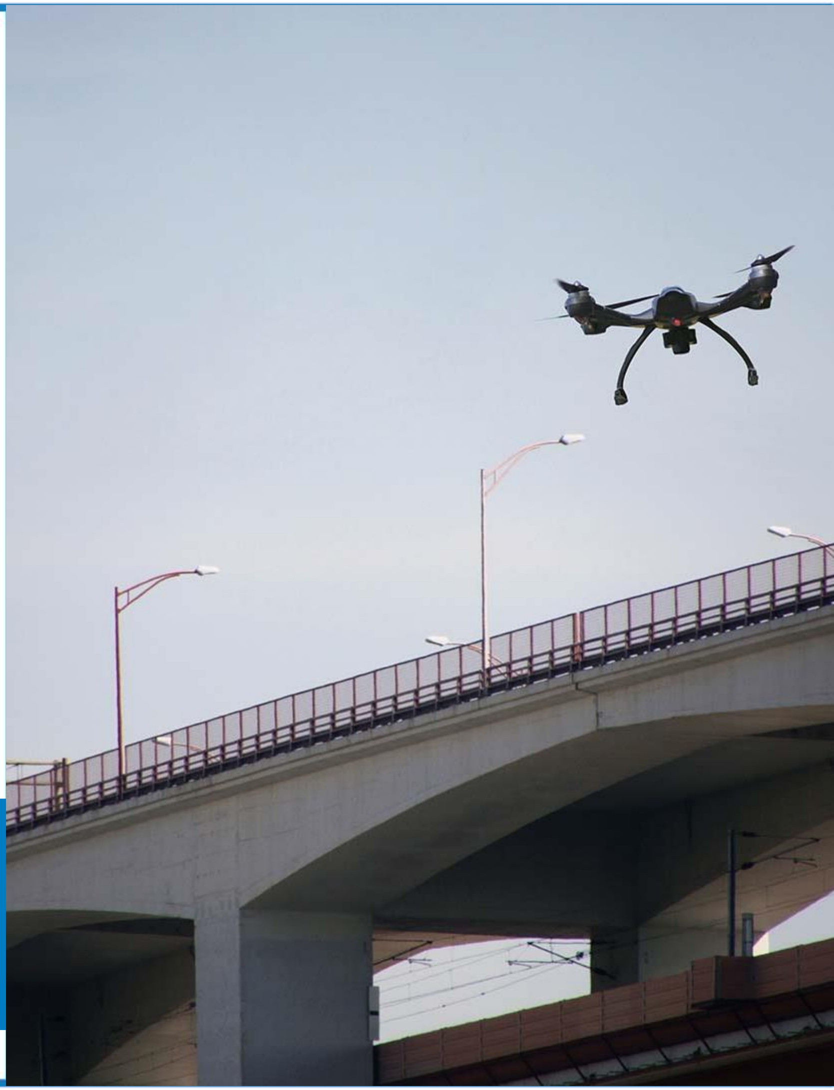
# Breakout Session Track 2: Structural Inspection

*Jennifer Wells, Minnesota DOT*
*Dr. Chris Parrish, Oregon State University*
*Jag Mallela (Moderator)*



U.S. Department of Transportation
Federal Highway Administration

OKLAHOMA Transportation

LOCAL TECHNICAL ASSISTANCE PROGRAM
College of Engineering, Architecture and Technology

# Structure Inspections Utilizing UAS

Jennifer Wells, PE - State Bridge Inspection Engineer

DEPARTMENT OF TRANSPORTATION

# Presentation Outcomes

- UAS Program Implementation Overview
- Understand Benefits and Limitations
- Participants will learn the current and future drone technologies that are effective for structure inspection
- Understanding of how to successfully implement drone technology into structure inspections
- Understand the costs associated with implementing drones and the cost savings that can be realized compared to traditional methods
- Understand drone data needs

# UAS Program Implementation Overview

- Phased research began in 2015
  - Phase III completed in summer 2018
  - Published report - http://www.dot.state.mn.us/research/reports/2018/201826.pdf
- Metro District drone purchase – Elios
  - Phase IV – Project almost complete…
- FHWA EDC – 5 UAS Committee
  - STIC Grant
  - $125k in drone purchases

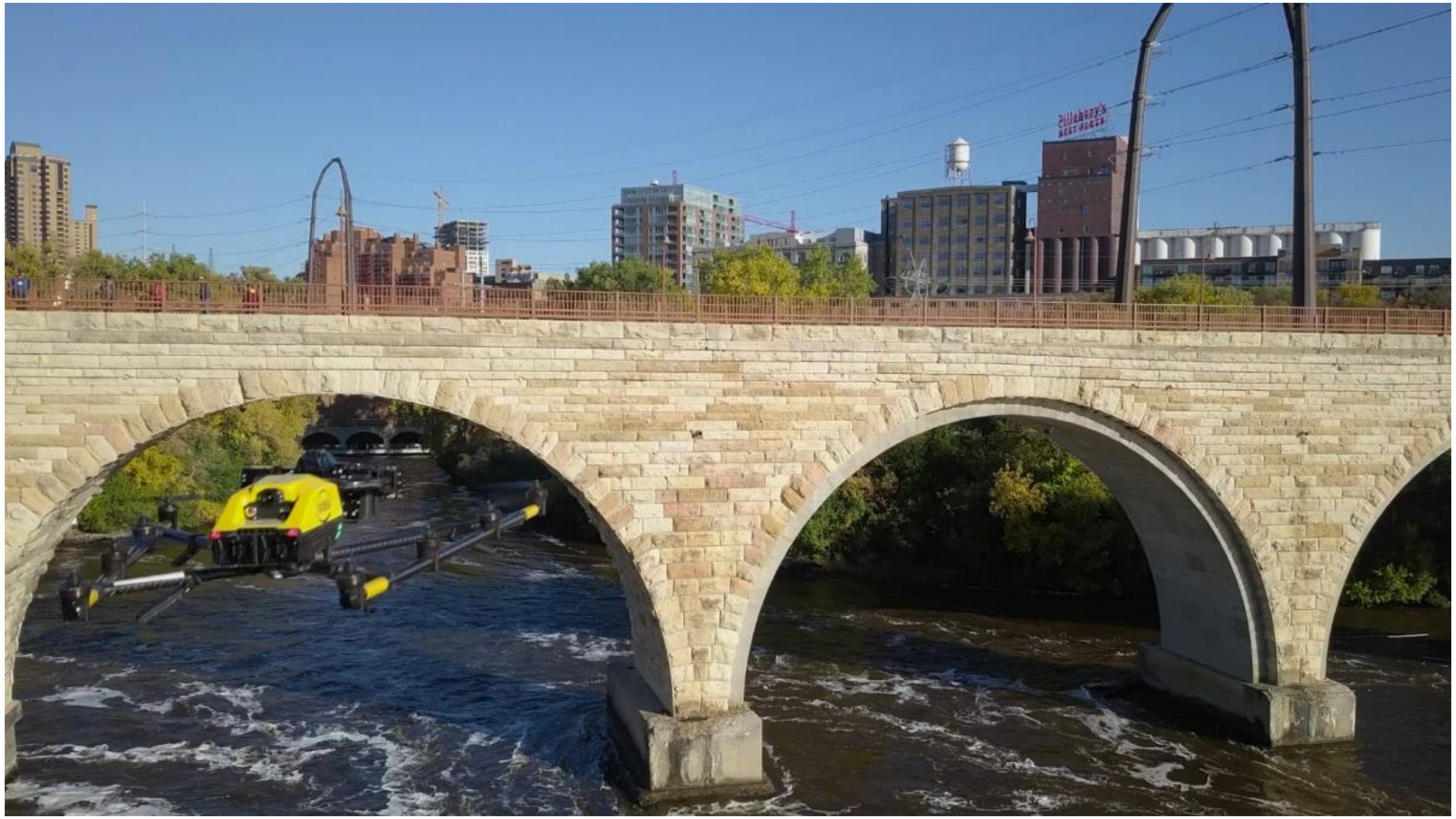
# Assessment of UAS Technology

- Inspection-specific UAS
- Object Sensing
- Capable of looking up
- Fly without GPS, under bridge decks
- Photo, Video and Thermal Imaging
- Confined Space

# Assessment of UAS Technology

Commercial Drones ($20,000 - $35,000)

- Intel Falcon 8+
- DJI Matrice 210
- Flyability Elios



Benefits

- Sensor Size
- Reliability
  - Dual Batteries
- Durability
- Purpose Built for Inspection

# Assessment of UAS Technology

Consumer Level Drones ($500 - $2000)

- DJI Mavic
  - Object Avoidance
- Parrot Anafi
  - Thermal

Benefits

- Low cost
- Small size
- More risk tolerance

Limitations

- Non-professional perception
- Reliability
- Small sensor sizes
- Less sophisticated flight planning


DEPARTMENT OF TRANSPORTATION
217714

# Sensor Size Importance

# Assessment of UAS Technology

Propeller Aeropoints

- Automatic Ground Control Points
- Provides precision ground control
- Adds ability to accurately geolocate assets and inspection results

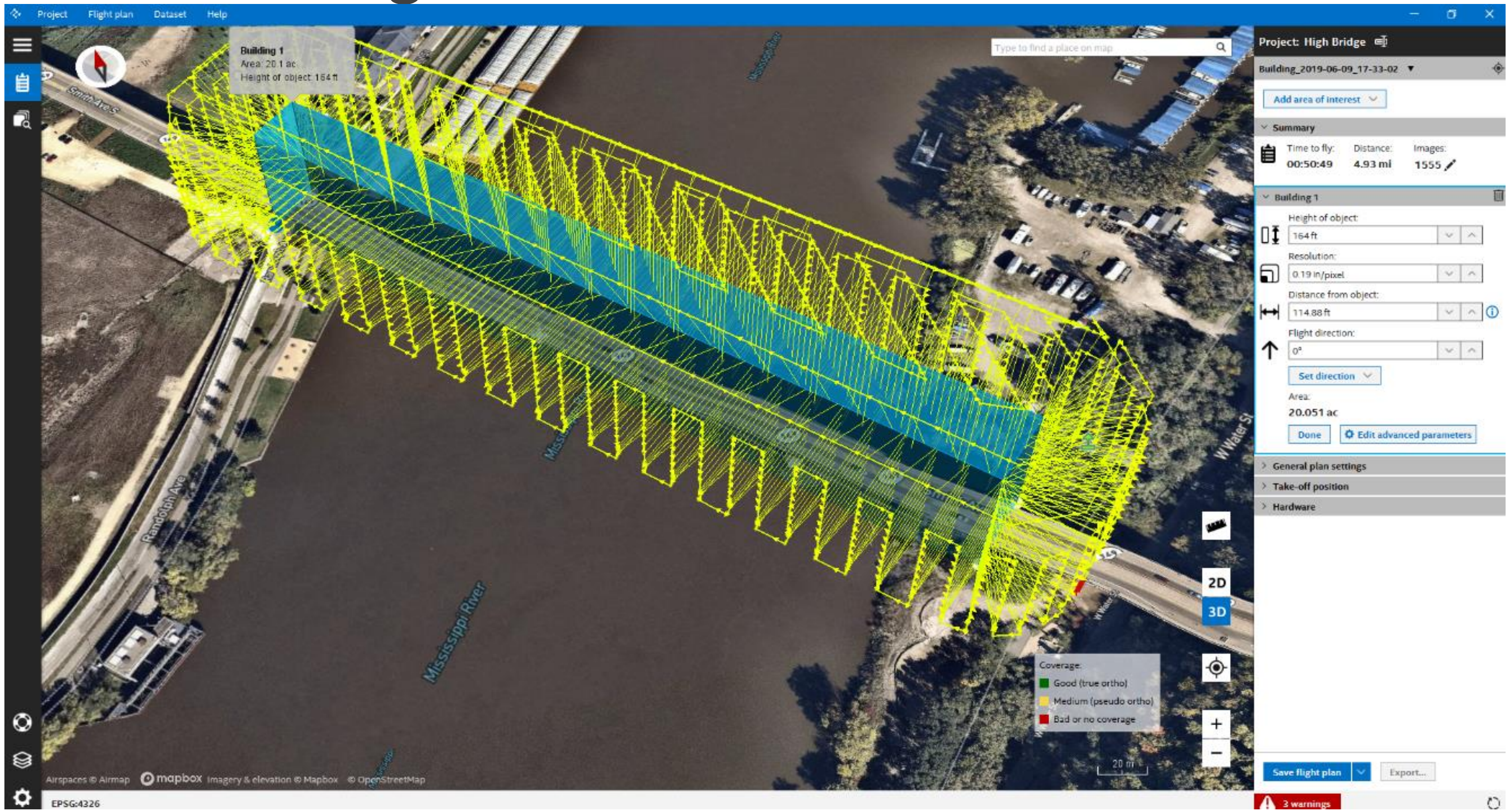
# Structure Inspection Goals

1. Inspection Planning
2. Detect Conditions and Deficiencies
3. Document
4. Communicate

# 1. Inspection Planning with UAS

## Flight Planning

- 3D Autonomous Flights



# 2. Detection of Defects and Deficiencies

- Use UAS as an access tool
- Traditional Access Tools
  - Aerial Work Platforms (AWP's)
  - Rope Access and Structure Climbing
  - Ladders
  - Binoculars

# 3. Document Conditions and Deficiencies

- Reality Modeling Software
  - Pix4D
  - Context Capture
- Input
  - Images
  - Ground Control
- Output
  - Orthomosaics
  - GeoTIFF, DSM, DTM
  - Point Clouds
  - Classified by AI
  - 3D Mesh
  - CAD

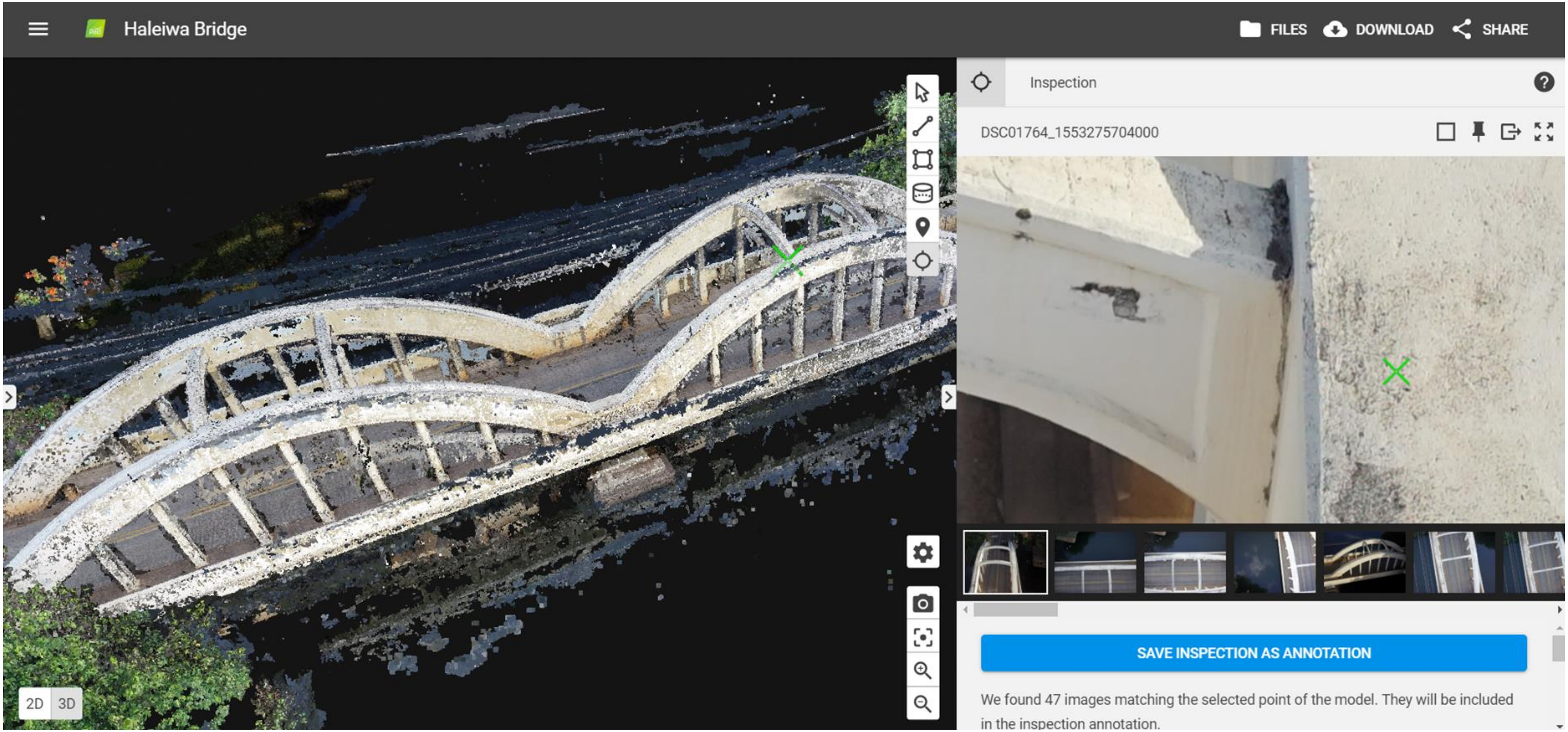
# 3. Document Conditions and Deficiencies

