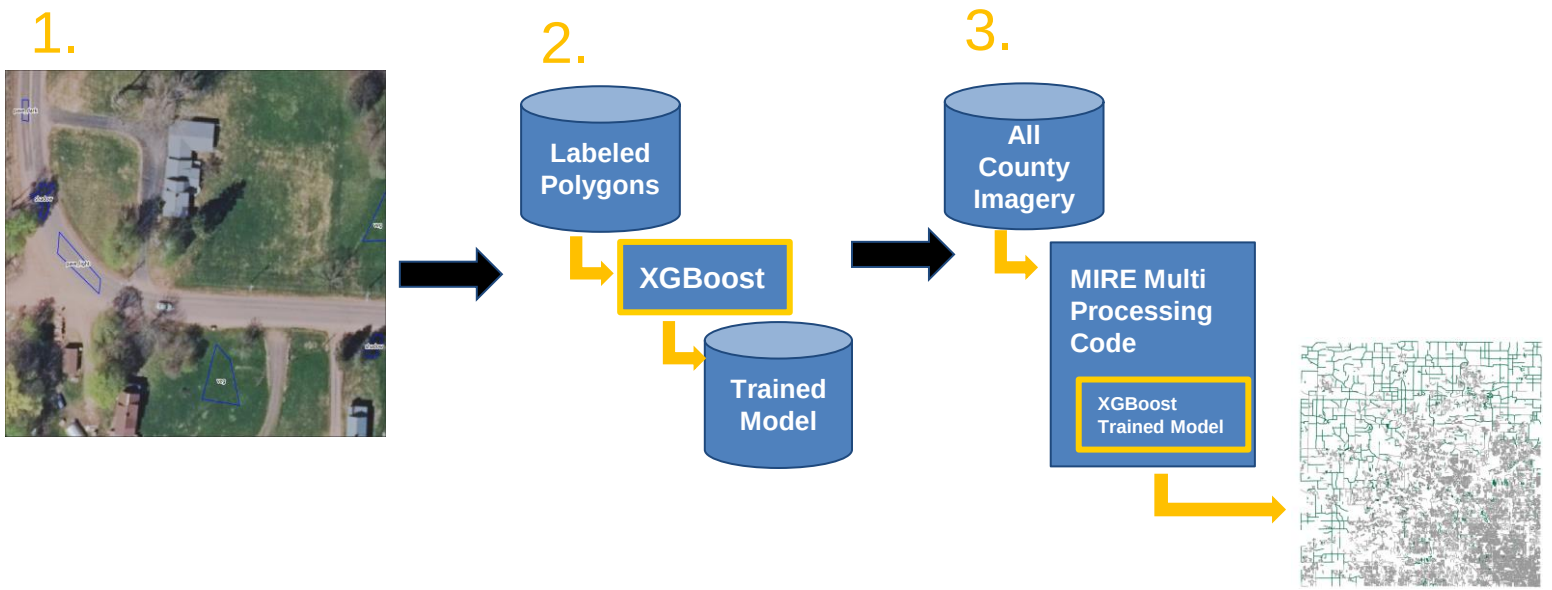
Original method: Brooks et al. 2017

- Brooks, C.N., Dean, D.B., Dobson, R.J., Roussi, C., Carter, J.F., VanderWoude, A.J., Colling, T. and Banach, D.M., 2017. **Identification of unpaved roads in a regional road network using remote sensing.** *Photogrammetric Engineering & Remote Sensing*, *83*(5), pp.377-383.

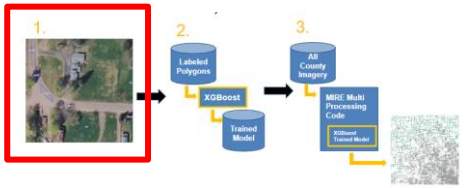


Road Surface Identification through AI Models - Workflow

1. Creating training data (polygons labelled as asphalt, concrete, unpaved, etc) for county based on available imagery
2. Create a pixel classifier model using generated training data and algorithm
3. Run MIREMultiProcess algorithm to generate Geopackage output of roads (can be exported to Shapefiles and File Geodatabases as well)

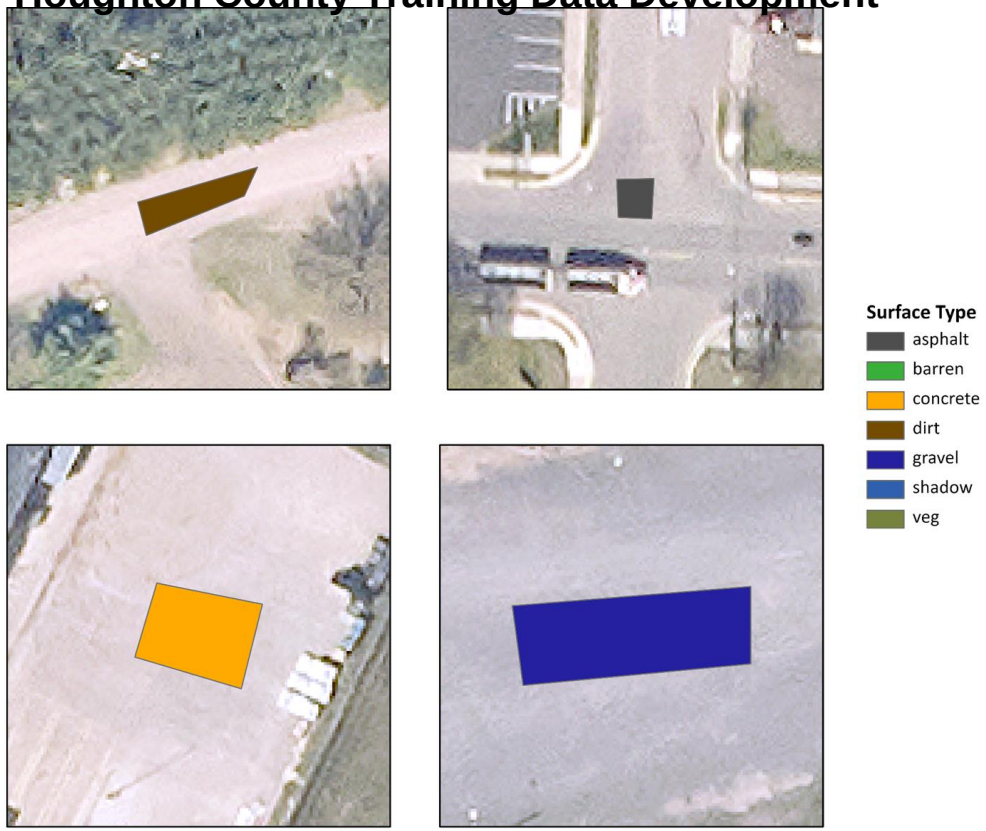


Developing Training Data

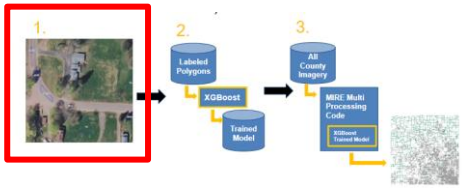


- Each county had between 40-60 training polygons built for each class using State imagery and Google Streetview

Houghton County Training Data Development

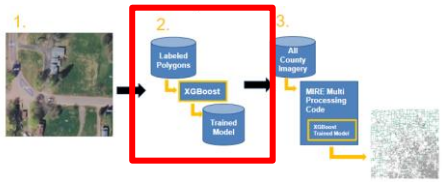


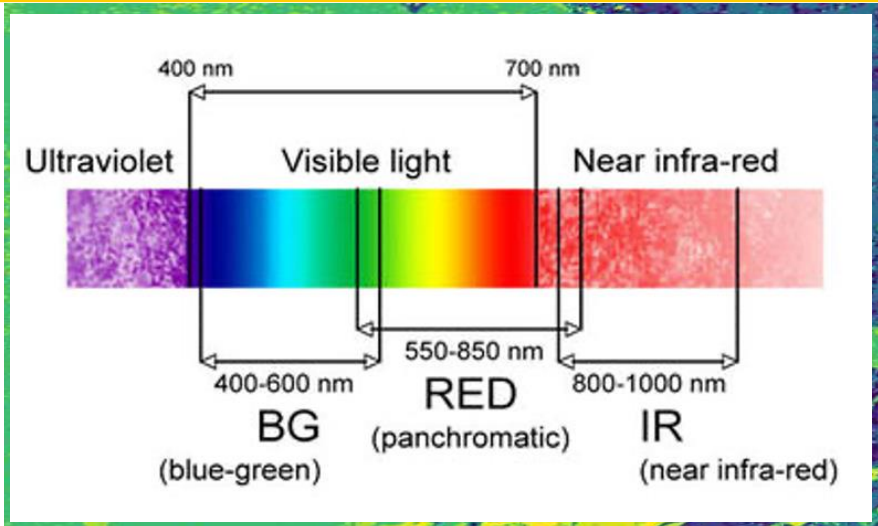
Field work- Ground truth in Kalamazoo Co, Michigan



