UAS Research in Support of ODOT Operations
Presentation Overview

• Project Objectives, Scope, and Team

• Hardware and Software Platforms
  • UAVs
  • Common Operating Platform
  • Mobile Mission Milestone Box

• Automated Traffic Monitoring
  • Uninterrupted Flow
  • Interrupted Flow

• Aerial Mapping and Construction Monitoring

• Bridge and Facility Inspection
Project Objectives

• How can we improve ODOT core business functions by application of drone technologies?

• What are these missions? What drone configurations and capabilities are necessary to perform these missions?

Scope of Work

• Acquire the sensors and hardware and develop supporting software in order to integrate into prototype systems.

• Test and demonstrate prototype systems for select identified missions.

• Develop mission SOPs and training.

• Deliver all prototype equipment and supporting materials to ODOT.

Team

• Profs: Cohen (Aero), Helmicki (EECS), Hunt (EECS), Kumar (MechE), Norouzi (EECS)

• Staff/Students: Balasubramaniam, Brown, Chiddarwar, Garauv, Krishnan, Kumar, Saxena
Opportunity of drone-based solution

Max Return on Investment

- Video pre and post processing for feature extraction
- Development and optimization of algorithms
- Accuracy, precision, false alarms, missed detections, etc.

ODOT mission needs

- Rapid deployment at most locations subject to safe operations, FAA regs, and other legal considerations
- Obtain views not available from fixed mounted cameras
- Automated processing to obtain features: detection, classification, count, speed, headway, saturation rate, etc.
- Field data based as opposed to simulation based
- Interfacing/upload to Milestone

Processing capabilities

- UAS vehicles
- Sensor/camera package
- Mission profile (position, duration, piloting, etc.)

Flight capabilities
Current Standard Operating Procedures (SOPs)

SOPs for flight Operations, Mapping Structures and Producing 3D Models, and Traffic Monitoring using UAS
Current Project Flight Locations and Test Cases

D2 – Facilities Inspection
D6 – Facilities Inspection (ODOT HQ)
D7 – I75 Construction Work Zone
D7 -- County Line Road
D8 – I-75 Traffic Monitoring
D8 – Facilities and Bridge Inspection
D10 – Facilities Inspection
D10 – Construction Site Mapping
UAS Equipment, Payloads, and Software
Primary UAVs Used

**DJI Matrice 100**
- Specifications:
  - Development Platform
  - Flight Time of 20 – 35 minutes
- Use Cases:
  - Aerial Mapping
  - Traffic Monitoring

**DJI Matrice 210 RTK**
- Specifications:
  - Dual Camera System
  - Top Mounted Gimbal
  - Uses RTK (Real-Time Kinematic) GPS
  - Flight Time of 25 – 38 minutes
- Use Cases:
  - Bridge and Facilities Inspection
  - Aerial Mapping

Matrice 100 with Z3 Camera
Matrice 210 RTK with Z30 and XTR Cameras
Tethered Platform

Tethered Matrice 100

• Specifications:
  • Long endurance vehicle powered by generator
  • Current tested flight time: 4hrs

• Use Cases:
  • Primarily used for traffic monitoring

A test of the Matrice 100 with Tether flying for 4 hours, manufacture tested for over 19 hours
Primary Camera Systems

- Z30 – 30x Optical Zoom Camera (Bridge Inspection and Traffic Monitoring)
- Z3 – 3x (4K) Optical Zoom Camera (Mapping and Facilities Inspection)
- X5/X5S – High Resolution Camera with interchangeable lenses (Mapping and Traffic Monitoring)
- XTR – Thermal Radiometric Camera (Bridge and Facilities Inspection)
Mission Box Vision

- Milestone
- Common Operating Platform
- Visualize processed 3D Models, Videos, images, reports
- Video Encoder
- Video Post Processing
- Mission Box Controller
- Software Capture
- Video Capture
- Video Encoder
- Software Capture
- HDMI
- Wifi
- Mission Box Vision