## Deliverables – Orthomosaic

# 3. Document Conditions and Deficiencies

## Deliverables – Point Clouds

# 4. Communicate Conditions and Deficiencies



# 4. Communicate Conditions and Deficiencies

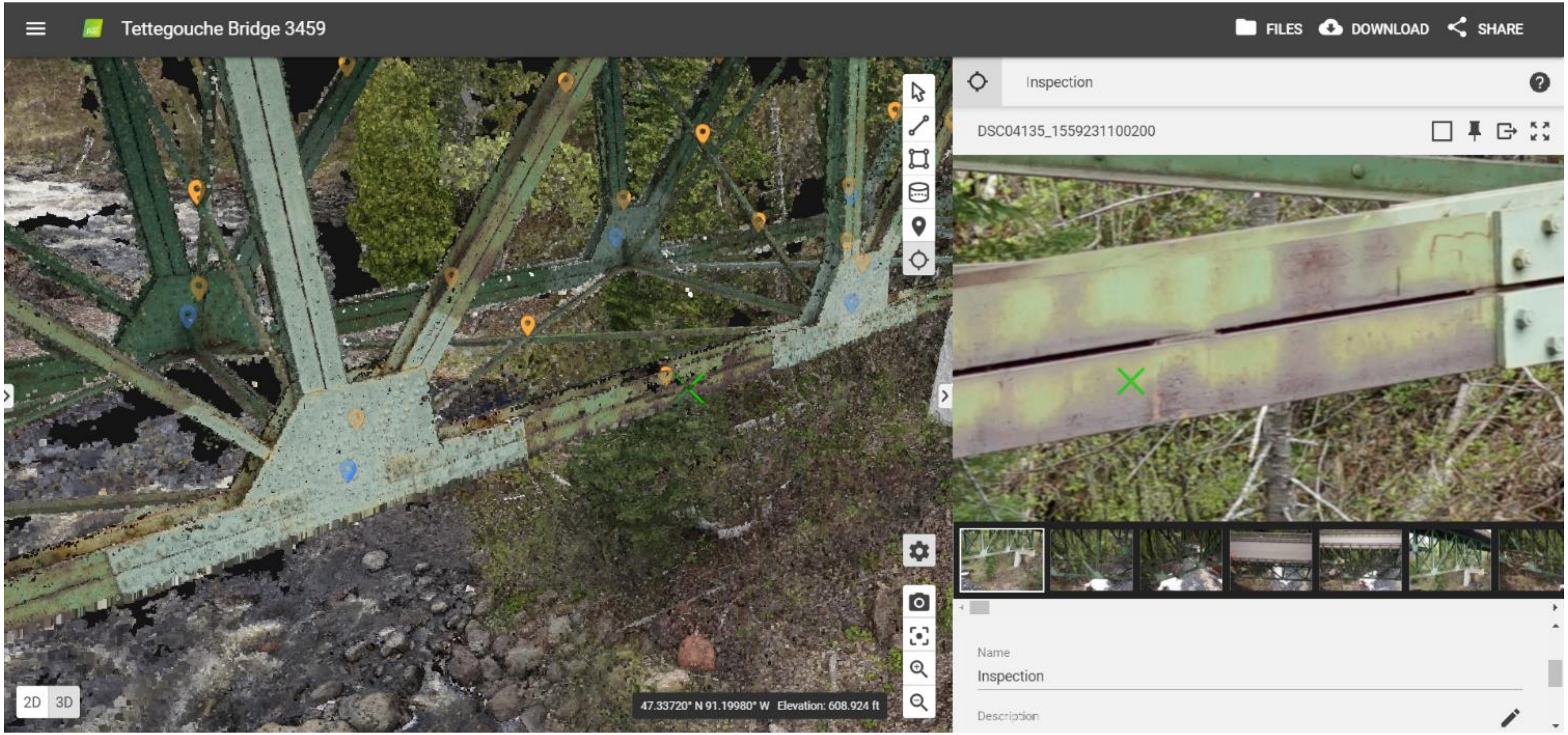
- Traditional Reporting

| BR 3459 -- Span #3 Field Notes | | |
|---|---|---|
| **Location** | **North (upstream) Truss** | **South (downstream) Truss** |
| **L0-L1 Bottom Chord (4 angles, 5" x 3-1/2" x 5/16")** | [2004] Bottom chord angles reinforced (bolted plates) at L0, L1 and at the center.<br>[2008] There is pitting and section loss (painted over) just west of the center section reinforced in 1994 - the horizontal legs of the two exterior angles have rusted through.<br>[2011] No change.<br>[2015] Through corrosion top horizontal leg of bottom exterior angle west of retro fit.<br>**[2017] Pitting on the upper legs of the chord inside the panel point.** (Photo 20) | [2008] Upper angle is bent at mid-panel. [2008] The horizontal legs of the truss bottom chord angles have pack rust (minor section loss) at L0. [2008] The vertical leg of the bottom interior angle has pack rust (section loss) along the edge of the interior L0 gusset plate.<br>[2011] No change.<br>[2015] Pitting 3/16" deep at L0. Through corrosion on bottom interior angle horizontal leg inside panel point L0. Pitting ¼" deep on top interior horizontal legs inside L1. |
| **L0-L1 Lower Lateral Bracing** | [2004] Lower lateral bracing members replaced.<br>[2011-2015] No deficiencies noted. | |
| **L1 Gusset Plates (1/2" thick)** | [2004] Repainted - L0/L1 & L1/L2 connections reinforced (bolted plates).<br>[2011] No deficiencies noted.<br>[2013-2015] 1/8" bow on EGP from PR. | [2004] Repainted. [2010] Minor corrosion.<br>[2011] No change<br>[2013-2015] IGP has 1/4" PR distortion over upper angle of lower chord, E side. |
| **L1-U1 Vertical (4 angles, 3" x 2-1/2" x 1/4")** | [2008] Vertical has minor section loss at L1.<br>[2011] No deficiencies noted. [2013] NC to section loss @ L1.<br>[2013-2015] Paint failures over upper half of N face of both flanges.<br>**[2017] 3/16" pitting at L1N** (Photo 21) | [2011] No deficiencies noted.<br>[2015] Paint failure throughout. |

# 4. Communicate Conditions and Deficiencies

# 4. Communicate Conditions and Deficiencies

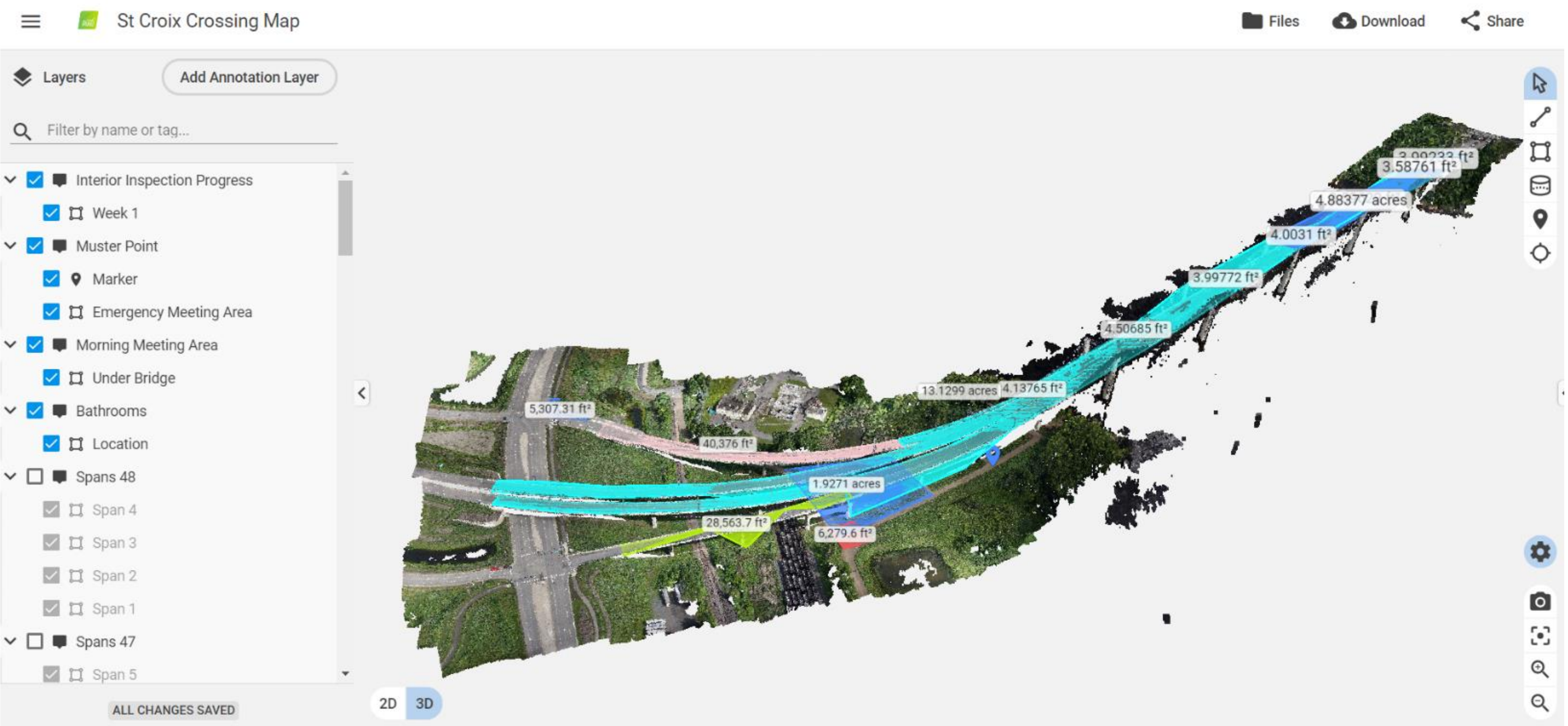
- Cloud Sharing



# Case Study – St. Croix Crossing Extradosed Bridge

- Crosses the St. Croix Scenic Riverway
- Construction complete in July 2019
- Scope – Routine Inspection

# Case Study – St. Croix Crossing Extradosed Bridge

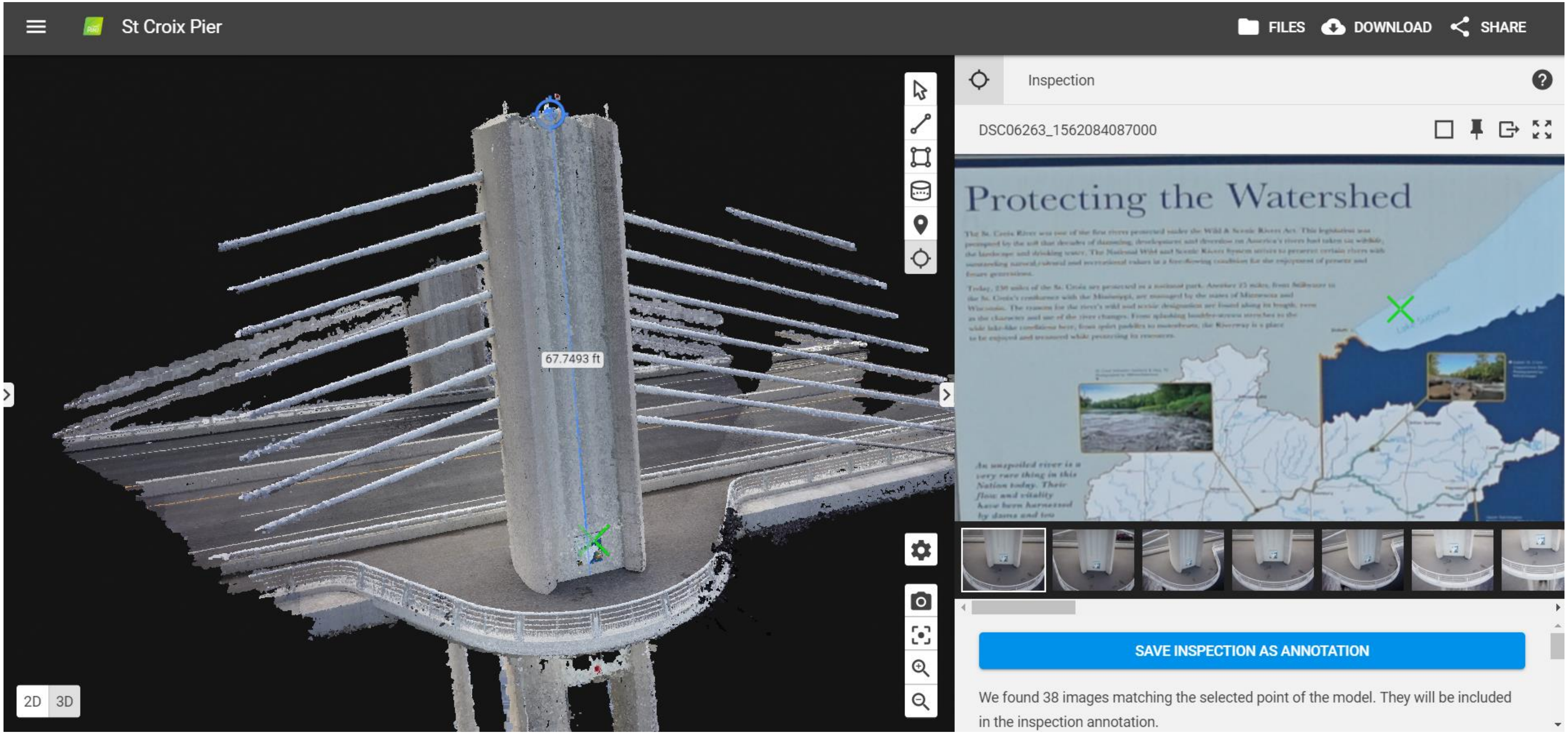



https://cloud.pix4d.com/pro/project/507277/model?shareToken=352346c7-7098-44ca-9b52-07f1c9eecee1

- Intel Falcon 8+
- Capable of looking up
- Fly without GPS, under bridge decks
- High wind tolerance
- High Resolution Images
- Propeller Aeropoint Automatic GCP’s

# Deliverables

- 3D Models and High resolution photolog



# Bridge Candidates

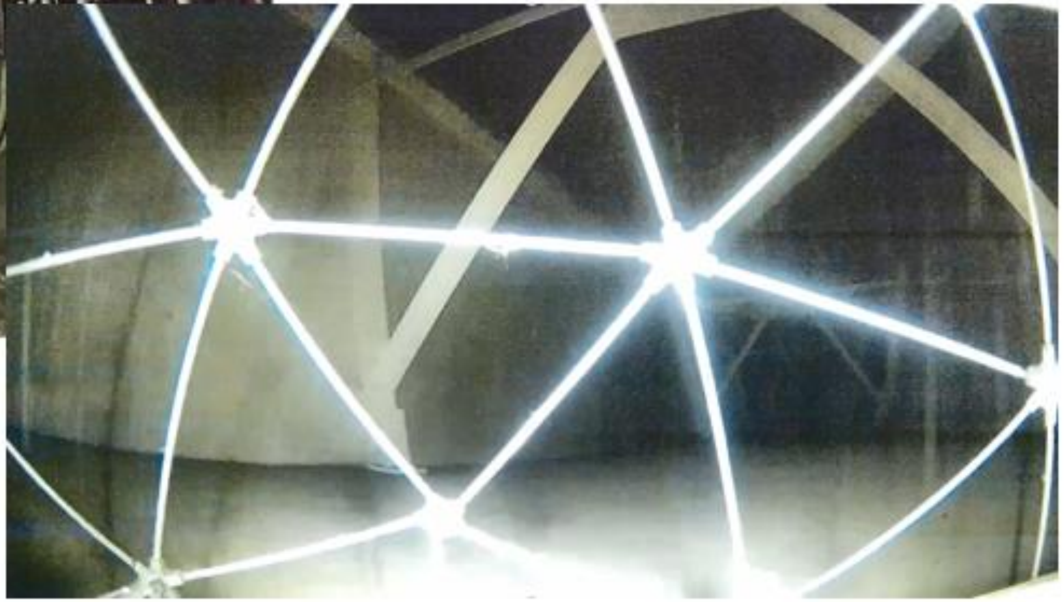
## Works Well

- Large Bridges
- Bridge in open areas
- Bridges that depend on traffic control and UBIV's for inspection