- Went out to collect additional ground truth data for Kalamazoo county in July (similar work done for Gogebic/Ontonagon)
- Randomly selected roads to attribute as paveTruth= Yes (paved) or No (unpaved)
- Sealcoat = paved (left)
- Loose gravel= unpaved (right)

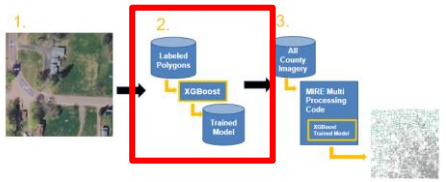
Pixel Classifier



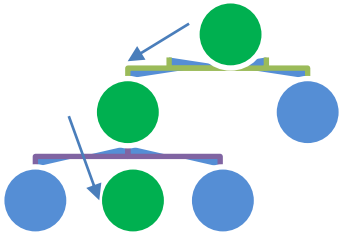


Harsen's Island – Land cover classification map created using XGBoost

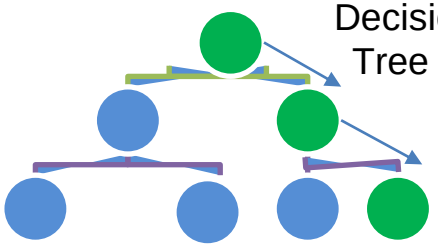
AI Random Forest Model Pixel Classifier



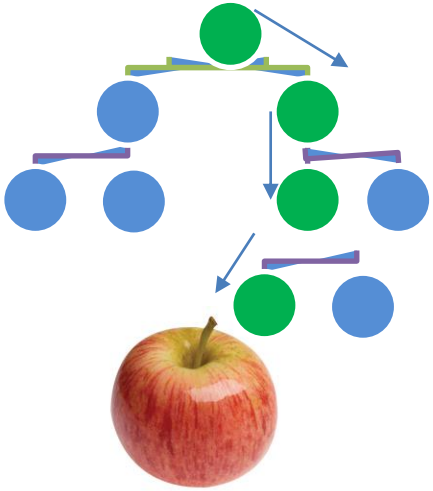
Decision Tree 1



Decision Tree 2

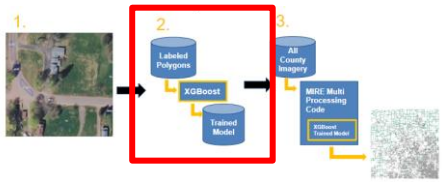


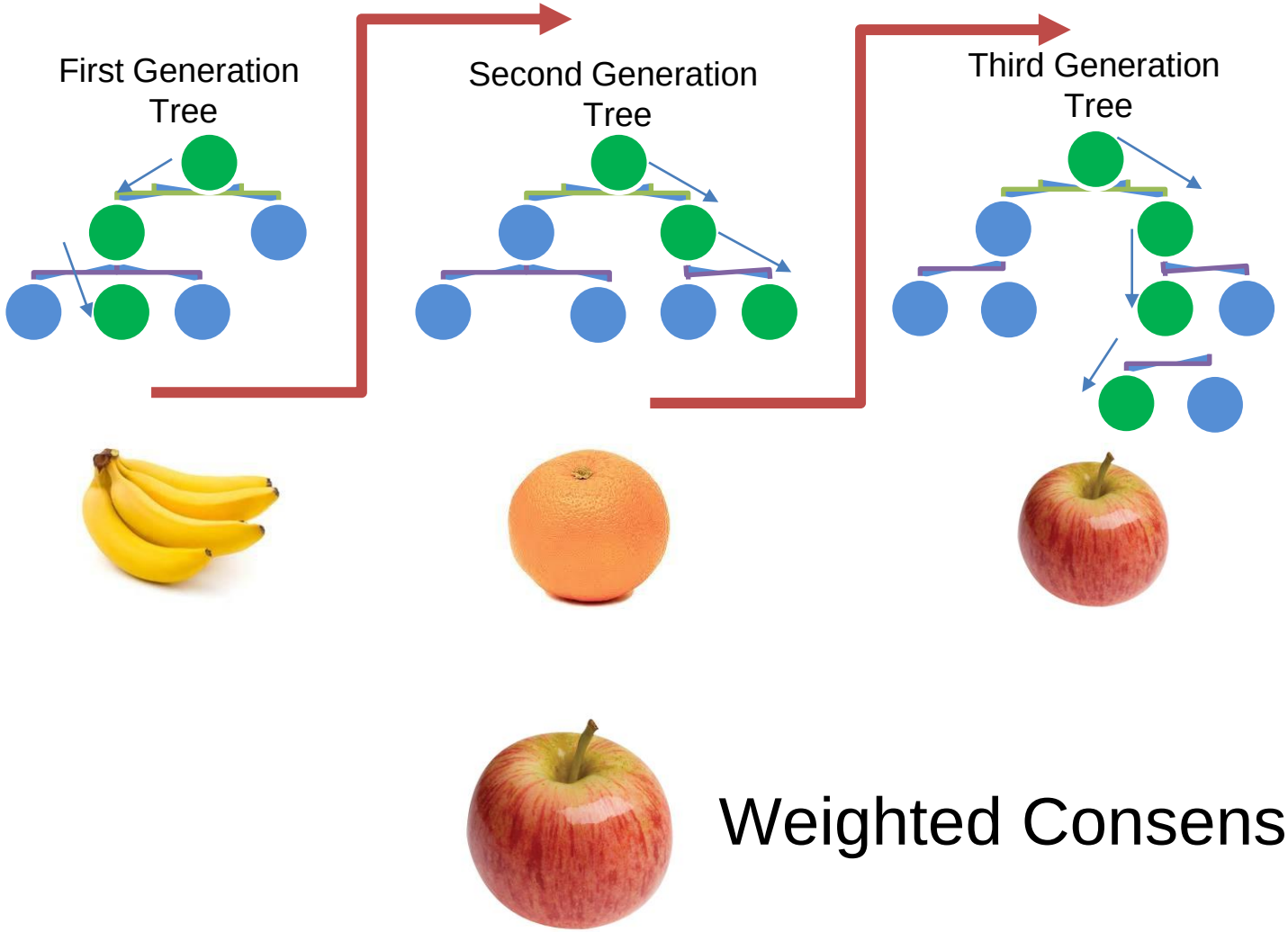
Decision Tree 3



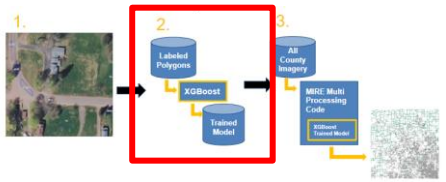
Consensus Voting

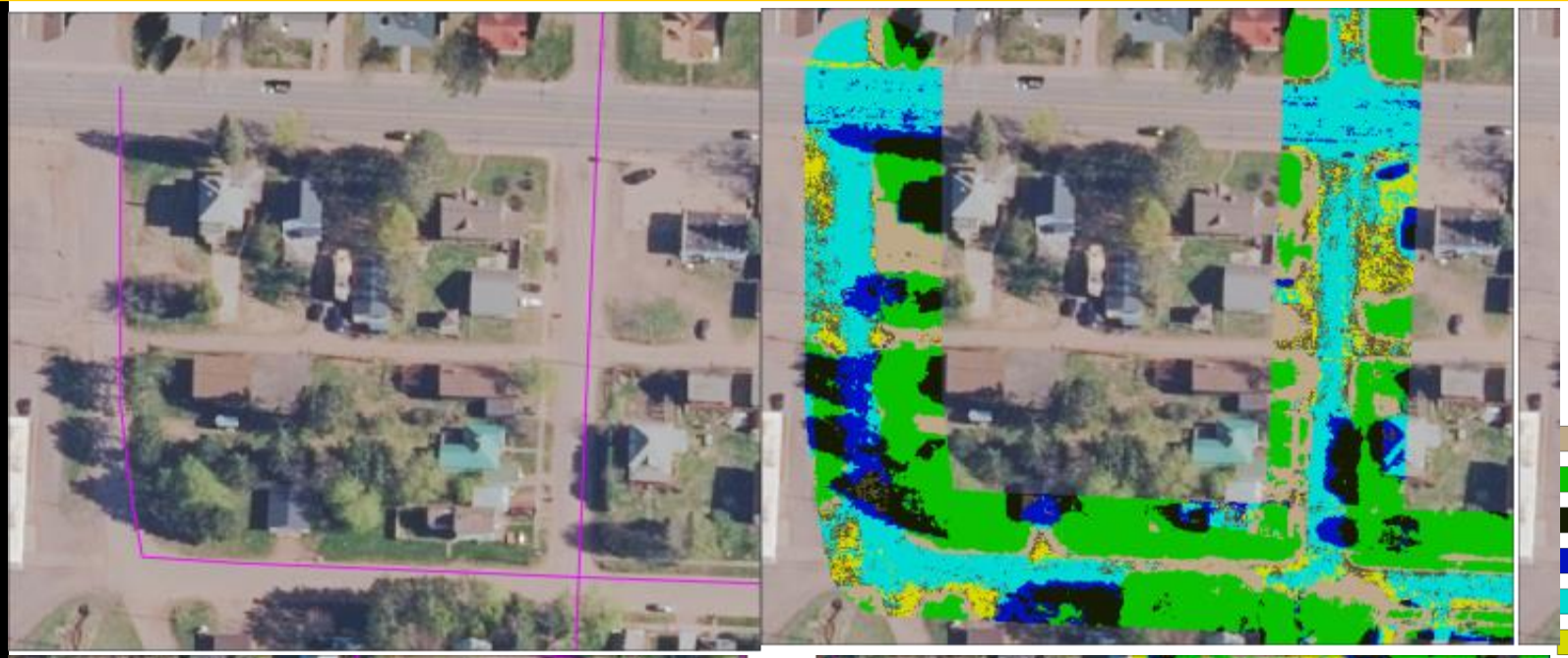
XG Boost Pixel Classifier

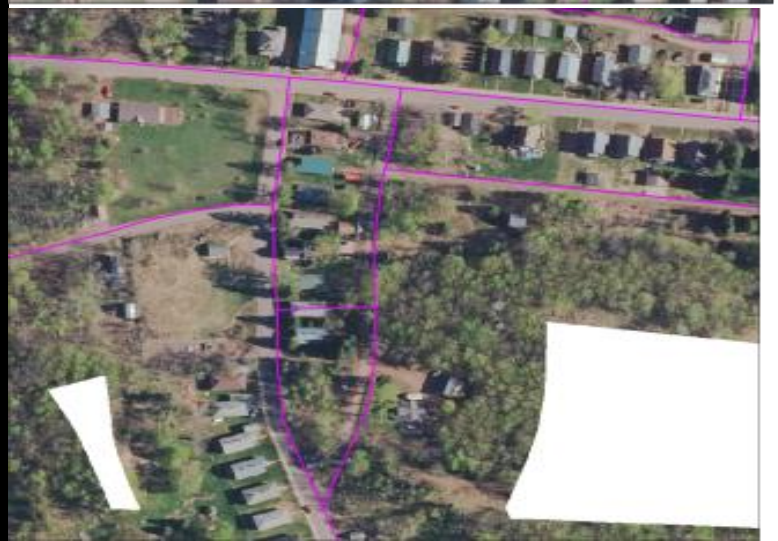


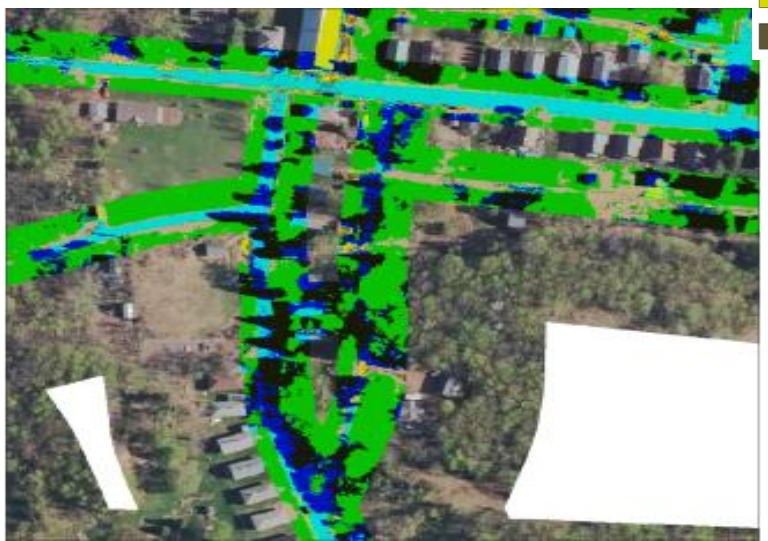


Pixel Classification – XG Boost Results / Gogebic



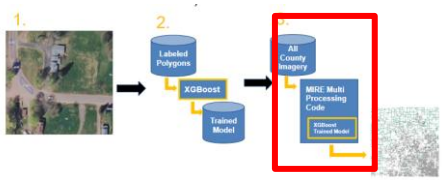






- Barren
- Vegetated
- Shadow
- Dark Pavement
- Light Pavement
- Gravel Road
- Dirt Road

MIRE Multi-Processing Code

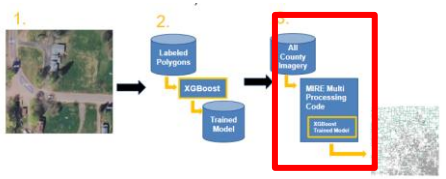


- Code analyzes pixel counts/ratios to determine whether a road is paved or unpaved.

- Additionally, the code calculates the following attributes for each road feature
  - Average road offset from database digitized feature
  - For paved roads, a determination of whether the road is concrete or asphalt as well as statistics indicating algorithmic confidence in that declaration

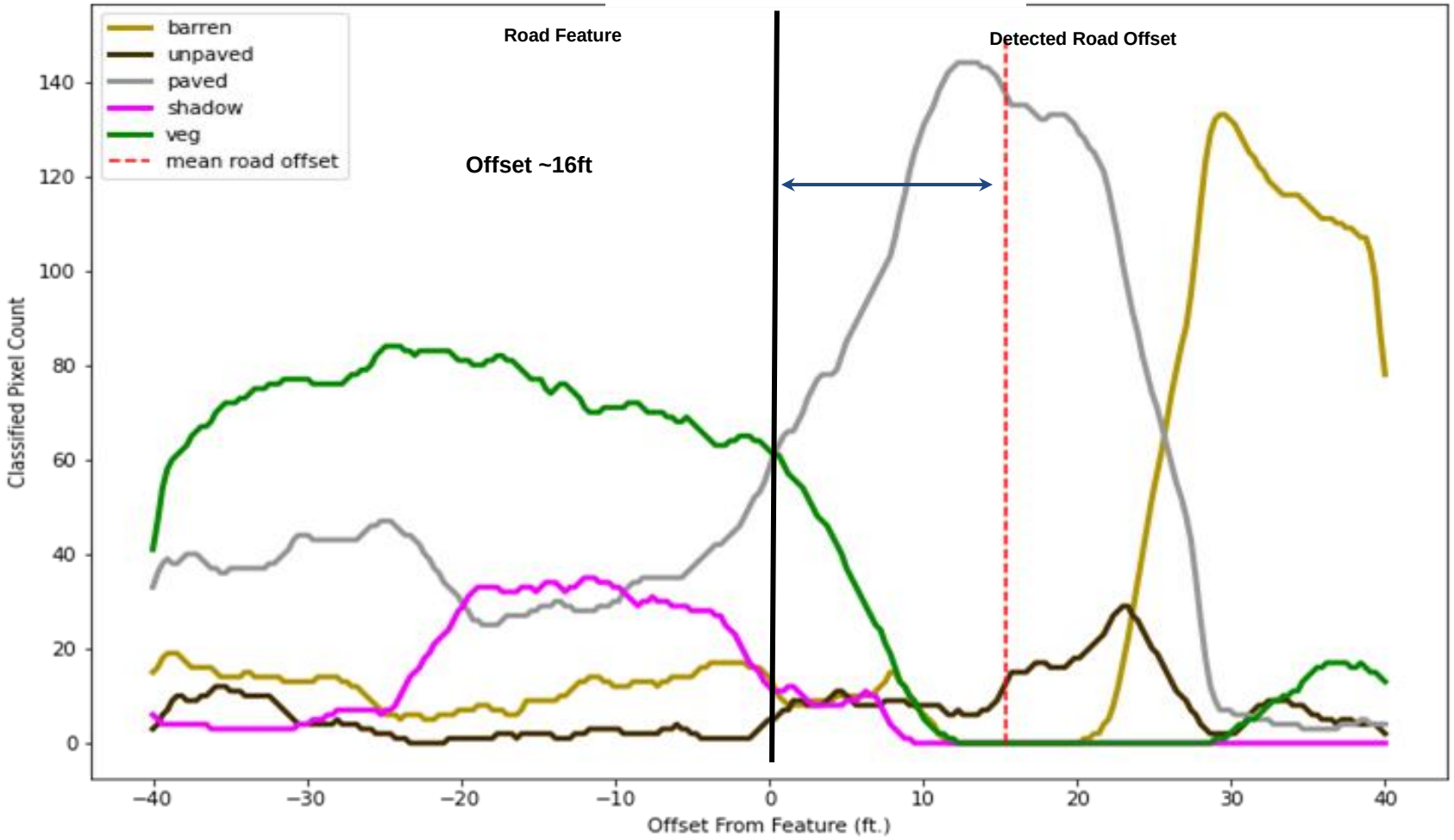
These attribute calculations are discussed on the following slides