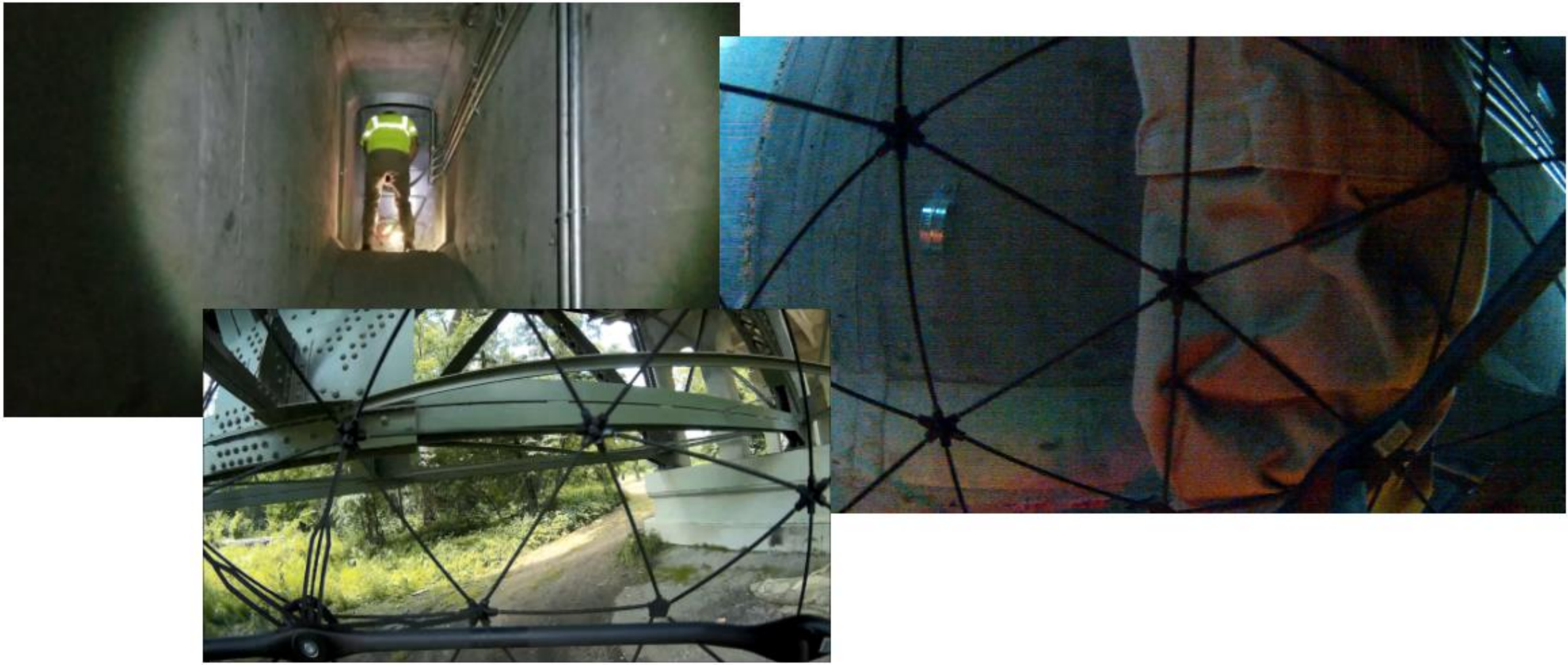
## Does not Work Well

- Bridges over high ADT roadways
- Bridges in heavily wooded areas

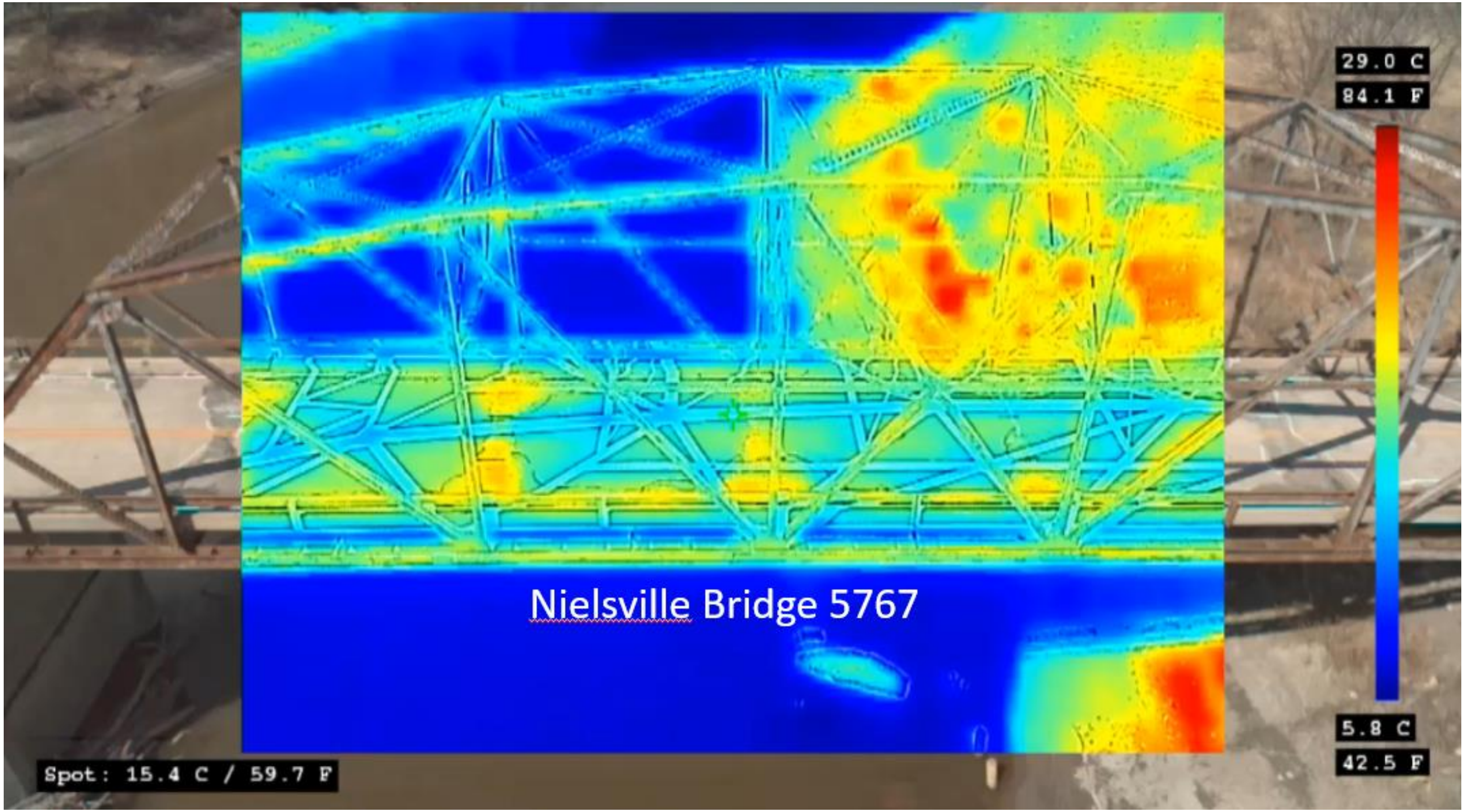
# Other Applications – Confined Spaces



# Other Applications – Confined Spaces

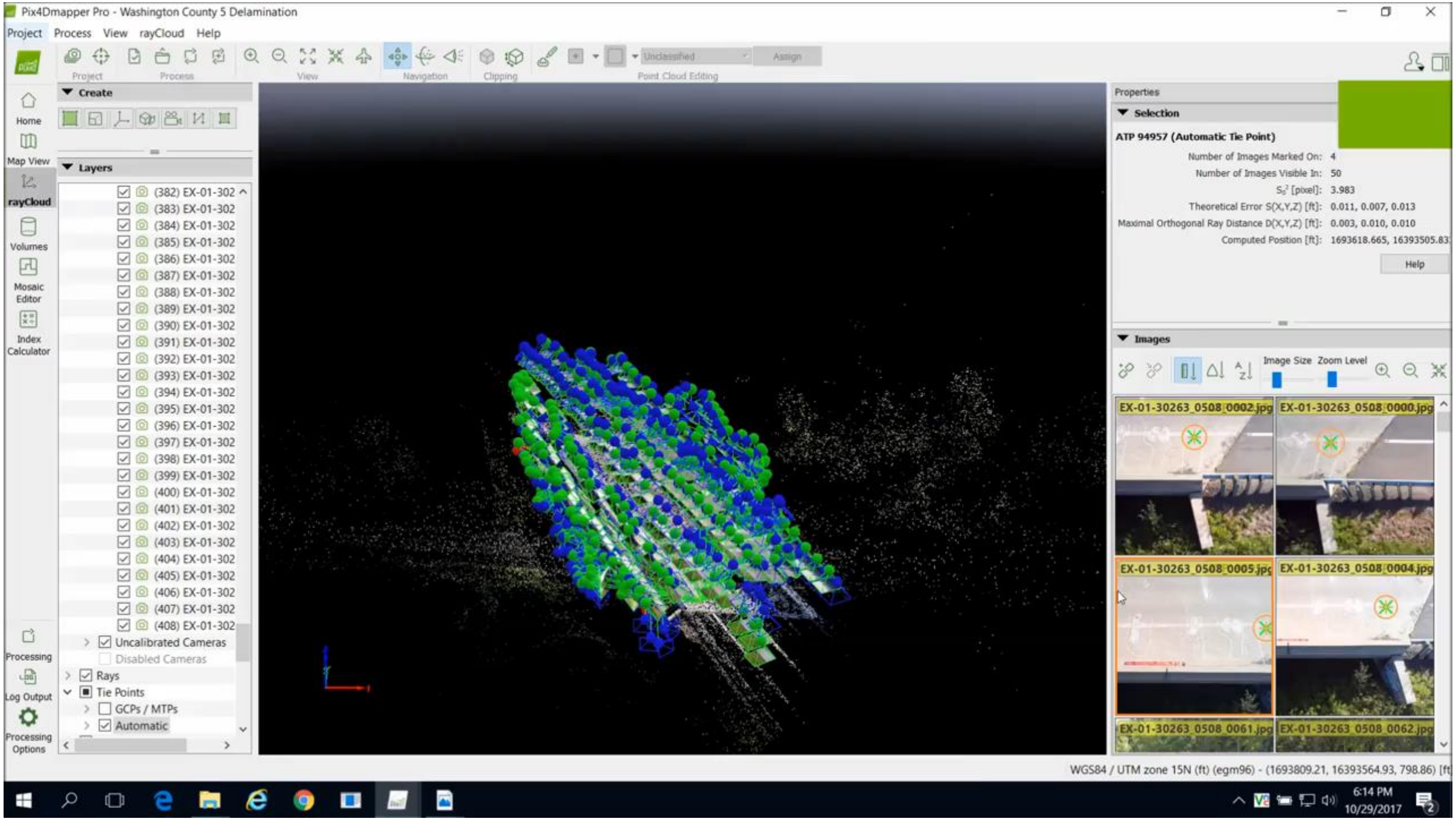


# Other Applications - Infrared

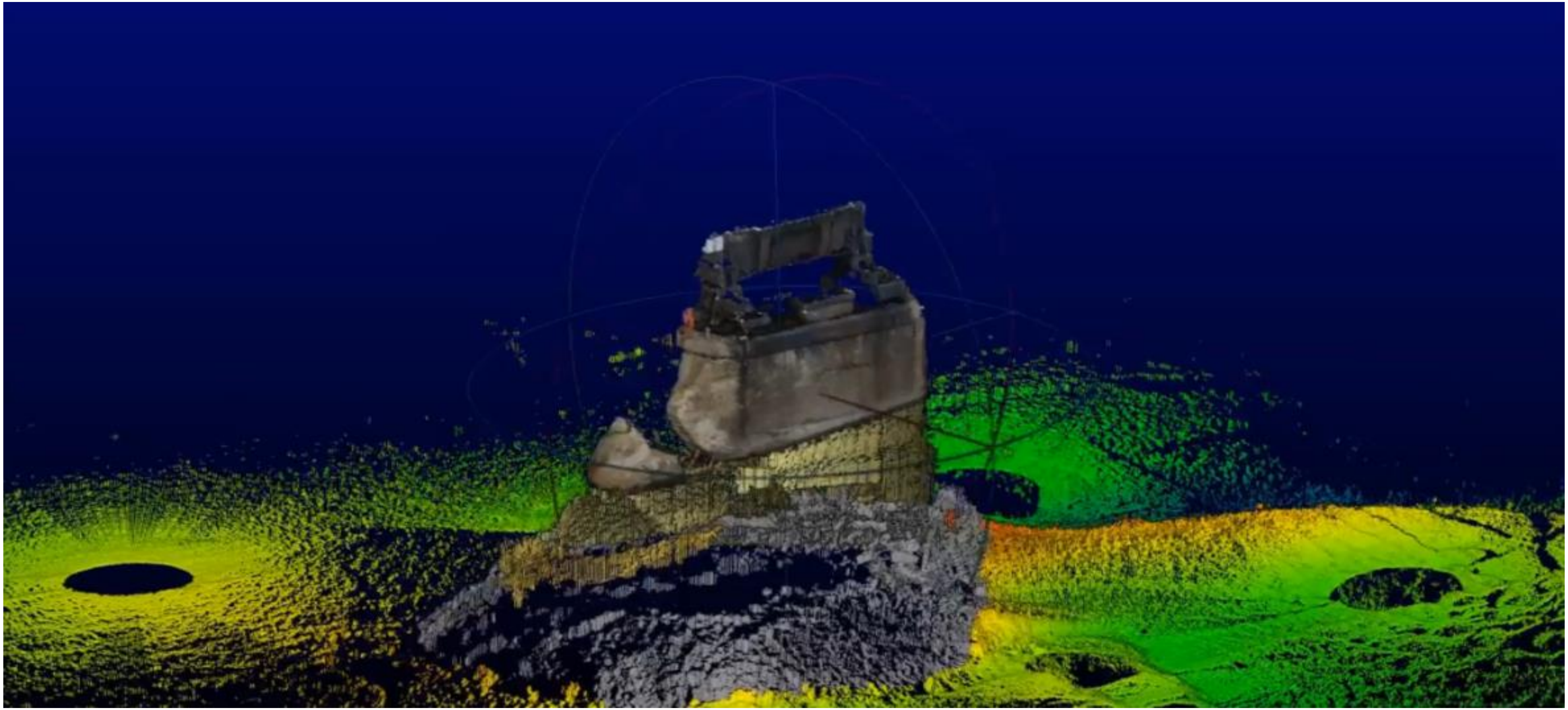


# Other Applications – 3D Modeling

# Other Applications – 3D Modeling (Photo Log)



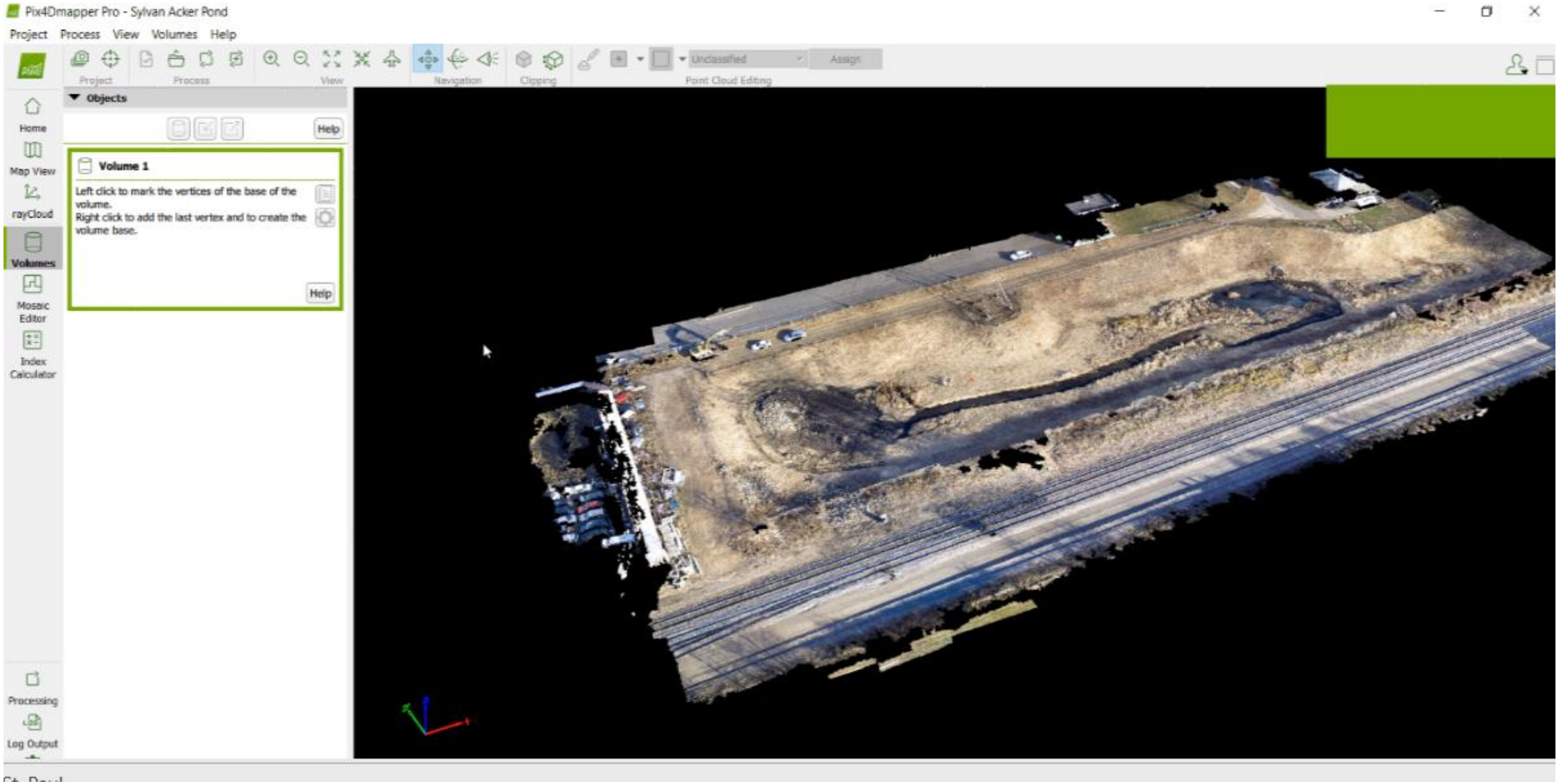
# Other Applications – Pairing with Underwater 3D Modeling