Road Alignment

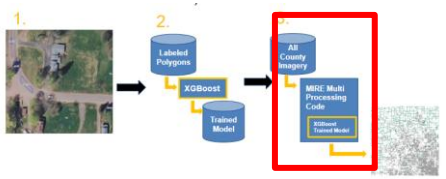


Pixel Counts vs. Distance from Road Feature

Left: Gogebic Road ID 327011 **ID 326826**



Road Alignment Examples



Oakland County
IDs: 105566 and 105551
Lexington Blvd and Mount Vernon Blvd
.17 and .17 Miles
Alignment Offset: 18.58ft and -27.72ft
NFC: 7 (Local Roads)
Urban Roads with Greenspace in the Middle

Ontonagon County
ID: 278807
Old M 35 Rd
.52 Miles
Alignment Offset: 40ft
NFC: 7 (Local Road)
Offshoot from Highway

Gogebic County
ID: 328185
Burt St
.24 Miles
Alignment Offset: 40ft
NFC: 7 (Local Road)
Rural Road outside Ramsay

0 0.25 Km

0 0.25 Miles

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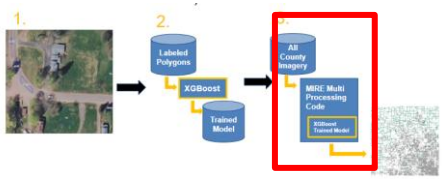
Road Alignment Examples



Oakland County
IDs: 108085 and 108716
N Altadena and N Gainsborough
.14 and .14 Miles
Alignment Offset: -0.6ft and -0.9ft
NFC: 7 (Local Roads)
Detroit Suburb

Ontonagon County
ID: 278593
107th Engineers Memorial Highway
.16 Miles
Alignment Offset: -3.46ft
NFC: 7 (Local Road)
Bridge over Big Iron River

Gogebic County
ID: 326934
Peters St
.07 Miles
Alignment Offset: -3.78ft
NFC: 7 (Local Road)
Suburb in Wakefield

0 0.1 Km
0 0.1 Miles

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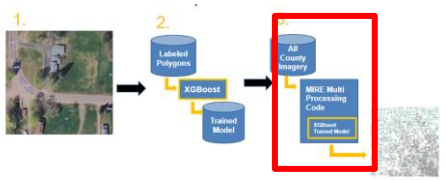
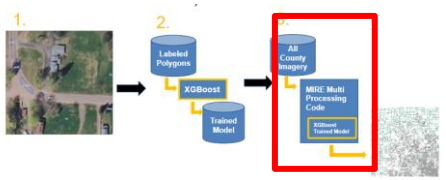
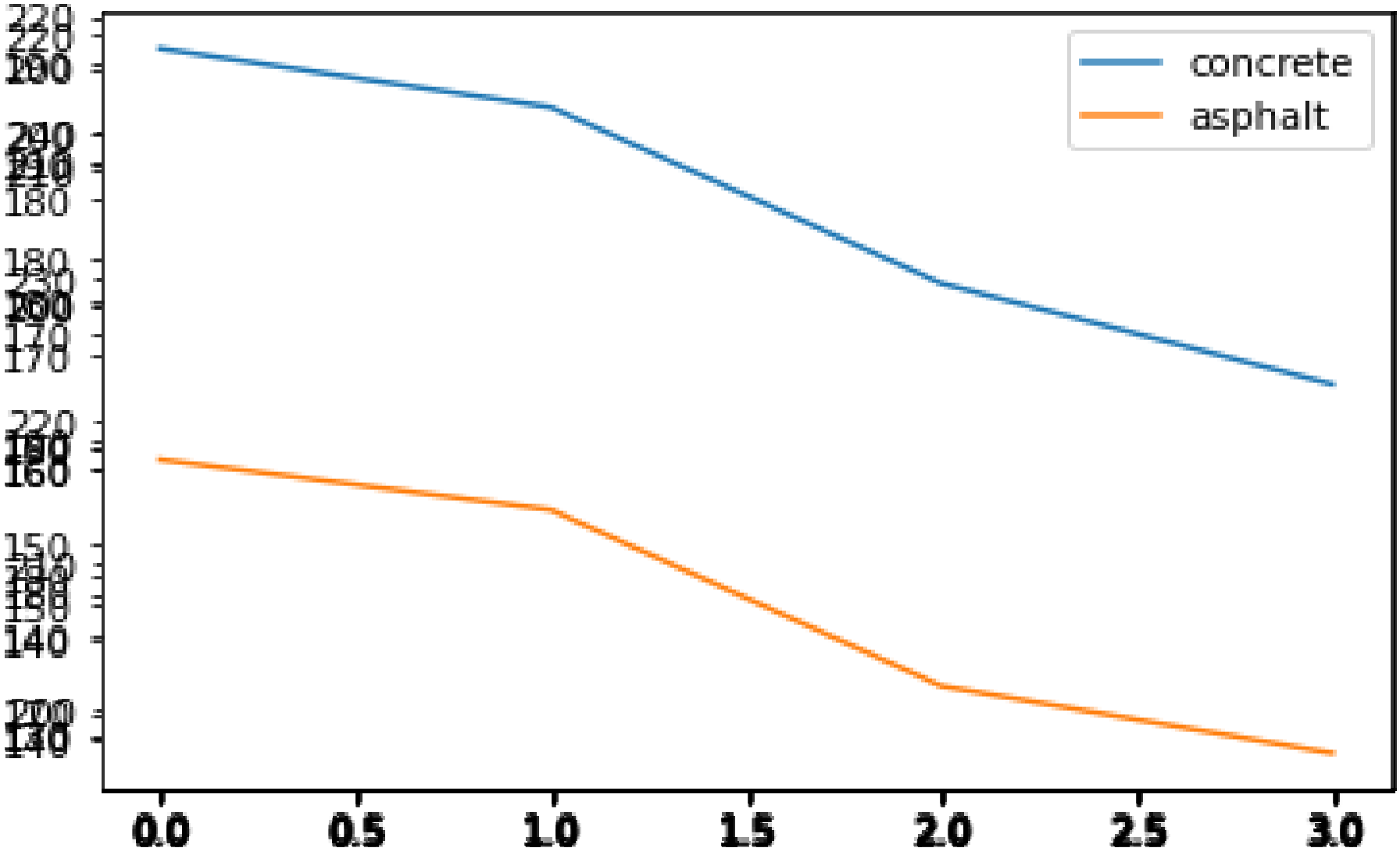
Determining Asphalt vs. Concrete - Initial Result

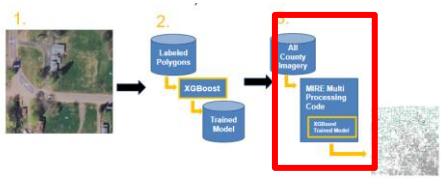


Asphalt vs. Concrete Classification

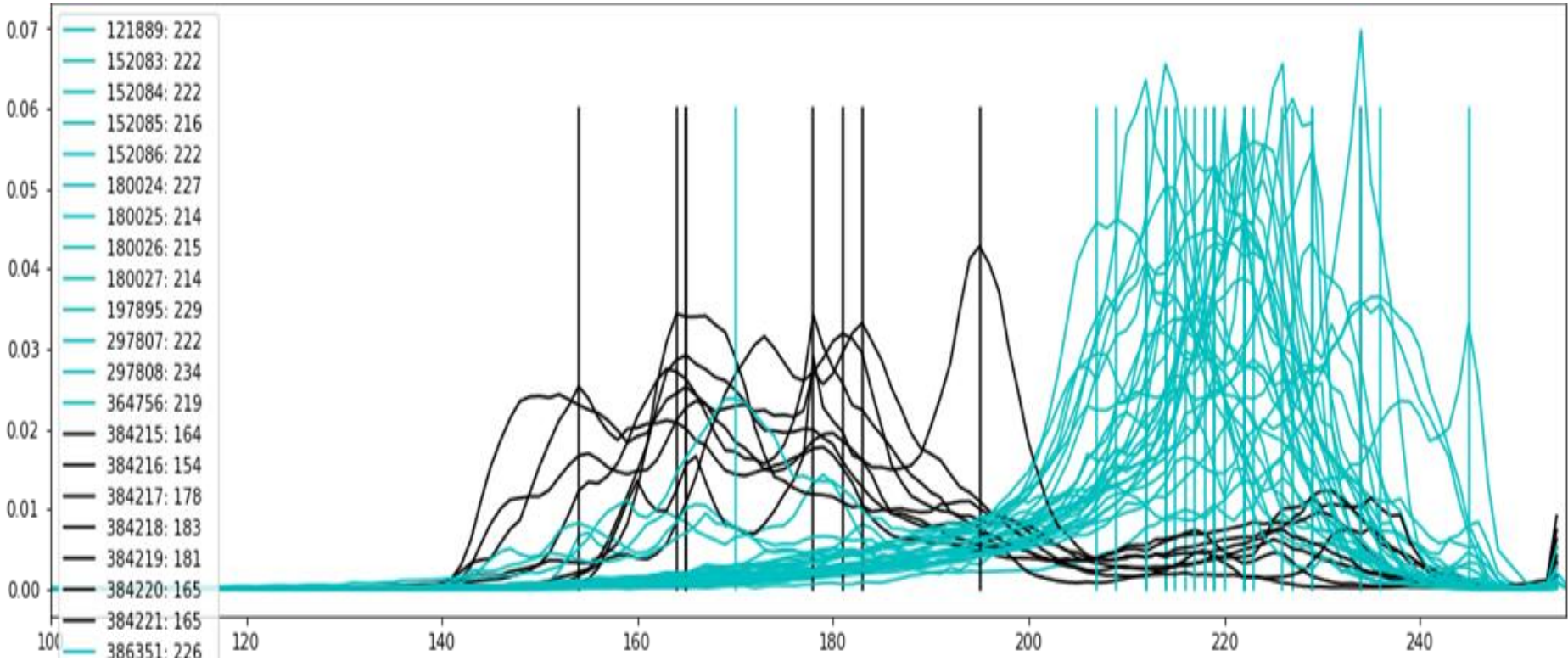




Asphalt vs. Concrete Classification

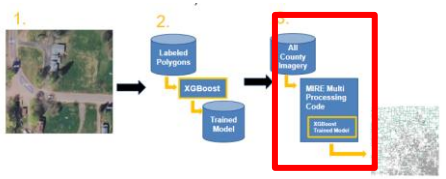


- Instead of classifying individual pixels, we have transitioned to classifying the distribution of the red channel over all pixels found along a road segment



- When looking at average distributions over entire counties, we start to see differences

Asphalt vs. Concrete Distribution Classification Results



- (old) indicates the pixel class prevalence was used to classify asphalt vs concrete.
- (new) indicates the brightness distribution was used to classify asphalt vs concrete.
- Overall significant improvement to these stats

	Monroe (old)	Oakland (old)
Precision Asphalt	94.7%	77.4%
Recall Asphalt	92.6%	94.4%
F1 Asphalt	93.6%	85.1%
Precision Concrete	43.0%	60.5%
Recall Concrete	51.8%	23.6%
F1 Concrete	47.0%	34.0%

Classification Statistics Used: Precision, Recall, and F1 Scores

Our county-wide metrics include 3 summary statistics for both paved and unpaved classes and then concrete vs. asphalt

- ***Precision*** – If a road is given a particular label, what is the probability the label is correct?
  - Categorizes prevalence of Type I errors (i.e. false positives)
- ***Recall*** – If a road was supposed to be labeled X, what is the probability the classifier found the road?
  - Categorizes prevalence of Type II errors (i.e. false negatives)
- ***F1 Score*** – The harmonic mean of Precision and Recall
  - 2* (Precision * Recall) / (Precision + Recall)

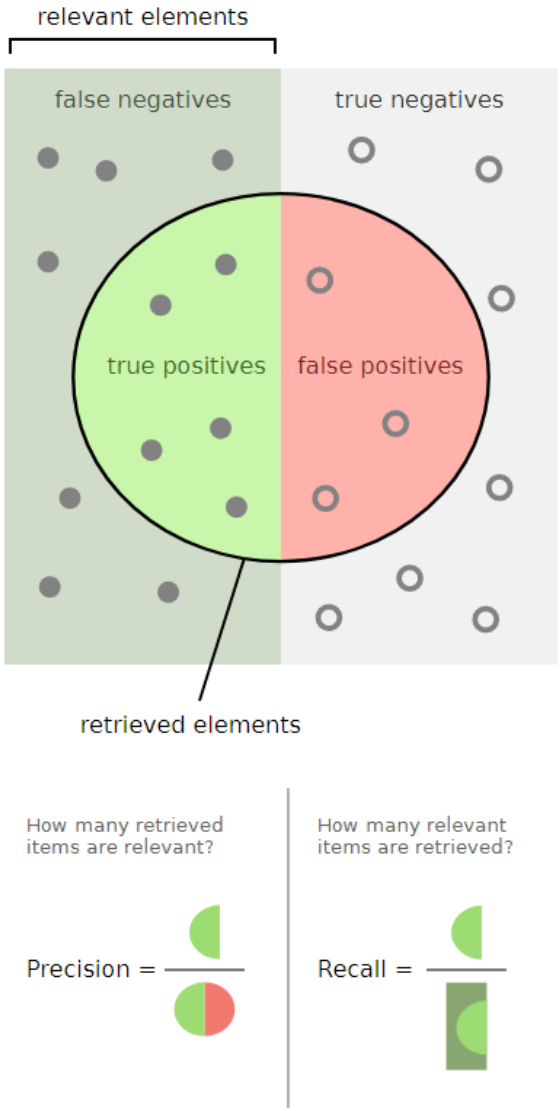
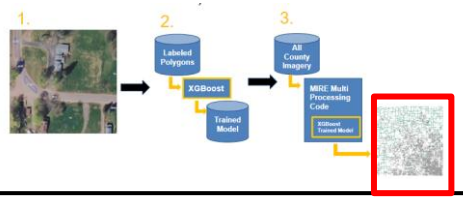


Image By Walber - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=36926283

Final Output - File Geodatabase



- File geodatabase contains original MIRE fields with MTRI added fields:
  - IsPaved, PaveType, PaveType_combined, QualWarnings, AlignmentOffset, ClassMatrixTypeUvP, ClassMatrixTypeAvC, AsphaltProbability
- With ESRI-formatted metadata:

Gogebic County

Tags Gogebic County, Michigan, roads, unpaved, gravel, dirt, surface type, model inventory road element, Michigan Department of Transportation, Michigan Tech Research Institute, Center for Technology and Training, MIRE, machine learning, XGBoost