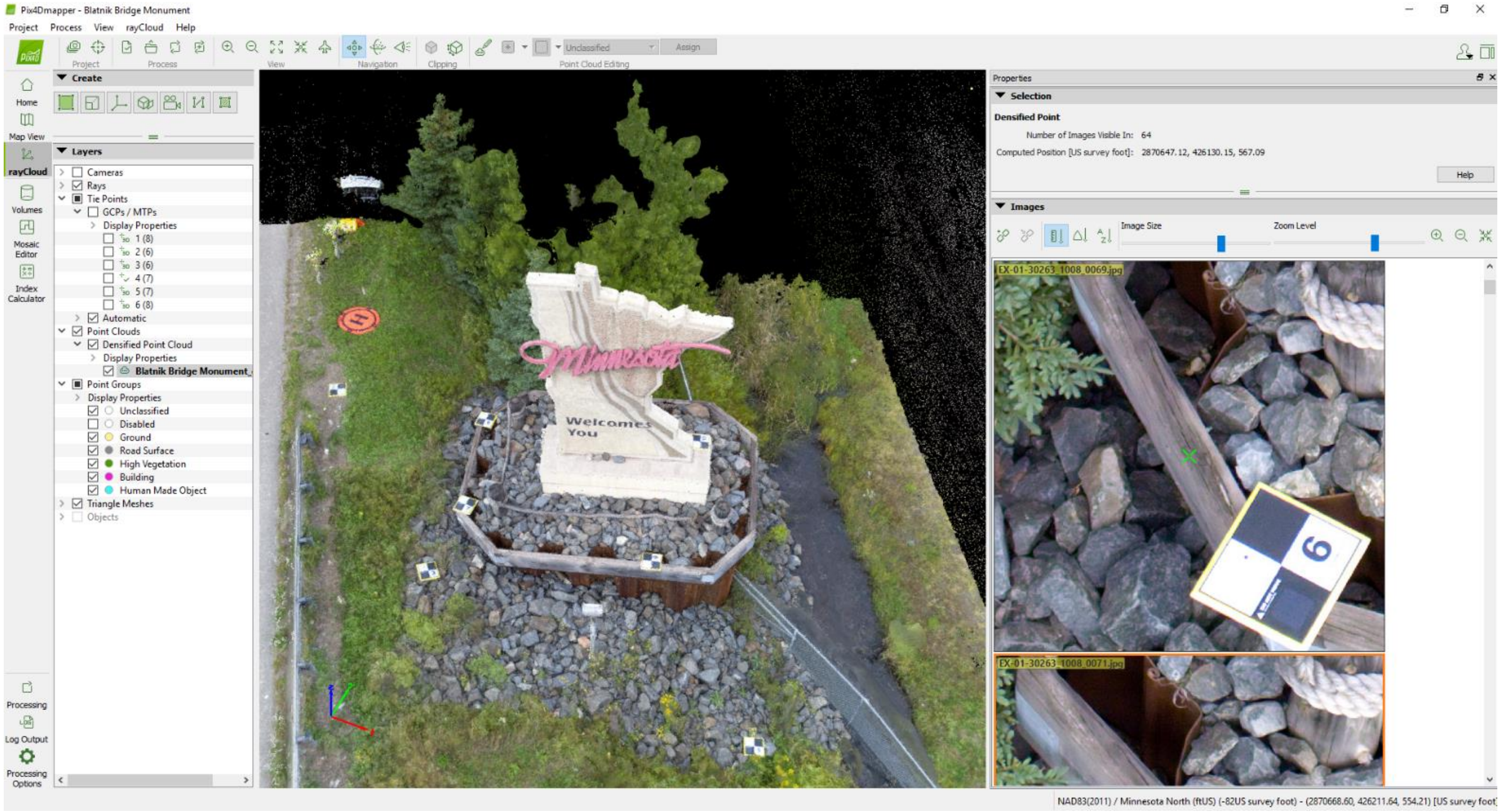
# Other Applications – Corridor Modeling

# Other Applications – Overhead Signs

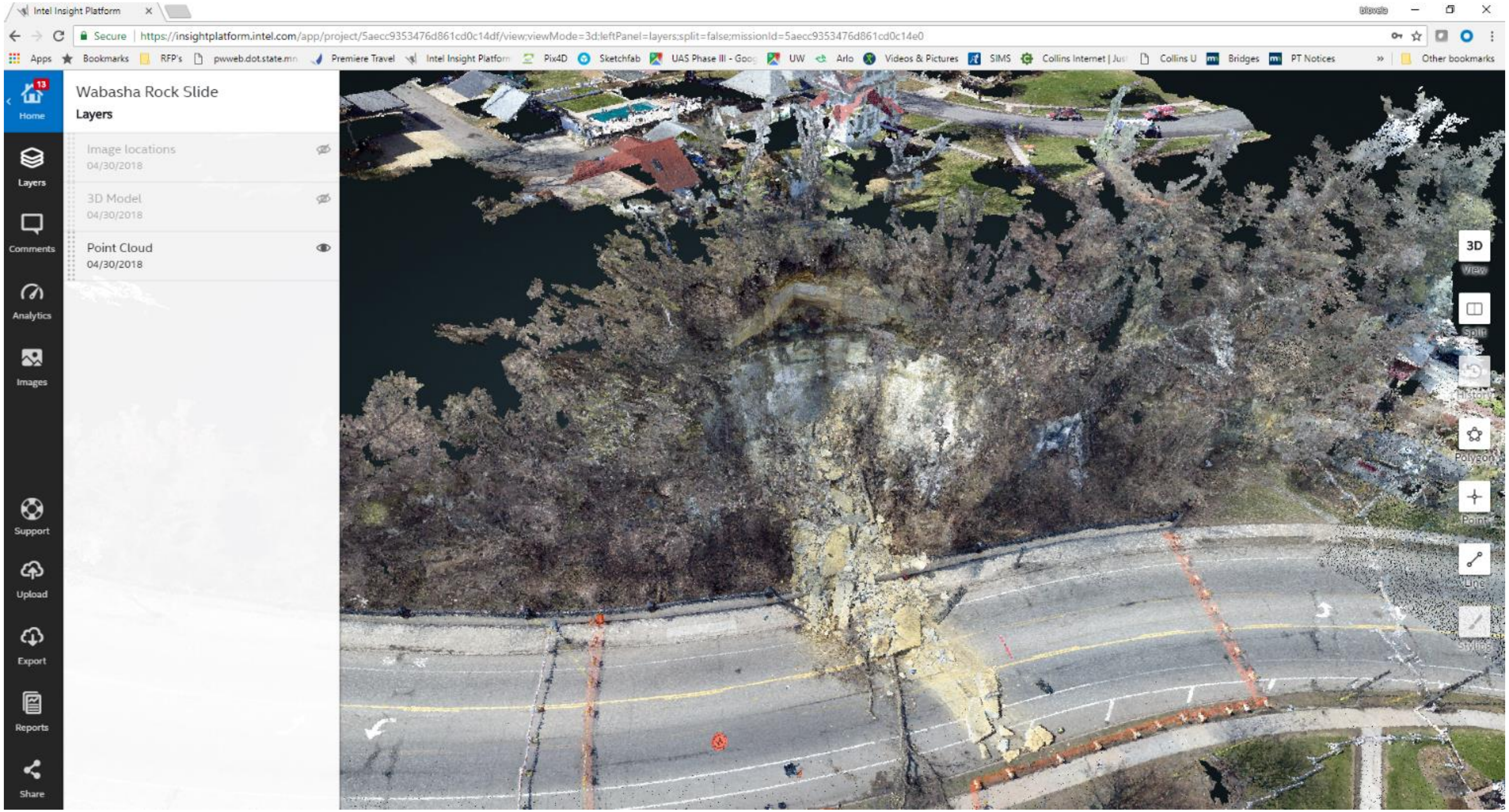
# Other Applications – Volume Calculations



# Other Applications – Monument Inspection/Inventory



# Other Applications – Rock Slides/Scour Inspection



# Other Applications – Roadway Mapping

# Benefits

- Safety Improvements
  – Inspectors
  – Public
- Quality Gains
- Cost Savings

# Challenges

- Learning Curves
- Not Hands On
- Acceptance
- Rules and Regulations
- Data Storage

# Safety Analysis

- Remove inspectors from harms way
  - Heights
  - Traffic
- Reduced traffic control improves safety for inspectors and public
- Hundreds of Inspection Flights with no incidents or close calls
- Work zone accident occurs every 5.4 minutes in the United States
- In 2014 669 Fatalities in Work Zones
- UAS are a way to remove personnel from the ROW
- FAA is focused on airspace safety but need to look at overall risks

# Cost Savings

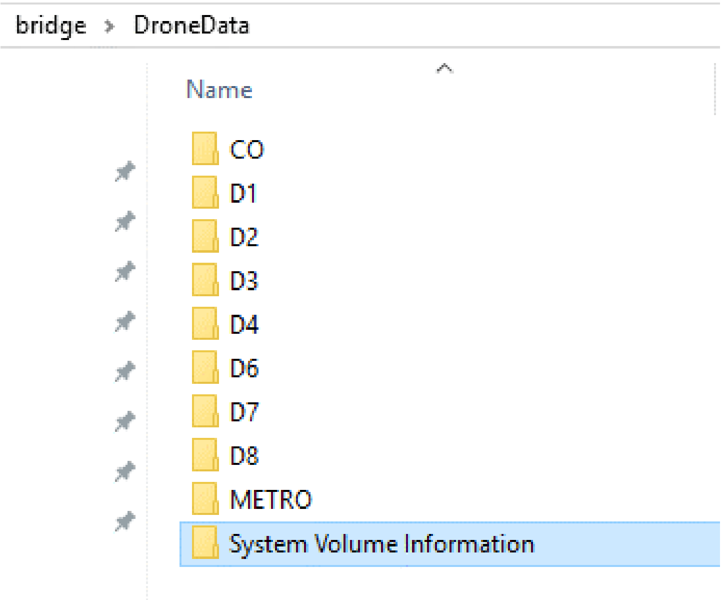
- Cost Savings up to 40%
- Most cost savings where traffic control and access equipment can be reduced or eliminated.

| Structure | Traditional Inspection Cost | UAS Assisted Inspection Cost | Savings +/- | Savings Percentage |
|---|---|---|---|---|
| 19538 | $1,080 | $1,860 | -780 | -72% |
| 4175 | $15,980 | $13,160 | 2,820 | 18% |
| 27004 | $6,080 | $4,340 | 1740 | 29% |
| 27201 | $2,160 | $1,620 | 540 | 25% |
| MDTA Bridges | $40,800 | $19,800 | 21000 | 51% |
| 2440 | $2,160 | $1,320 | 840 | 39% |
| 27831 | $2,580 | $540 | 2040 | 79% |
| 82045 | $2,660 | $1,920 | 740 | 28% |
| 92080 | $2,580 | $1,350 | 1230 | 48% |
| 92090 | $2,410 | $1,570 | 840 | 35% |
| 62504 | $3,660 | $1,020 | 2640 | 72% |
| 82502 | $3,240 | $2,400 | 840 | 26% |

**Average Savings** **40%**

# Data Storage

- Super Computer
- Super Storage
- Security




# Conclusions

- Know your intended purpose for the drone – "off-the-shelf" UAS has limited inspection capabilities
- Using UAS for access is important but documentation and communication of results is more compelling
- UAS can supplement inspections as a tool
- Does not need to replace entire inspection
- Collaborate with other owners to share knowledge and promote future advancement

# Additional Information

- Phase III Report Published
  - http://www.dot.state.mn.us/research/reports/2018/201826.pdf
- MnDOT Office of Aeronautics UAS Policy/Info
  - http://www.dot.state.mn.us/aero/drones/index.html

**Jennifer L. Wells, P.E.**
*Bridge Inspection Engineer*
MnDOT Bridge Office
3485 Hadley Avenue North
Oakdale, MN  55128-3307
Phone: 651-366-4573
jennifer.Wells@state.mn.us


# QUESTIONS?

U.S. Department of Transportation
Federal Highway Administration

OKLAHOMA Transportation

LOCAL TECHNICAL ASSISTANCE PROGRAM
College of Engineering, Architecture and Technology


Photo: Getty Images


Photo: Getty Images


Photo: Getty Images

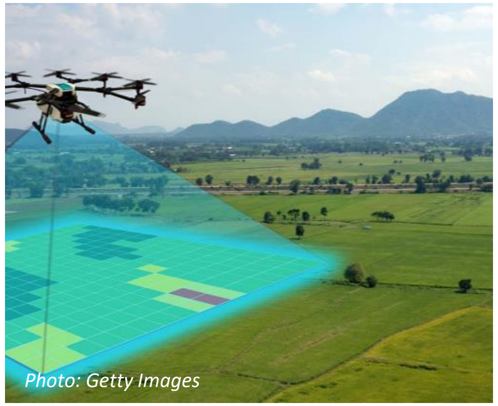


Photo: Getty Images


Photo: Getty Images

# Use of UAS in Bridge Inspection

Christopher Parrish
Oregon State University

*FHWA – EDC-5*

Oregon State University

# Outline

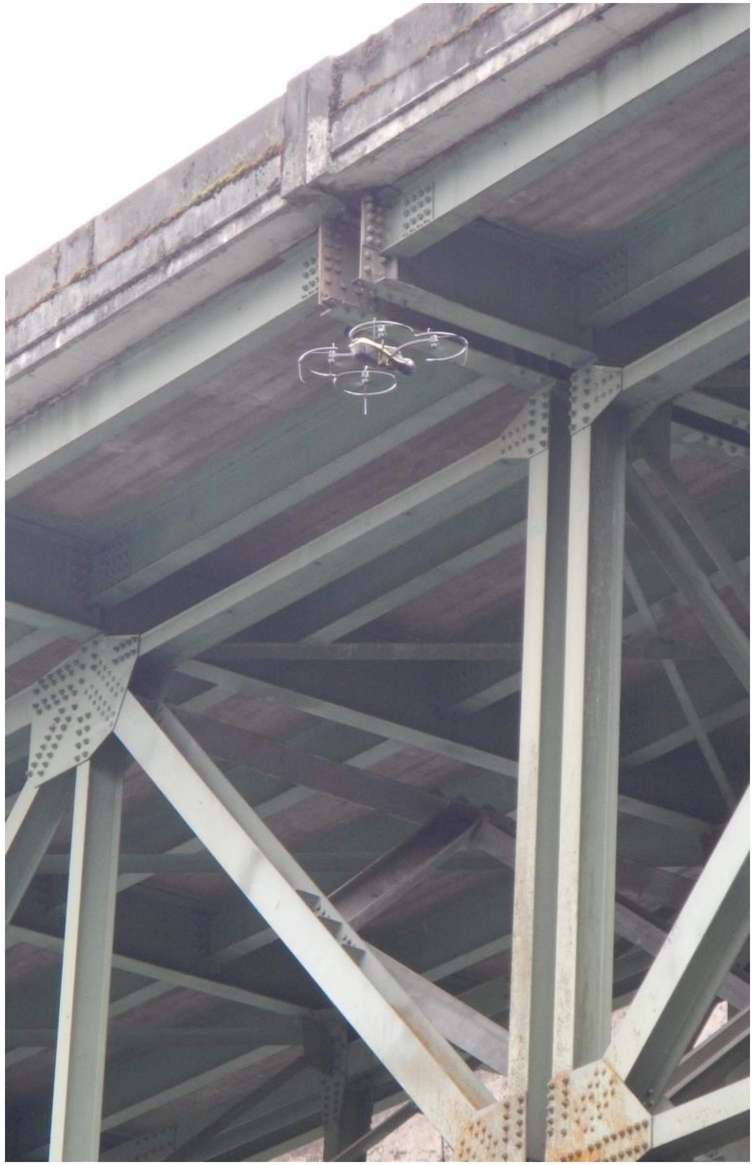
- Projects conducted to date
- Motivation for use of UAS in bridge inspection
- Operations
  - » Aircraft and sensor selection
  - » Workflow
  - » Safety plan
- Results of bridge inspections
- Cost-benefit analysis
- Key findings

# Projects

- OSU UAS Bridge Inspection Projects:
  - » PacTrans (2015): Cost-Effective Bridge Safety Inspection using Unmanned Aerial Vehicles
  - » Oregon DOT (2015-2018): SPR 787 - Eyes in the Sky: Bridge Inspections with Unmanned Aerial Vehicles
- Related projects
  - » FHWA (2015-2017): Effective Use of Geospatial Tools in Highway Construction (with WSP)
  - » PacTrans (2018): UAS in Transportation Expo
  - » PacTrans (2017-2019): An Airborne Lidar Scanning and Deep Learning System for Real-time Event Extraction and Control Policies in Urban Transportation Networks
  - » PacTrans (2020): Unmanned Aircraft Systems in Transportation: Research-to-Operation (R2O) Peer Exchange

# Motivation

- UAS
  - » Simply one tool--but a potentially powerful one--for bridge inspection
    - – Provides new method of remotely viewing bridge elements at high-resolution, while keeping both feet on the ground
    - – Can reduce lane closures, use of bucket trucks, and climbing for some percentage of bridges to be inspected annually
      - ✓ *Enhance safety and reduce costs for some percentage of inspections*



# Specific Project Goals (SPR 787)

- Evaluate performance of UAS for bridge inspection
- Identify inspection requirements that can and cannot be satisfied with UAS
- Provide cost-benefit analysis
- Develop SOPs
- Develop safety plan
- (Also extend analysis to inspection of communication towers)

# Aircraft and Sensor Analysis

- Main categories of remote aircraft:

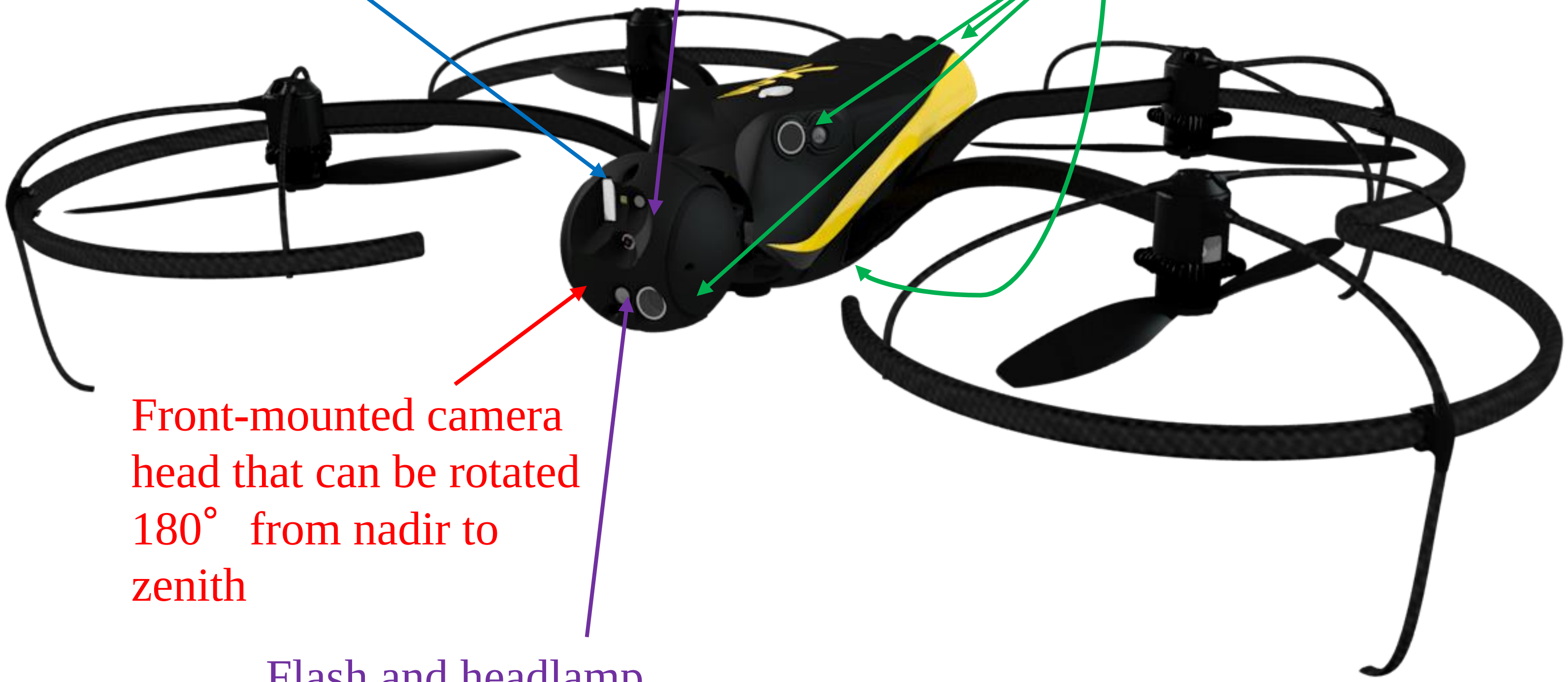
Best option for structural inspections

Helicopters

Fixed-wing

Multi-rotor

# Components of a UAS Designed for Structural Inspections




Flight planning software designed to facilitate inspection projects

# Importance of Rotating Sensor Head

A) Camera optical axis pointing down (nadir)

» Typical mapping configuration

B) Camera optical axis pointing horizontal

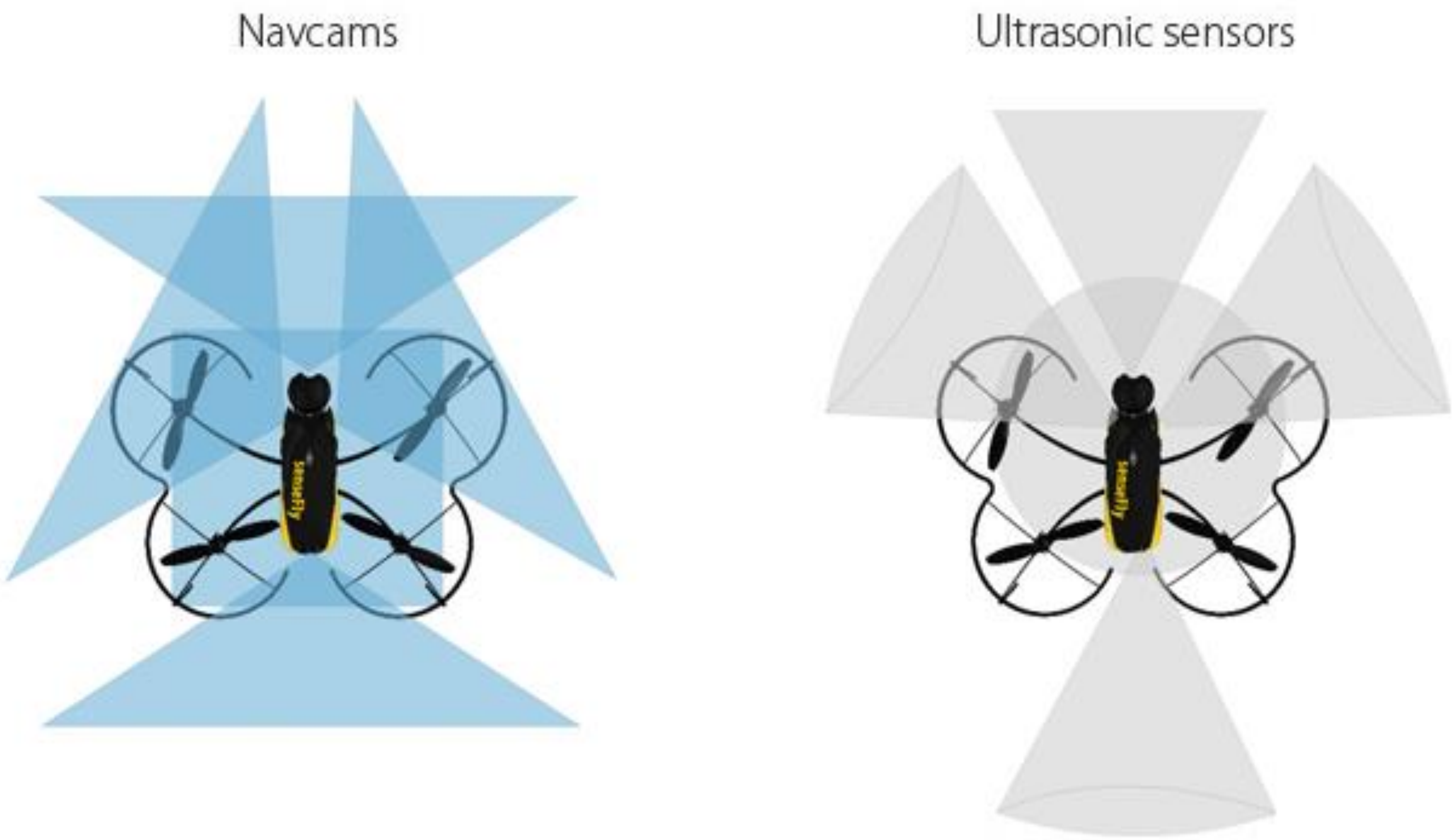
» Common in inspection work

C) Camera optical axis tilted up

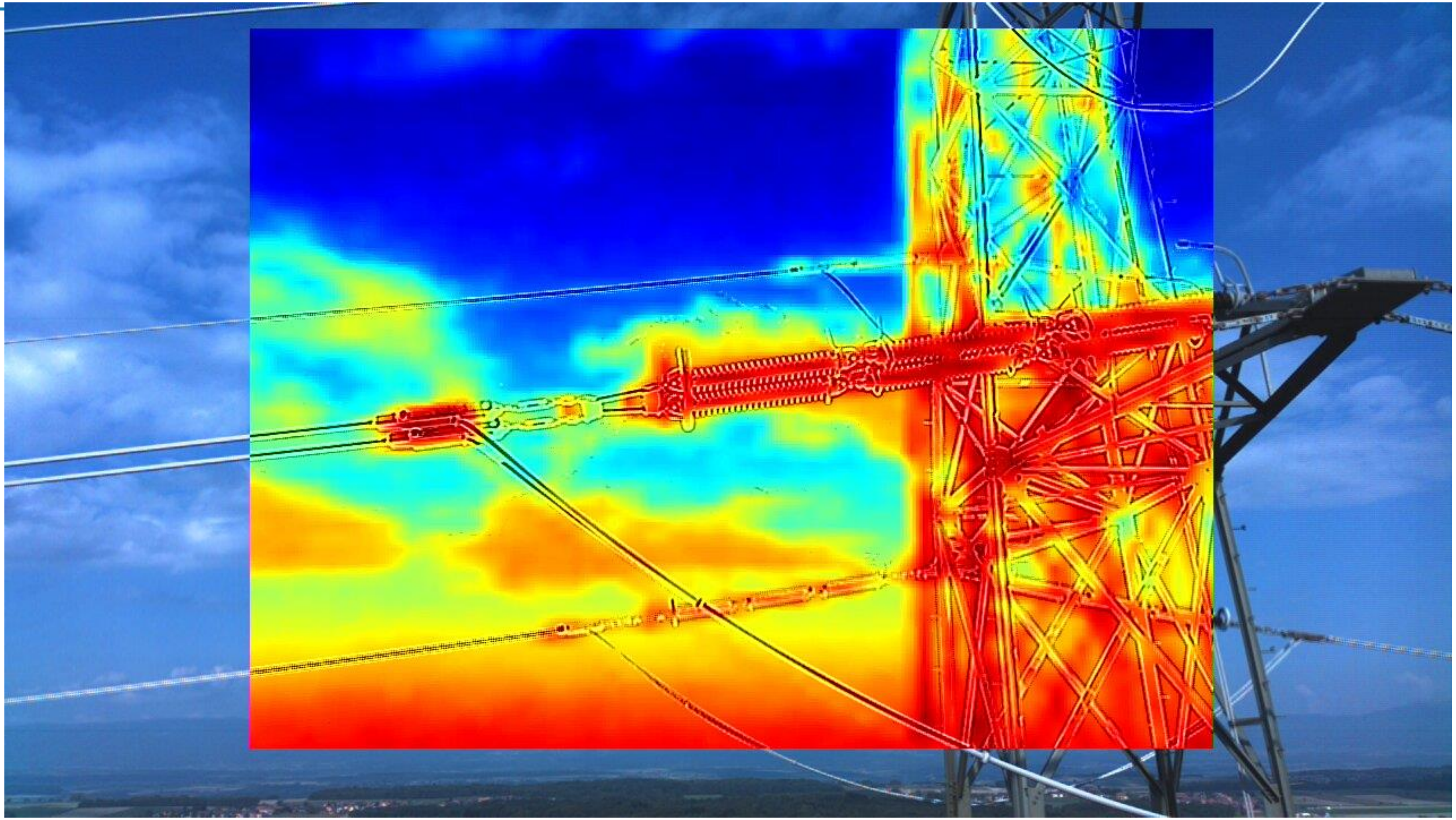
» Common in inspection work



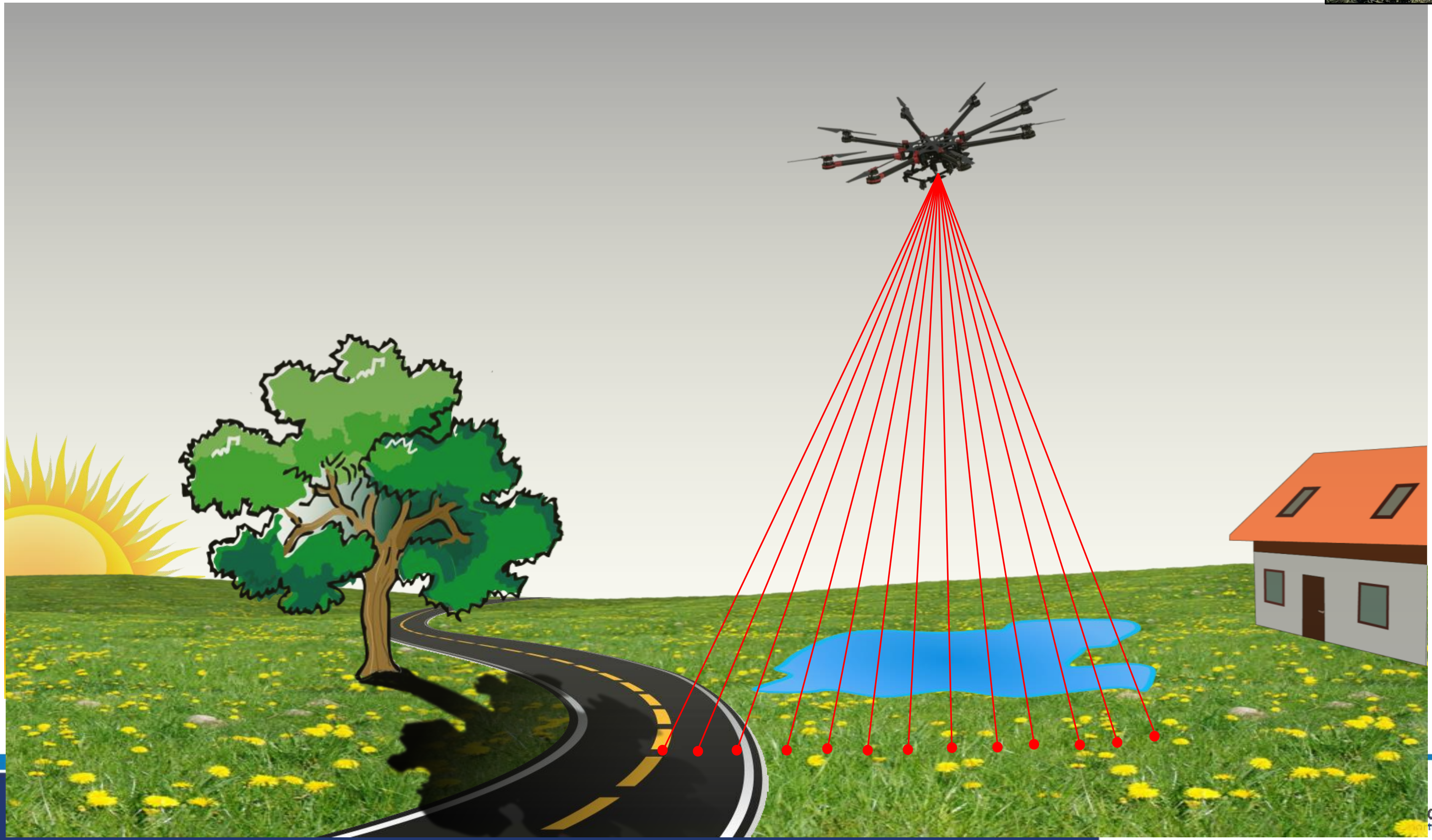
# Importance of NavCams & Obstacle Avoidance



# Thermal Camera



# Sensor Types: Lidar



# Sensor Types: Cameras

# Ground Control Station


- Takeoff and landing zone
  - » Large, clear, flat area
  - » Away from people
  - » Access permissions (!)

# Test Bridge Inspections

(1) Independence Bridge

(2) Crooked River Bridge

(3) Mill Creek Bridge

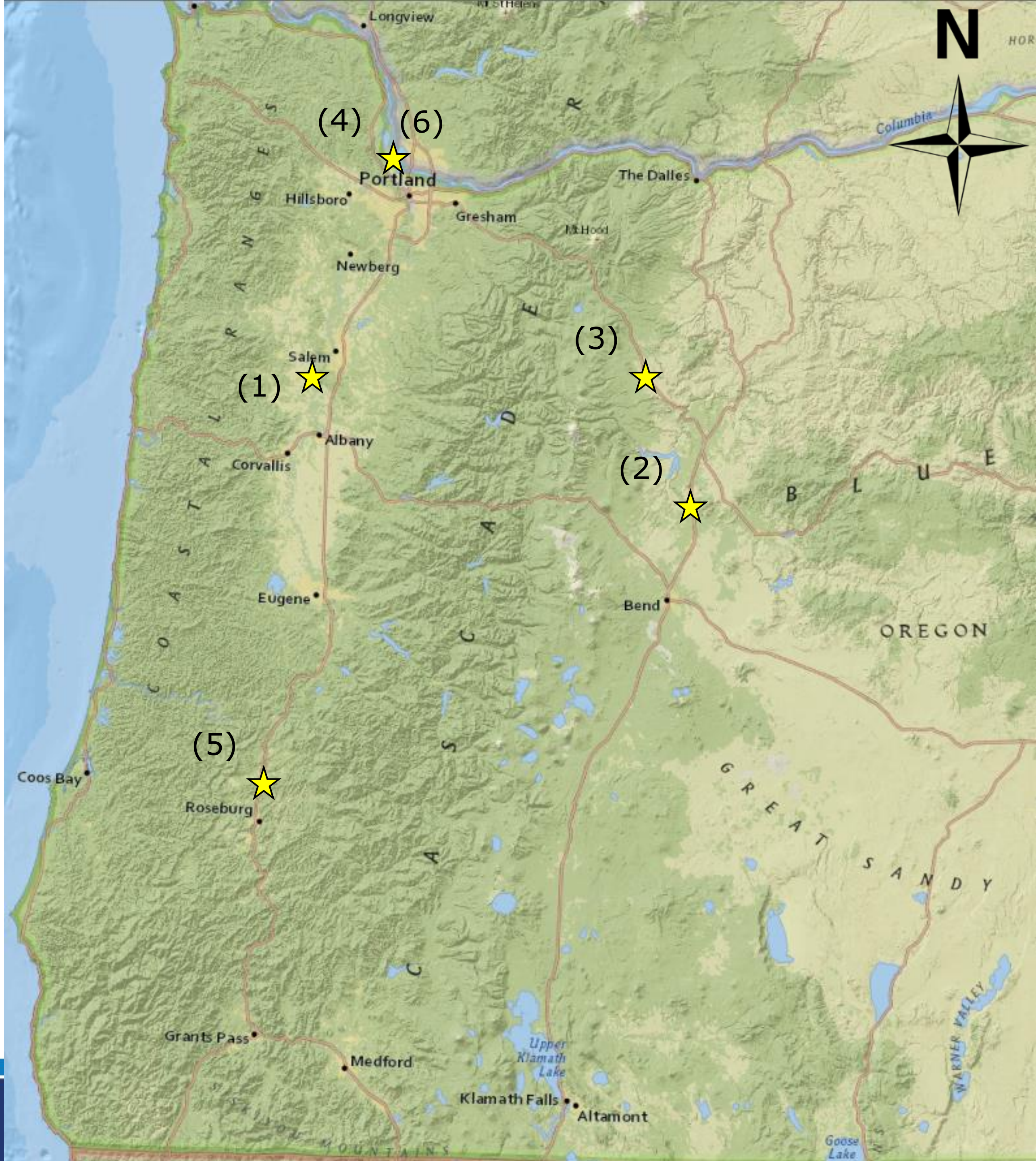
(4) St. Johns Bridge

» Preliminary

(5) Winchester Bridge

(6) St. Johns Bridge

» Detailed



# Test Bridge Inspection: Independence Bridge, Sept 2015

- Location: Independence, OR
- Airframe: Phantom 3 Pro
- Flight objective
  - » Test bridge inspection workflow
  - » Capture still and video imagery
- Details
  - » Large deck plate girder bridge
    - – 675.4 m long
    - – Longest span: 46.3 m
  - » Classified as Fracture Critical