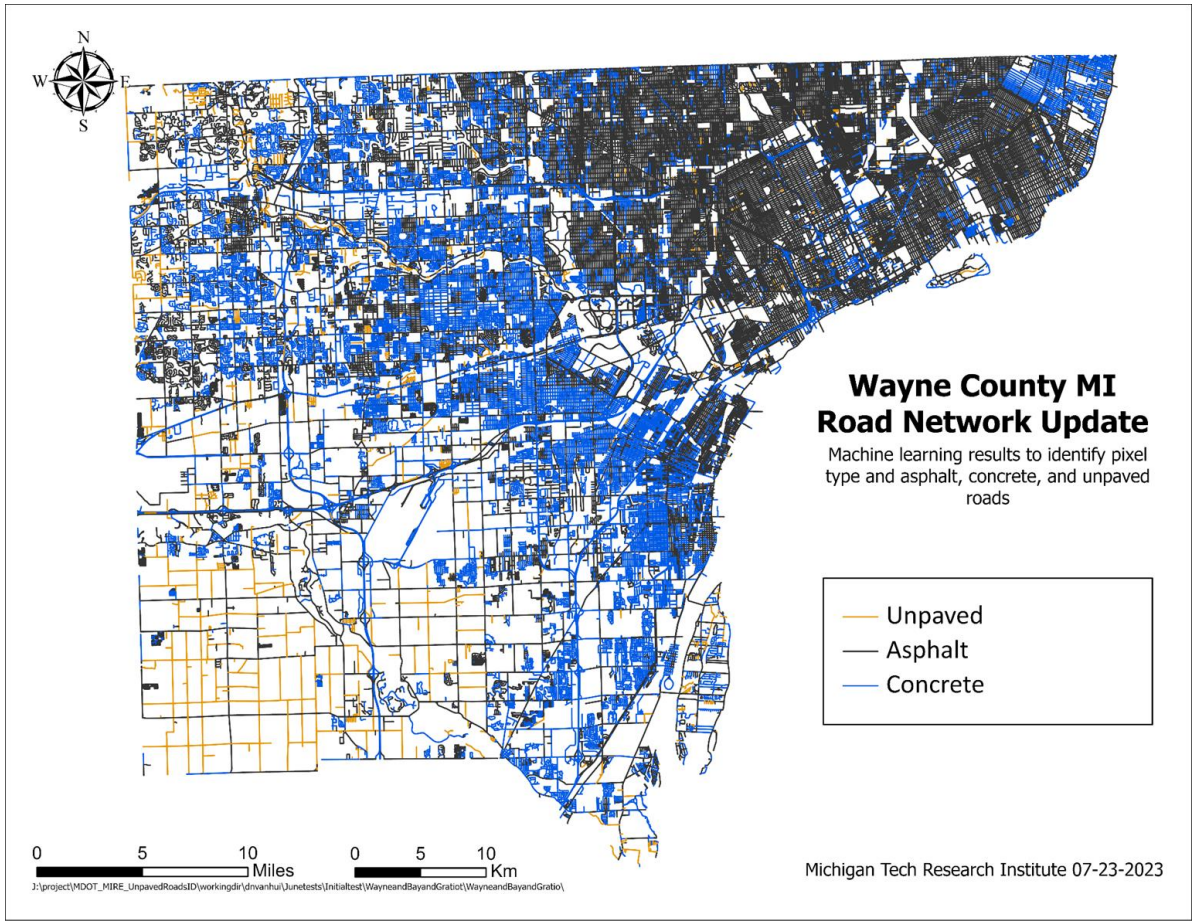
Summary

Segmented roads layer for Gogebic County, MI using the RoadSoft segments, with paved vs. unpaved surface type and asphalt vs. concrete status identified using high-resolution aerial photography from the State of Michigan and image analysis methods developed by MTRI to help MDOT meet the requirement to have Model Inventory Road Element (MIRE) Fundamental Data Elements (FDEs) features available for local agency owned roads. The machine learning methods utilized have been updated in 2022-2023 and focus on XGBoost.

Description

The geometry of this dataset is the RoadSoft version of the Michigan Framework Roads Layer (v23), with additional attributes that were assigned by MTRI using automated image analysis methods. These attributes include an updated "IsPaved" field, along with several other fields that were derived from the machine learning decision-making process. In brief, the automated process 1) opens up high resolution 4-band aerial imagery within a user-defined buffer around the road feature centerline, 2) adds additional imagery indices derived from the 4 bands, 3) classifies all the pixels within the buffered area into classes (barren, vegetated, shadow, dirt, gravel, concrete, and asphalt) using a pre-trained classification model, 4) aggregates class pixel counts by distance to the feature centerline, 5) computes the average road offset from the centerline to focus analysis, 6) extracted road pixel class counts are combined with the pre-existing road classifications to automatically train a new per road segment paved/unpaved classifier and asphalt/concrete classifier, 6) updates the "IsPaved" field with "Yes", "No". 7) uses the asphalt/concrete classifier to update the PaveType field for any segment classified as paved. Additional fields are also created including; "PaveType: "Asphalt", "Concrete", or empty if the road is unpaved. "PaveType_combined": contains "Unpaved", "Asphalt", or "Concrete". "QualWarnings": contains the letter "E" if the road contains relatively few road type pixels per mile indicating the road may not exist or is heavily obscured. "AlignmentOffset": contains the average offset in feet from the road centerline. These values are positive if the average alignment is to the right of the road feature and negative if to the left. Right and left are defined based on the geometry definition of the road segment, consistent with an observer standing at a vertex and looking towards the next vertex. "ClassMatrixTypeUvP": "TP" if the road is listed as paved and the classifier predicts paved, "FP" if the road is listed as unpaved and the classifier predicts unpaved, "TN" if the road is listed as unpaved and the classifier predicts unpaved, "FN" if the road is listed as paved and the classifier predicts unpaved, "NULL" if the road does not list a pavement type. "ClassMatrixTypeAvC": "TP" if the road is listed as asphalt and the classifier predicts asphalt, "FP" if the road is listed as concrete and the classifier predicts asphalt, "TN" if the road is listed as concrete and the classifier predicts concrete, "FN" if the road is listed as asphalt and the classifier predicts concrete, "NULL" if the road does not list a pavement type. "AsphaltProbability": The [0.0,1.0] probability that the classifier believes the road segment is asphalt, or empty if the road was classified as unpaved.

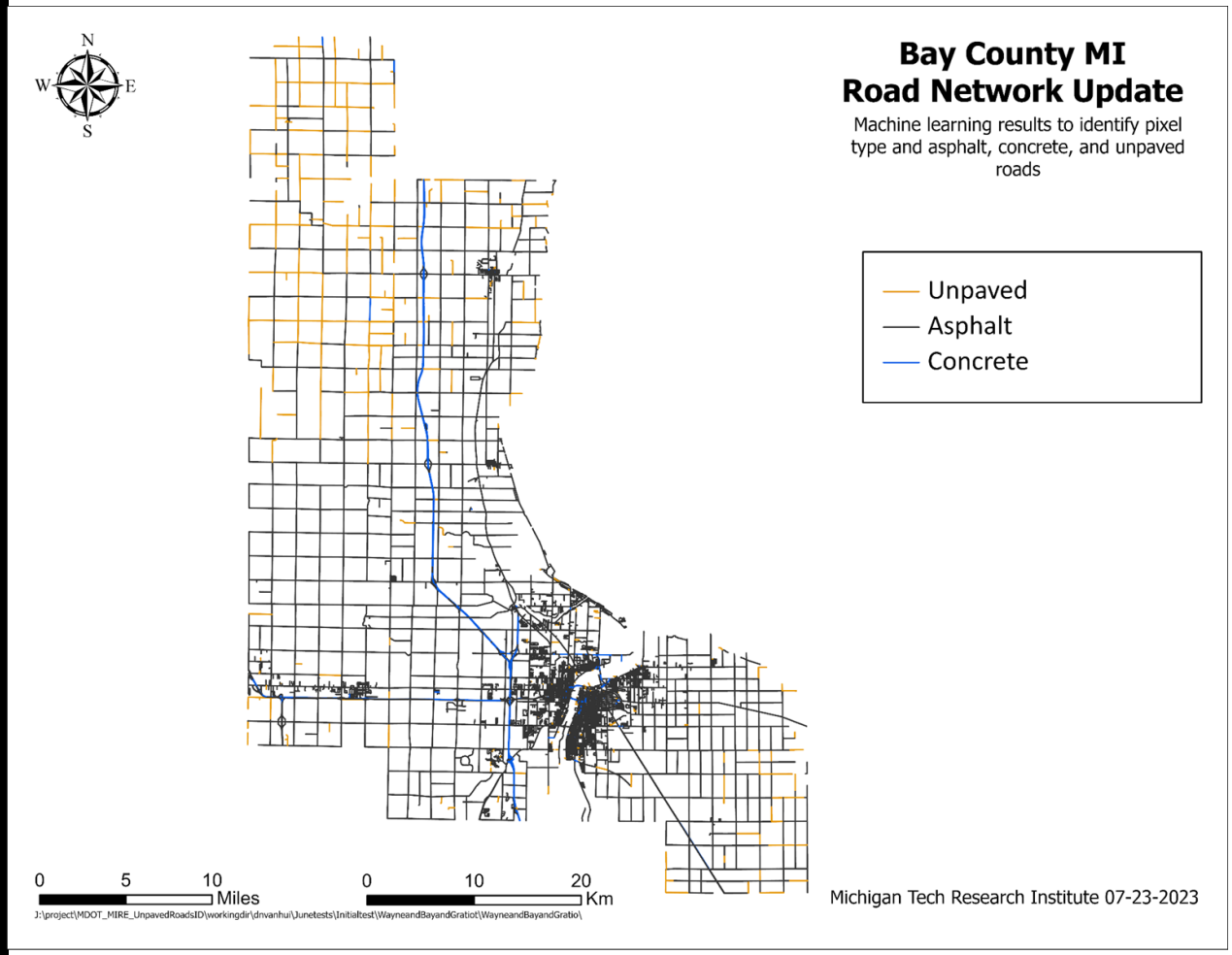
Road Surface Identification through AI Models - Example Output



Paved and Unpaved Accuracy	
Precision Paved	99.4%
Recall Paved	99.8%
F1 Paved	99.6%
Precision Unpaved	96.4%
Recall Unpaved	87.4%
F1 Unpaved	91.7%

Concrete and Asphalt Accuracy	
Precision Asphalt	94.6%
Recall Asphalt	93.5%
F1 Asphalt	94.0%
Precision Concrete	91.6%
Recall Concrete	93.1%
F1 Concrete	92.3%