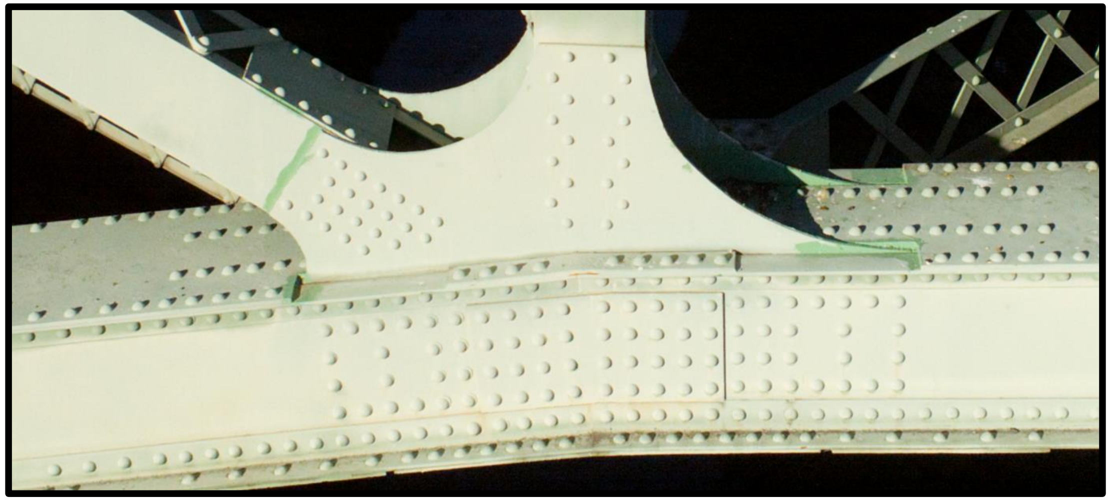
# Independence Bridge: Imagery Examples

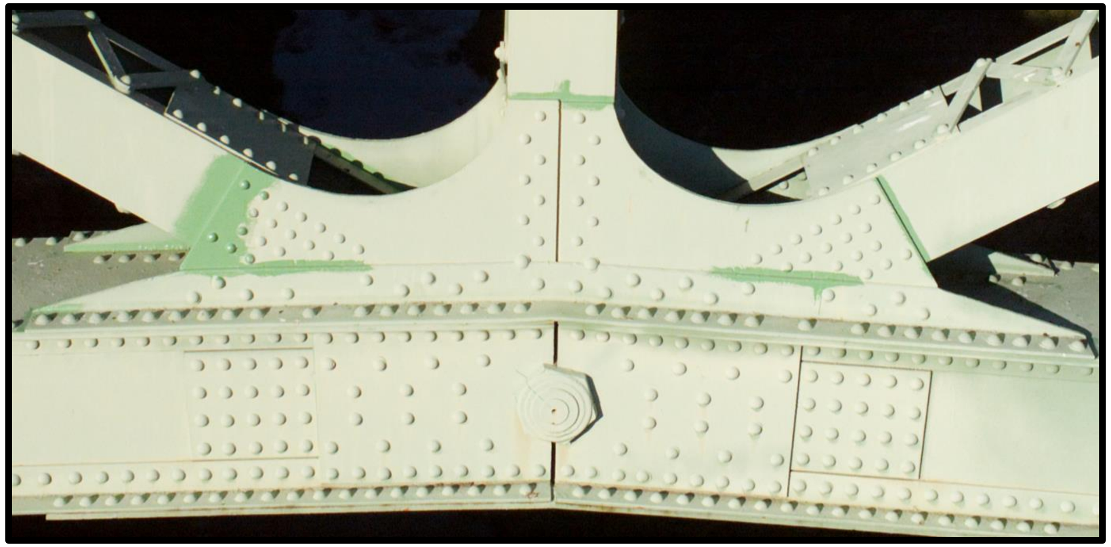
# Independence Bridge: Imagery Examples

# Test Bridge Inspection: Crooked River Bridge, July 2016

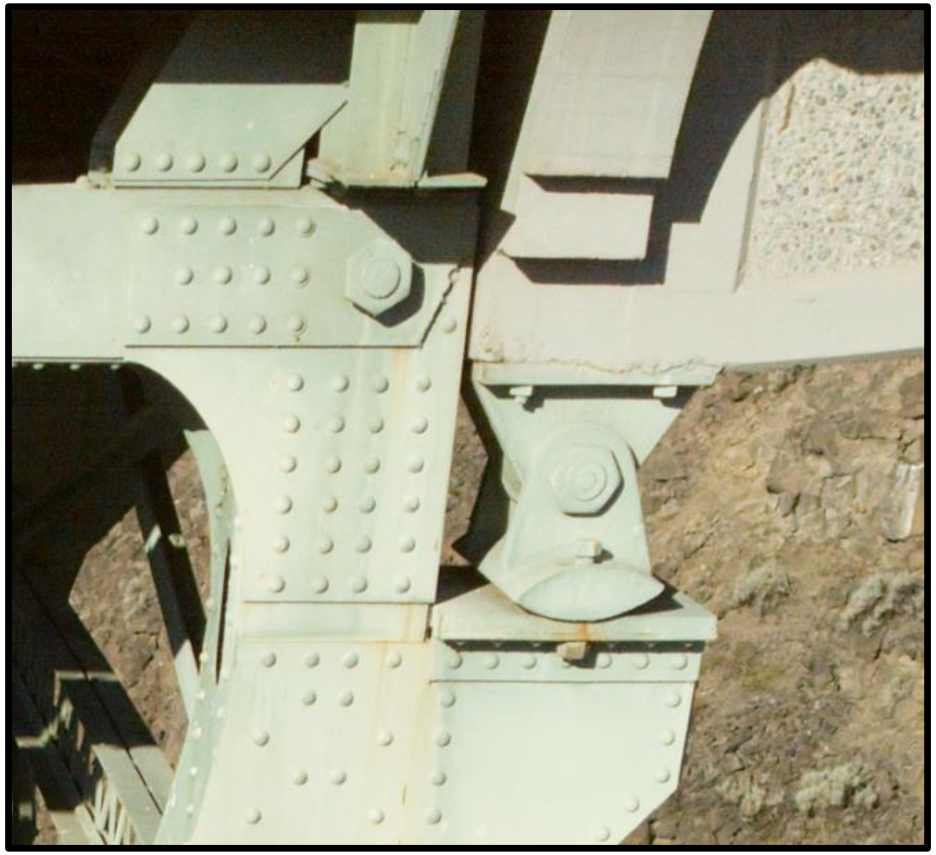
- Location: 8 km north of Terrebonne, OR
- Airframe: senseFly Albris
- Flight objective
  - » Capture high-quality imagery for inspection purposes
  - » Targeting specific areas that are difficult to inspect using traditional methods
  - » Create 3D model via SfM
- Details
  - » Steel Arch Bridge
  - » 141 m long
    - – Longest span: 100 m
  - » Pedestrian only

# Crooked River Bridge: Imagery Examples

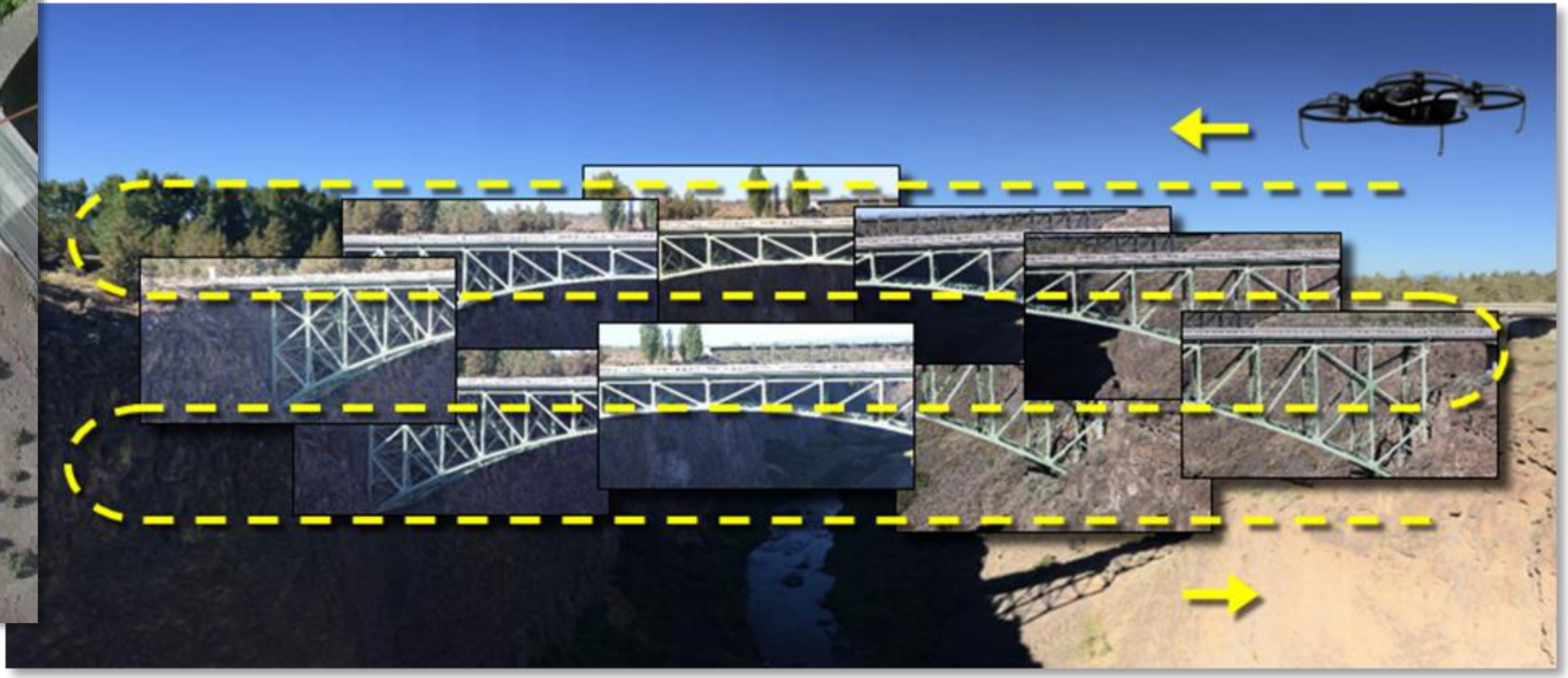




# Crooked River Bridge: Imagery Examples

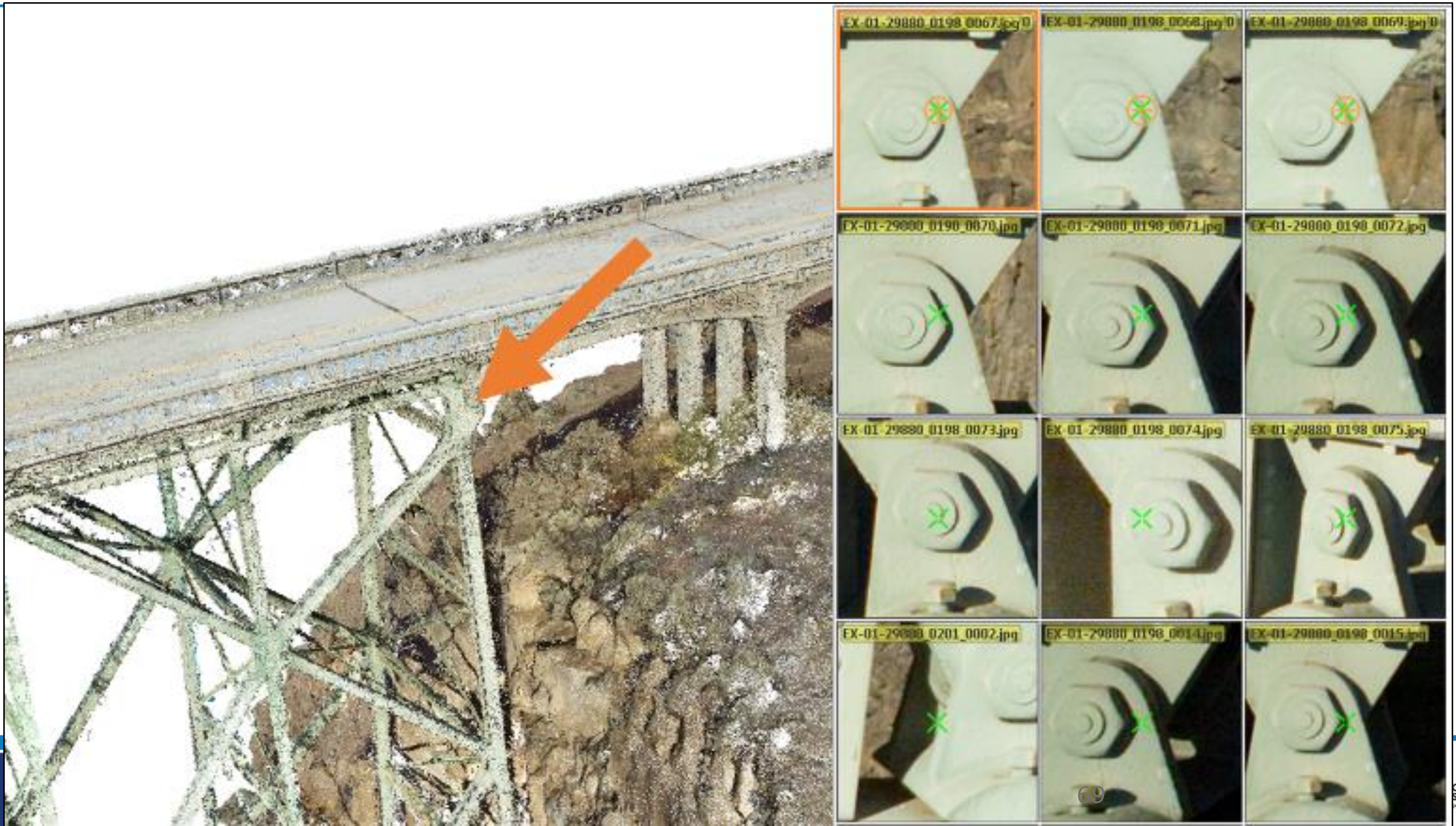


# Crooked River Bridge: Mapping Flights

# Crooked River Bridge: Point Cloud

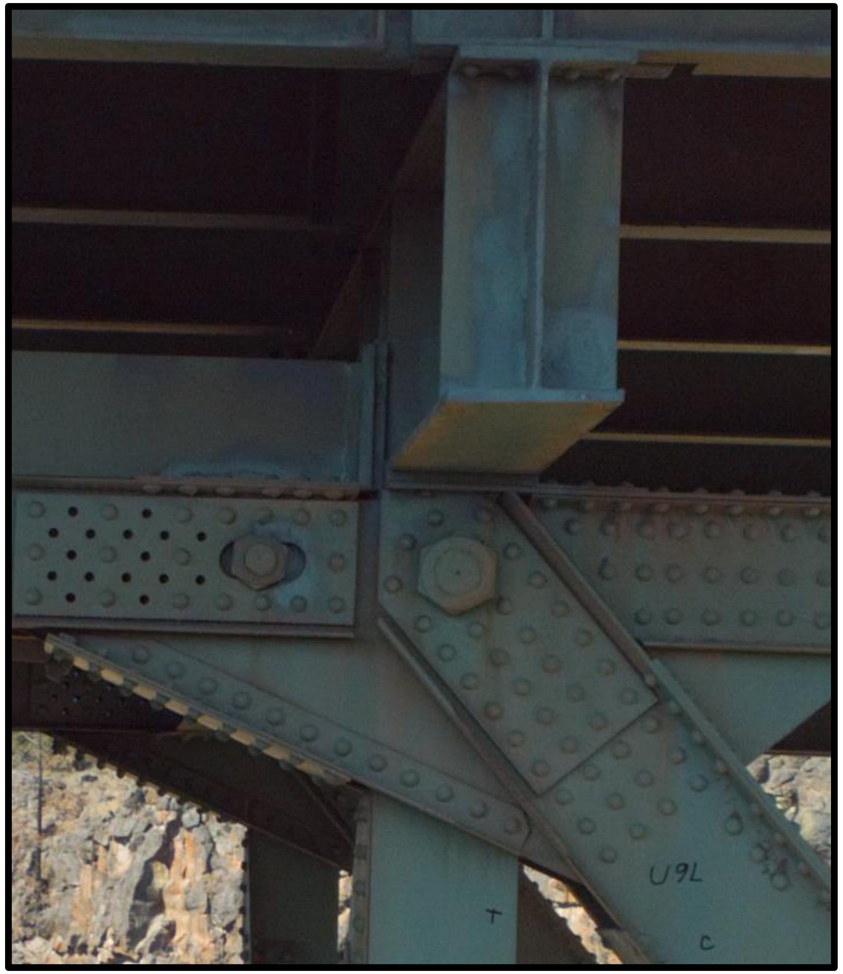
# Point Cloud ↔ Raw Imagery



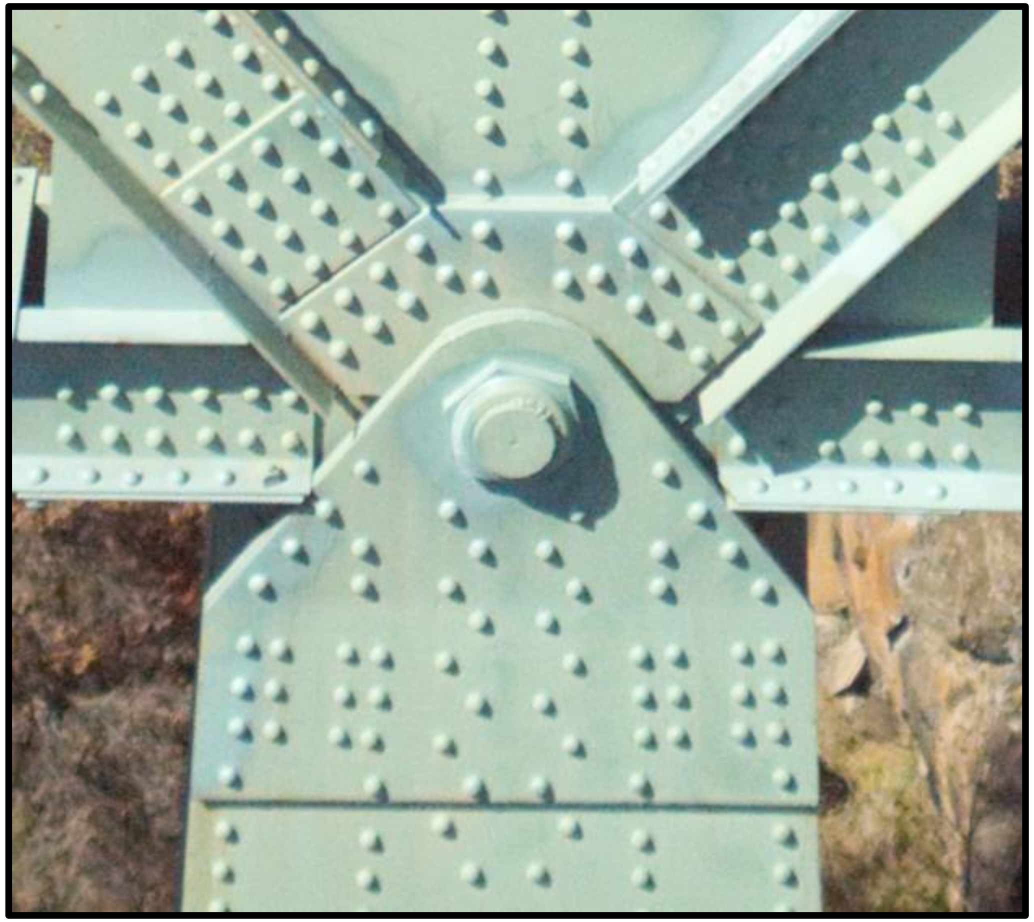
# Test Bridge Inspection: Mill Creek Bridge, July 2016