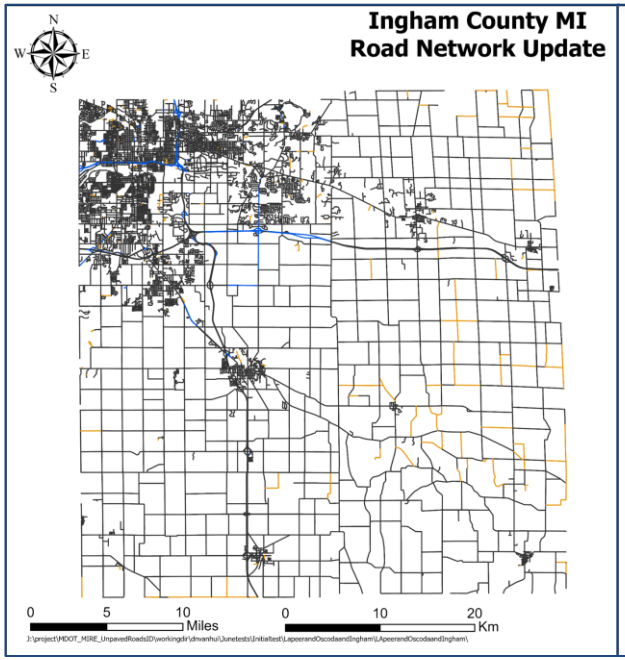
Road Surface Identification through AI Models - Example Output

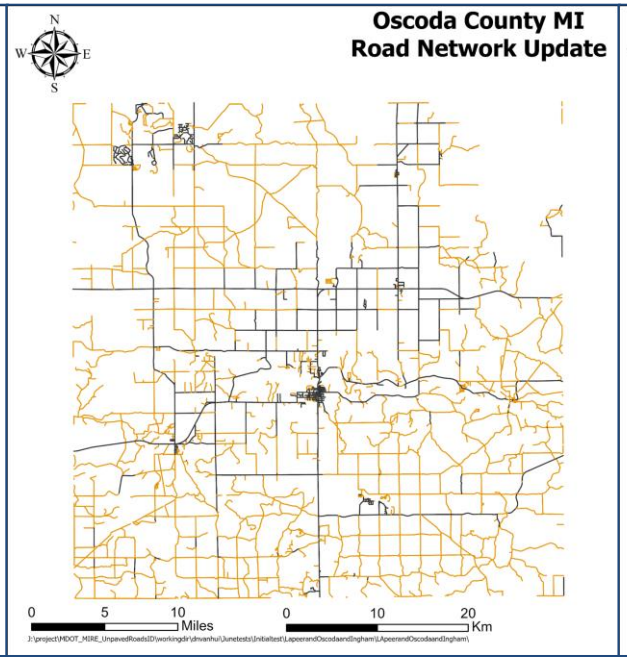


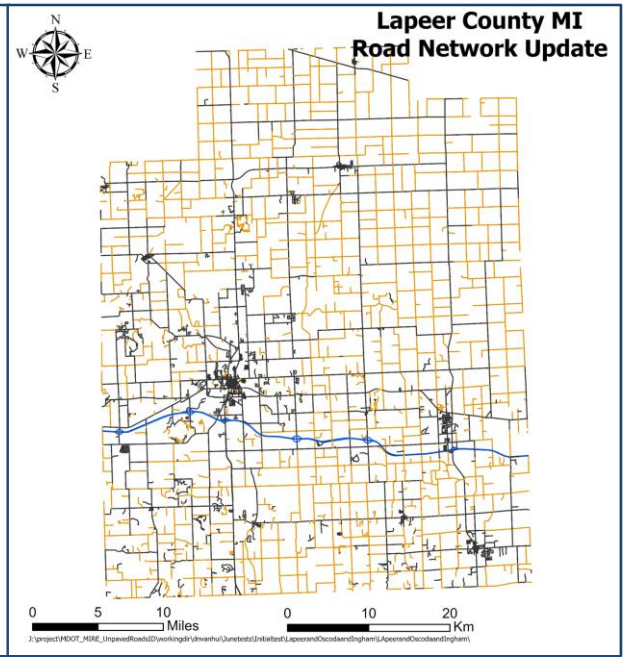
Paved and Unpaved Accuracy	
Precision Paved	98.6%
Recall Paved	99.5%
F1 Paved	99.0%
Precision Unpaved	95.8%
Recall Unpaved	89.2%
F1 Unpaved	92.4%

Concrete and Asphalt Accuracy	
Precision Asphalt	98.8%
Recall Asphalt	99.9%
F1 Asphalt	99.3%
Precision Concrete	98.5%
Recall Concrete	85.8%
F1 Concrete	91.7%

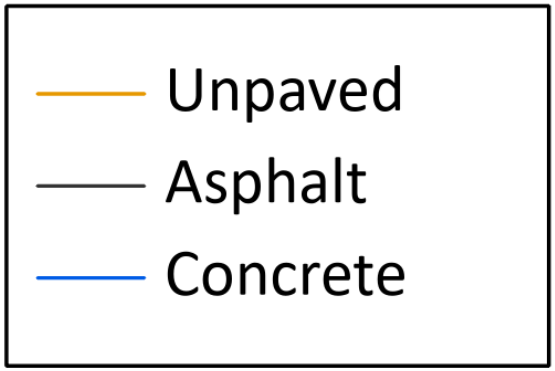
Road Surface Identification through AI Models - Example Output







- MIRE Process finished for 24 Michigan counties, with third phase to classify 59 additional counties in the next year



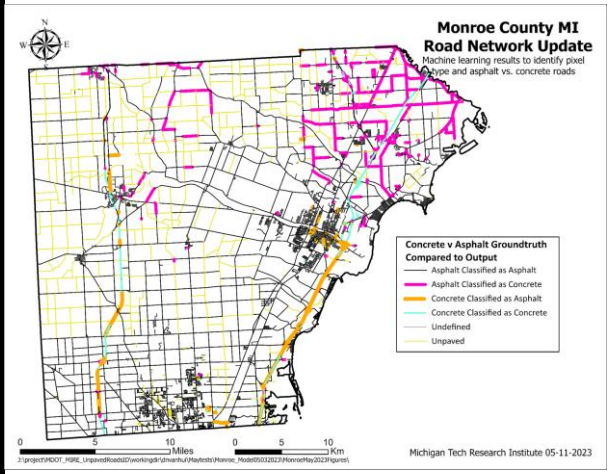
Classification Results Example

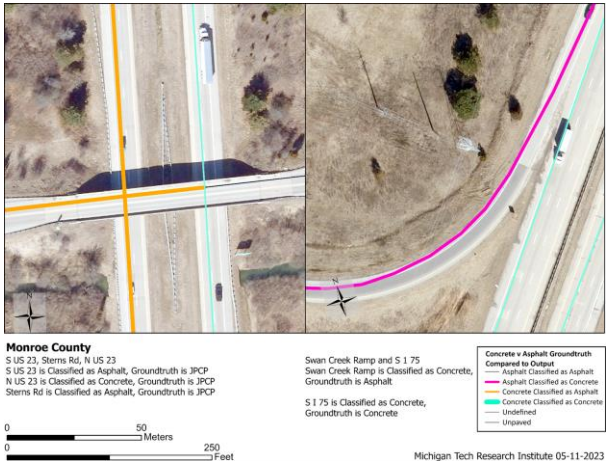
Paved and Unpaved Accuracy	Monroe	Oakland	Ontonagon	Gogebic	Wexford	Kalamazoo
Precision Paved	97.7%	98.5%	99.7%	96.3%	97.5%	99.2%
Recall Paved	98.6%	99.0%	99.9%	98.1%	96.2%	99.9%
F1 Paved	98.1%	98.7%	99.8%	97.2%	96.8%	99.5%
Precision Unpaved	95.2%	93.4%	98.9%	96.9%	97.2%	97.7%
Recall Unpaved	92.4%	90.3%	96.7%	93.9%	98.2%	86.8%
F1 Unpaved	93.8%	91.8%	97.8%	95.4%	97.7%	91.9%

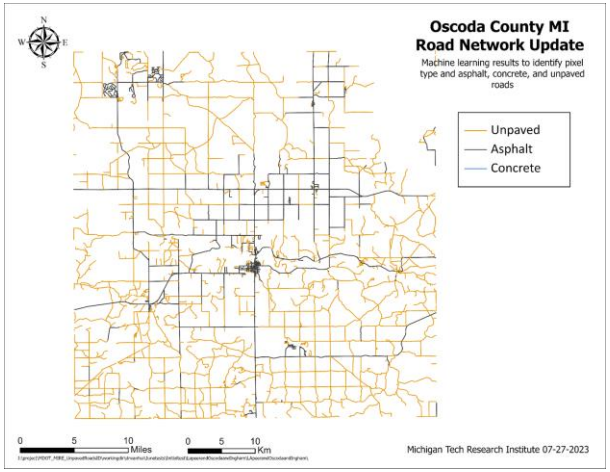
Concrete and Asphalt Accuracy	Monroe	Oakland	Kalamazoo	Ontonagon	Gogebic	Wexford
Precision Asphalt	99.4%	94.3%	99.5%	99.9%	99.9%	100.0%
Recall Asphalt	99.9%	96.3%	99.6%	100.0%	98.4%	98.3%
F1 Asphalt	99.7%	95.3%	99.6%	100.0%	99.1%	99.1%
Precision Concrete	99.3%	89.3%	85.1%	Not enough Mileage of Concrete Roads to Analyze Accuracy		
Recall Concrete	94.2%	84.0%	80.9%			
F1 Concrete	96.7%	86.6%	82.9%			