- Location: 17 km NW of Warm Springs, OR
- Airframe: senseFly Albris
- Flight objective
  - » Capture high-quality imagery for inspection purposes
  - » Targeting specific areas that are difficult to inspect using traditional methods
- Details
  - » Cantilevered Warren deck truss bridge
  - » 163 m long
    - – Longest span: 50 m

# Mill Creek Bridge: Imagery Examples




# Mill Creek Bridge: Imagery Examples



# Test Bridge Inspection: St. Johns Bridge (Prelim Test), Sept 2016

- Location: Portland, OR
- Airframes: senseFly Albris, s900 with Sony WX500 (30x optical zoom)
- Flight objective
  - » Test of optical zoom camera
  - » Capture high-quality imagery
- Details
  - » Metal Riveted Warren deck truss
  - » Wire Cable Suspension
  - » 1100 m long
    - – Longest span: 368 m

# St. Johns Bridge: Imagery Examples

# St. Johns Bridge: Imagery Examples

# St. Johns Bridge: Imagery Examples

# Test Bridge Inspection: Winchester Bridge, March 2017

- Location: Winchester, OR
- Airframes: senseFly Albris
- Flight objective
  - » Capture imagery while receiving real-time input from inspectors
- Details
  - » Warren deck truss bridge
  - » Southbound bridge of I-5
  - » 500 m long
    - – Longest span: 42 m

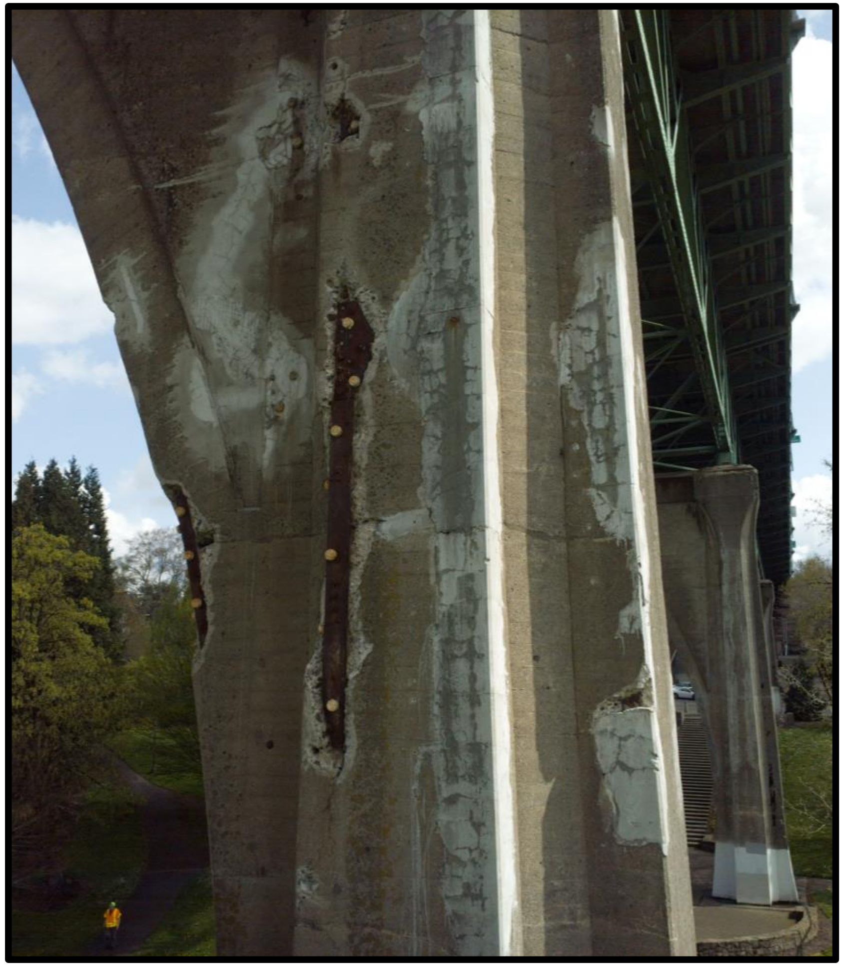
# Winchester Bridge: Imagery Examples

# Winchester Bridge: Imagery Examples

# Test Bridge Inspection: St. Johns Bridge (Detailed Test), April 2017

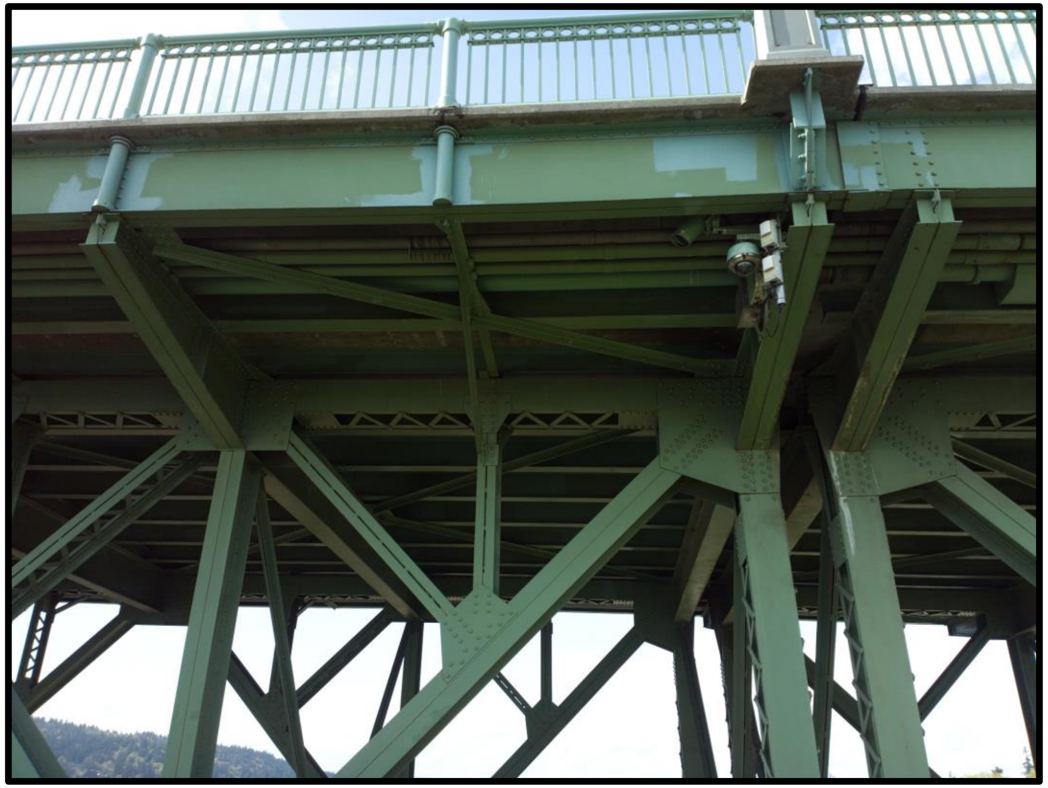
- Location: Portland, OR
- Airframes: senseFly Albris
- Flight objective
  - » Week-long, in-depth inspection
  - » Test inspecting directly under deck
- Details
  - » Metal Riveted Warren deck truss
  - » Wire Cable Suspension
  - » 1100 m long
    - – Longest span: 368 m
  - » Flight limited to eastern 550 m from center of main span

# St. Johns Bridge: Imagery Examples



# St. Johns Bridge: Imagery Examples

# St. Johns Bridge: Imagery Examples



# St. Johns Bridge: Imagery Examples

# St. Johns Bridge: Imagery Examples

# St. Johns Bridge: Imagery Examples

# Cost-Benefit Analysis Procedures

1. Establish baseline costs for bridge inspections conducted *without* the use of UAS by compiling existing data from Oregon DOT
   » 33 bridge inspection project budget spreadsheets
2. Determine the percentage of bridges that Oregon DOT inspects that are suitable for UAS inspection
   » Airspace, proximity to populated areas, vegetation, size of bridge, etc.
3. Establish which project cost categories could be reduced (not eliminated) through use of UAS:
   » Personnel time (field and office)
   » Equipment rental/usage (e.g., snooper trucks)
   » Traffic control
   » Travel (including lodging, meals and incidentals)

# Cost-Benefit Analysis Procedures (cont'd)

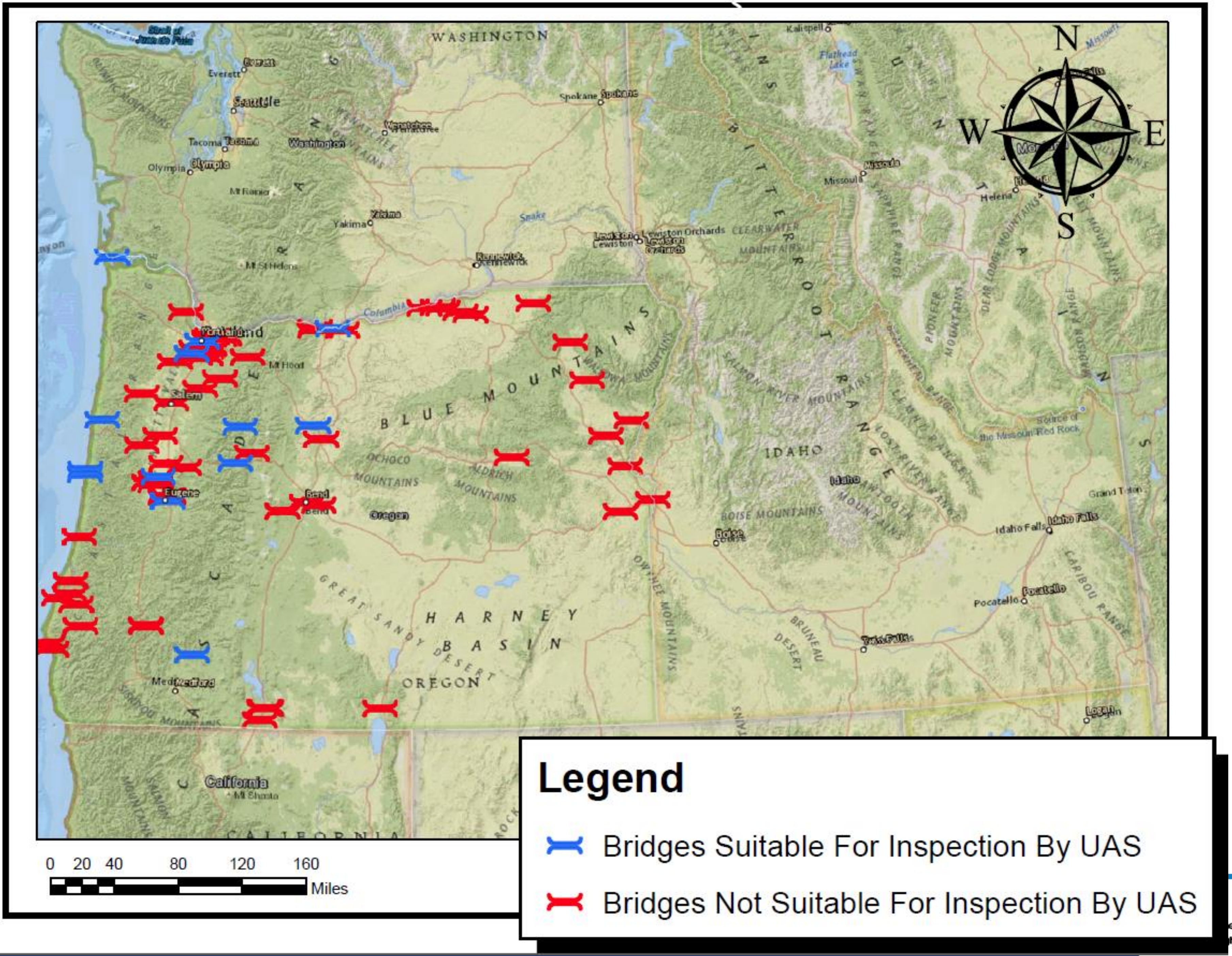
4. Estimated annual cost savings = (average cost savings per suitable bridge) × (# of bridges/yr inspected by ODOT) × (percentage of bridges suitable for UAS inspection)

5. Estimate costs:
   - » Cost of purchasing 3 UAS
   - » Annual maintenance cost
   - » Data storage

$$B = \$10{,}200(730 \times 0.16) = \$1{,}191{,}360$$

$$\sum C = \$117{,}237 + \$4{,}500 + \$5{,}700 = \$127{,}437$$

$$\boldsymbol{BCR = \frac{\$1{,}191{,}360}{\$127{,}437} \approx 9}$$




- Reasons bridges were deemed “not suitable”
  - Low height, low clearance bridges, where it wouldn’t be worthwhile to use UAS
  - Airspace
  - Access issues
  - Vegetation poses risks to UAS
  - Lack of suitable takeoff/landing site

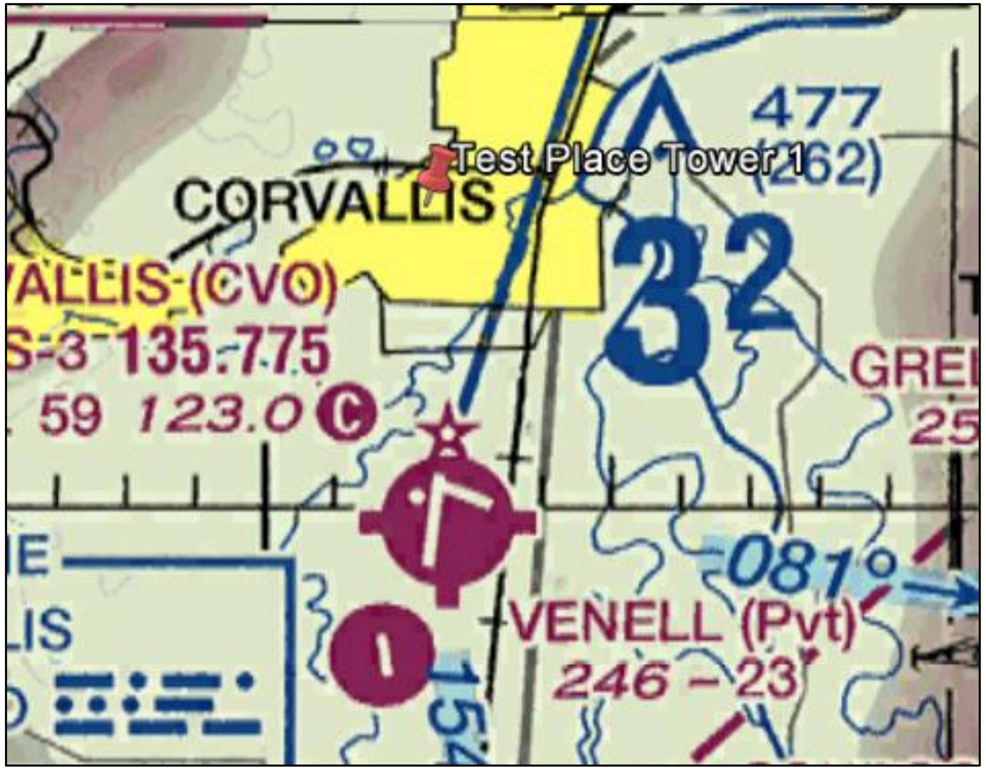
# Key Project Findings

- UAS can assist to varying degrees in many required elements of a bridge inspection
  - Very well suited for **initial and routine inspections** and for satisfying report requirements related to geometry and structural evaluation
- Cracks, pack rust, connections, hardware and bearing locations were all determined to be readily-identifiable in the imagery collected in this project, with the recommended flight procedures
- Cost-benefit analysis provides strong indication of positive ROI for implementing UAS in ODOT's bridge inspection program
  - Potential for >$1M in savings/year from use of UAS in structural inspections in large bridge inspection program
  - Should be refined as more data becomes available