Conclusions

- Michigan Tech AI-enabled image analysis methods can be deployed for other states needing road surface type identification
  - For MIRE compliance, updating GIS inventories, management by road surface type
  - Please contact Colin Brooks, cnbrooks@mtu.edu, 734-604-4196 for more information







MichiganTech Research Institute

Using multi-temporal imagery to improve mapping and inventory of forested roads in Michigan's western Upper Peninsula

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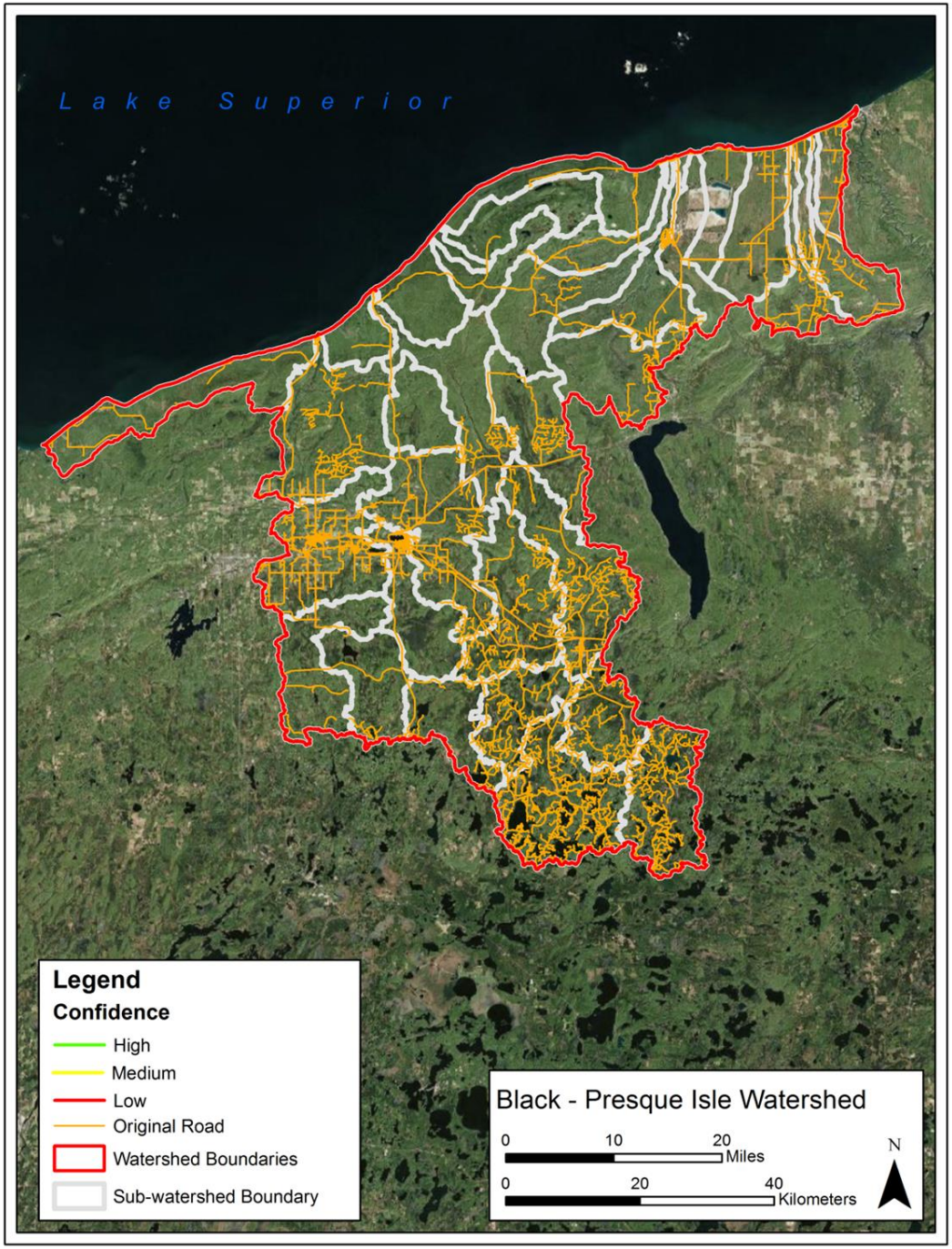
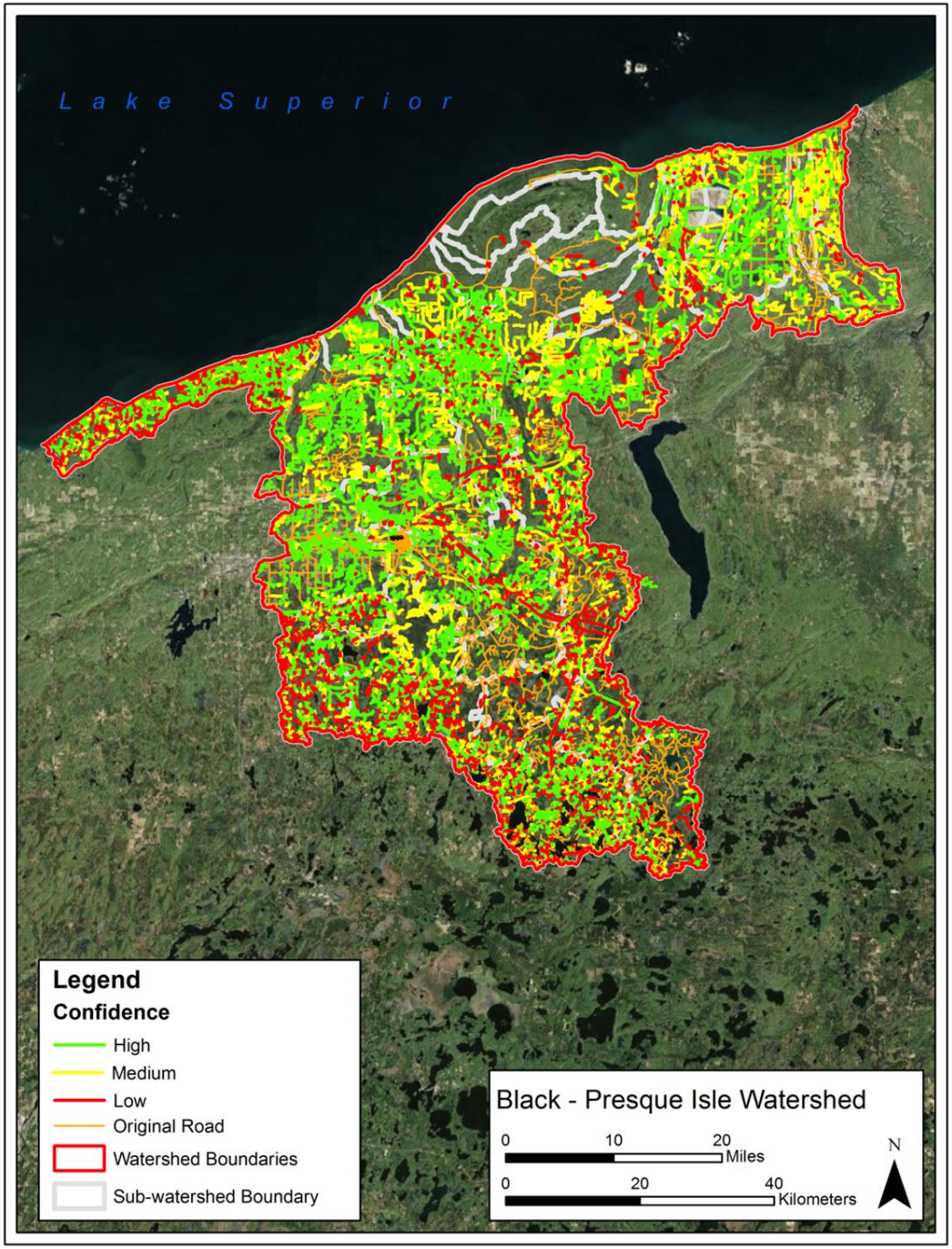

Lake Superior
Legend
Confidence
High
Medium
Low
Original Road
Watershed Boundaries
Sub-watershed Boundary
Black - Presque Isle Watershed
0 10 20 Miles
0 20 40 Kilometers
N


Lake Superior
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Original Road
Watershed Boundaries
Sub-watershed Boundary
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0 10 20 Miles
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N

Conclusions

- Michigan Tech AI-enabled image analysis methods can be deployed for other states needing road surface type identification
  - For MIRE compliance, updating GIS inventories, management by road surface type
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