# Practical Recommendations/Lessons-Learned

- Remote aircraft requirements
  - » Variable tilt (0-180°) camera
  - » Zoom lens
  - » Obstacle avoidance capabilities
  - » Establish max wind speeds for structural inspections (aircraft dependent)
- Personnel requirements
  - » UAS bridge inspection flight crews should have at least a basic level of expertise in photography
    - – ISO, aperture, shutter speed
  - » Frequent practice (proficiency flights) *specifically for structural inspection*
    - – Simulate: loss of GPS, wind gusts, operating near large structure

# Safety Plan

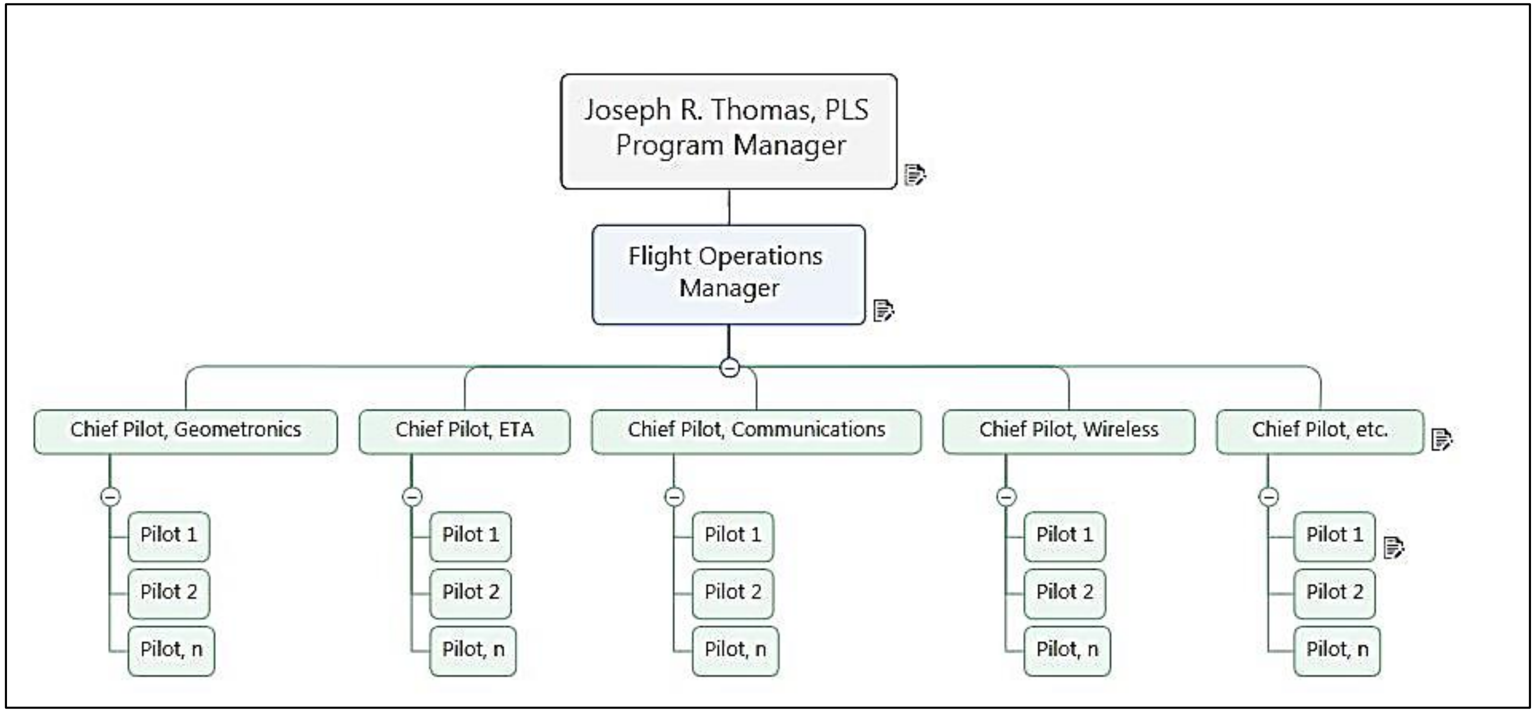


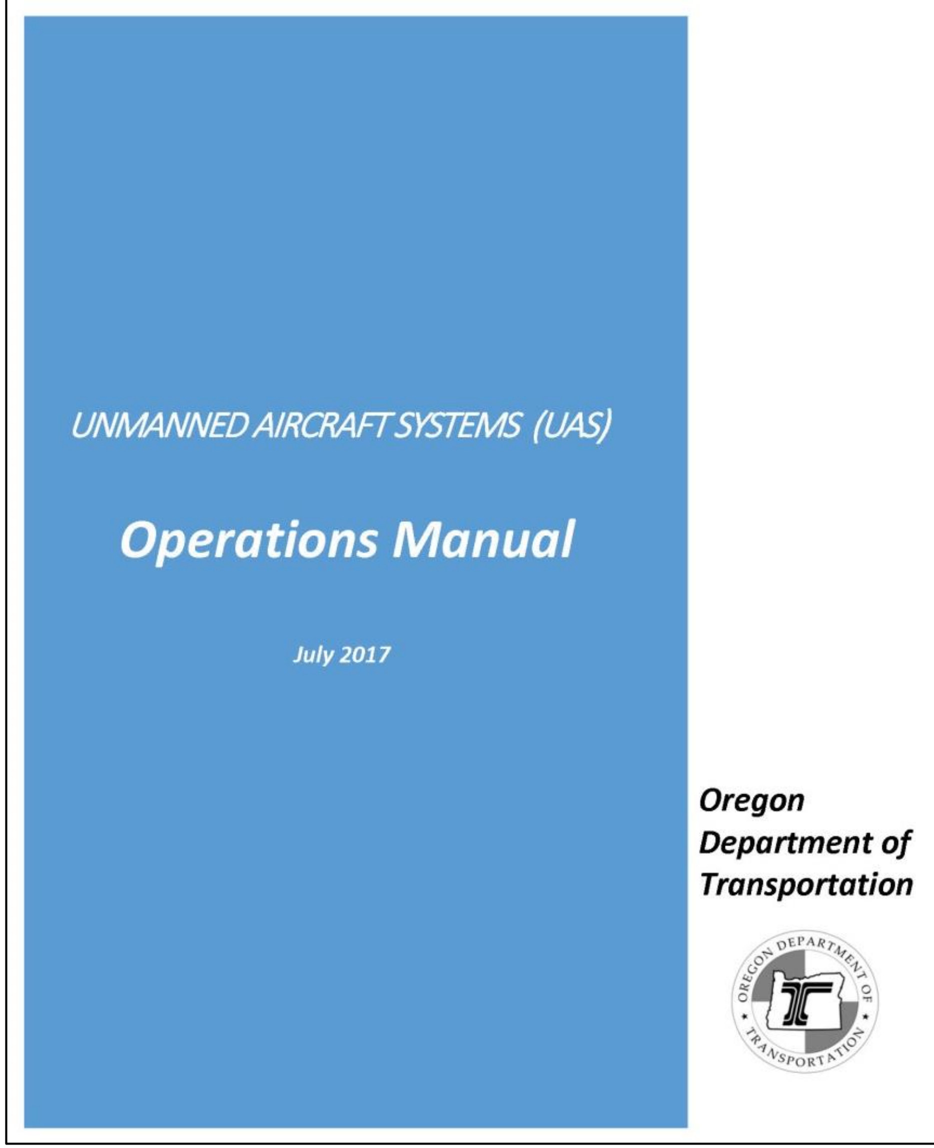

| | | | | |
|---|---|---|---|---|
| Date of Assessment: | 04/25/2016 | Personnel: | Pilot in Command: | Tom Normandy |
| Structure Type: | Communication Tower | | Primary Observer: | Matt Gillins |
| Location of Structure: | 44°26’10.8” N 122°59’07.1” W | | Other Spotters: | Farid Javadnejad<br>Dan Gillins<br>Chris Parrish |
| Owner of Structure: | ODOT | | | |
| Owner’s Contact info: | 555 13th St<br>NE Salem, OR 97301-6867<br>Phone (503) 986-2700 | | COA Number: | 2015-AHQ-105-COA-TS |
| | | | Team ‘s Emergency Contact Number: | (818)-497-8576 |
| Airport within 5 nm? | Yes: X | No: | Airport Manager: | Jacob Kropf |
| If Yes Which: | J & J airport | | Manger Contact info: | (541)-766-6783 |
| Distance from Airport: | 3.2 nm | | Radio Frequency Air Traffic Controller: | N/A<br>UNICOM 123.0 |

**Safety Inventory:** Mark yes or no if any of the following hazards are potential for work site.

| YES | NO | Equipment Hazards | YES | NO | Personal Hazards | YES | NO | Environmental Hazards |
|---|---|---|---|---|---|---|---|---|
| X | | Nearby Vehicular Traffic | | X | Twisting/Bending/Awkward Positions/ Heavy Lifting | | X | Falling Debris |
| | X | Nearby Heavy Equipment Operations | | X | Working Over water | | X | Confined Space |
| | X | Transport/Launch of Boat/ATV/Etc. | | X | Loose unstable footing | X | | Weather Related |
| | X | Boat/Watercraft Operations | X | | Slip/Trip/Fall Hazard | X | | Live Stock/Wildlife |
| | X | ATV Operations | | X | Ladders/Elevated Platforms | X | | Transients |
| X | | Other | | X | Other | | X | Other |

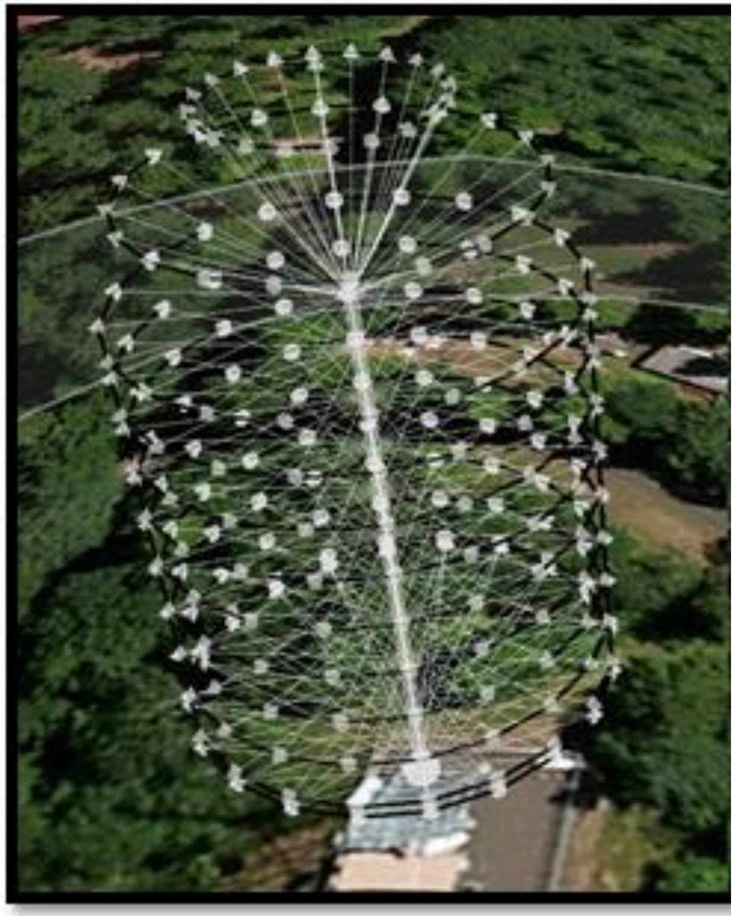
# Oregon DOT UAS Program



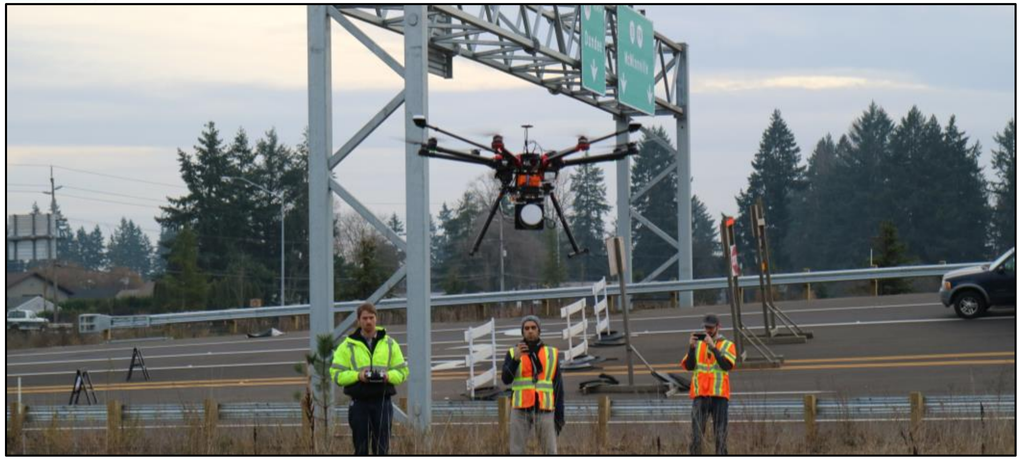



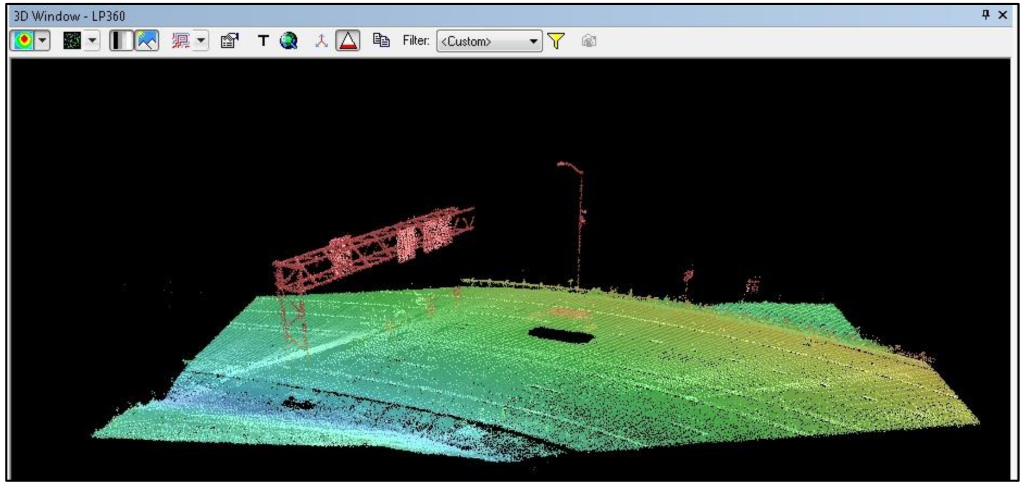

Courtesy of Chris Glantz, PLS, Oregon Department of Transportation

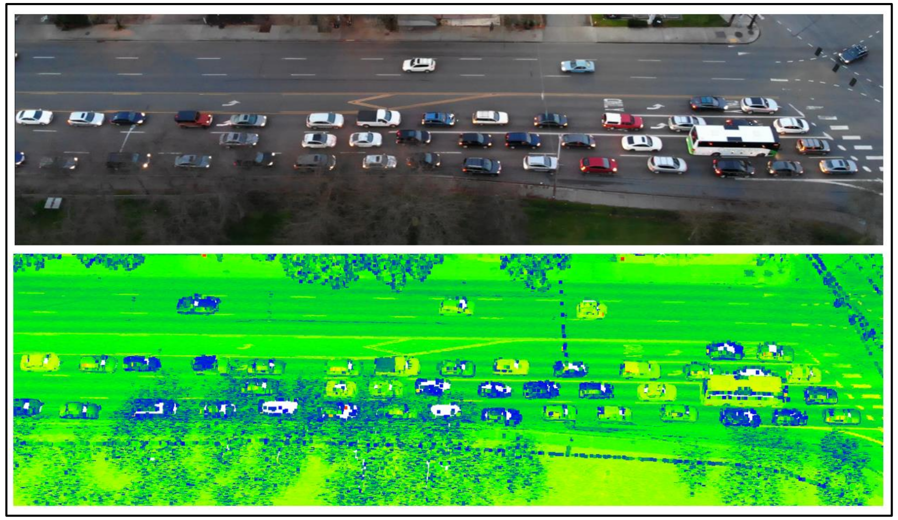
# Related Work: Communication Tower Inspections



# Related Work: UAS Traffic Network Monitoring (PacTrans)





U.S. Department of Transportation
Federal Highway Administration

OKLAHOMA Transportation

LOCAL TECHNICAL ASSISTANCE PROGRAM
College of Engineering, Architecture and Technology

# References

Gillins, D.T., C.E. Parrish, and M.N. Gillins, 2018. *Eyes in the Sky: Bridge Inspections with Unmanned Aerial Vehicles, SPR 787 Final Report*. Oregon Department of Transportation: https://www.oregon.gov/ODOT/Programs/ResearchDocuments/SPR787_Eyes_in_the_Sky.pdf

Gillins, M.N., D.T. Gillins, and C. Parrish, 2016. Cost-Effective Bridge Safety Inspection using Unmanned Aircraft Systems (UAS). GEO Structures Congress 2016 14-17 Feb, Phoenix, Arizona.

Parrish, C.E., D. Hurwitz, C. Simpson, S. Sorour, and A. Abdel-Rahim, 2019. *An Airborne Lidar Scanning And Machine Learning System For Real-time Event Extraction And Control Policies In Urban Transportation Networks*. PacTrans Final Project Report (in review).

Parrish, C., R. Slocum, and C. Simpson, 2018. UAS in Transportation Expo Final Report, online: http://depts.washington.edu/pactrans/wp-content/uploads/2018/11/UAS-in-Transportation-Report.pdf

# Questions/Comments/Additional Info:

Contact info:

Christopher.Parrish@oregonstate.edu

204 Owen Hall

Oregon State University

Corvallis, OR 97331

# Question & Answer

Jagannath Mallela
*Moderator*

Jennifer Wells
Minnesota DOT
651.366.4573
jennifer.wells@state.mn.us

Dr. Chris Parrish
Oregon State University
541.737.5688
Christopher.Parrish@oregonstate.edu