Devices:
- Analog Goggles
- Phones/Laptops/Digital Goggles
Mission Box Ongoing Issues (As of Sep 2018)

v3.1 (Production Model):
- Improve the reliability of the box
- Improve the configuration of the components
- Improve the cellular coverage (Getting help from Sierra)

v3.4 (FirstNet Model):
- Working with the MG90 modem FirstNet modem is a challenge; four times the size of a conventional modem, more power consumption, sophisticated configuration

v4.0 (Advanced Model):
- Communicate with Modem to get modem status and GPS/GLONASS Data
- Communicate with Modems through SDK
Create a project

Common Operating Platform
Web based platform for centralized processing of 3D models and traffic videos
Workflows

Original workflow: v1.0

Create project folder & upload images

Pix4D/ODM processes project

Process 3D model for viewing on site

View 3D model on website

Proposed traffic monitoring workflow: coming soon in v3.0

Upload video to website

Apply video processing algorithms

Extract analytics and visualize on website

New workflow: v1.5

Supported file formats: .las, .laz

v2.0: Customized processing options for Pix4D (coming soon)
Automated Traffic Monitoring
Overview of traffic monitoring system for interrupted/uninterrupted traffic flow

**Input**
- Drone video
  - Flight altitude
  - Zoom Level
  - Camera perspective

**Processing Unit Toolbox**
- Object Detection
- Object Classification and Tracking
- Parameter Estimation

**Outputs**
- Headway, Saturation Flow Rate
- Queue Length
- Processed video
- Messages to User

**Interrupted Flow Parameters**
- Plot Speed Vs. Density Curve
- Plot Flowrate Vs. Density Curve
- Plot Speed Vs. Flowrate Curve

**Uninterrupted Flow Parameters**
- CSV file (Interval, Flowrate, Speed, Density)
Terminology for classification

Currently, we have capability to count and track passenger cars, buses and trucks.

For demonstration, today we have only 2 bins for classification:

- Blue – Passenger cars
- Green – Trucks

Future work involves training CNN for additional classes/bins
CNN approach to traffic monitoring

- **Network model**: Custom trained Faster Recurrent Convolutional Neural Network feature detector (fine-tuned)
- **Dataset used**: Drone recorded traffic videos in different angles manually labeled as 2 classes
  - Training Dataset: 1020 labeled traffic images (28,000 labels)
  - Test Dataset: 320 labeled traffic images (8,000 labels)
- **Training**: The CNN has been trained on this dataset for 10000 steps, approx. 28 hours (Intel i5-3320M CPU@2.60GHz)
- **Loss Function**: During training, total loss is calculated and the lower it is the better the model performs. Loss is for actual class vs predicted class & actual prediction vs output

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Custom trained fine tuned FASTER RCNN</th>
<th>Pre-trained YOLO network</th>
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<tbody>
<tr>
<td>Mean Average Precision (mAP)</td>
<td>98%</td>
<td>95%</td>
</tr>
<tr>
<td>False Positives</td>
<td>None</td>
<td>10%-15%</td>
</tr>
<tr>
<td>Missed Detections</td>
<td>10%</td>
<td>12%</td>
</tr>
<tr>
<td>Speed of the model (frames per second)</td>
<td>0.150 fps</td>
<td>0.33 fps</td>
</tr>
</tbody>
</table>
Uninterrupted Flow Traffic Parameters

• Flowrate: Measure that quantify amount of traffic passing through a point on lane or roadway in a time interval of one hour.

• Average travel speed: Computed by dividing length of road by average travel time of vehicles traversing it.

• Density: Number of vehicles in a length of roadway at a particular instant expressed as vehicles per mile.
Traffic analysis at I-75 and Mitchell Ave

- Low speed and high density traffic
- Traffic parameters extracted: flowrate, average travel speed and density

Classification:
- Blue – Passenger cars
- Green – Trucks

Graph shows comparison of traffic parameters
Another perspective: eye in the sky
Interrupted Flow Traffic Parameters

- Saturation headway \( (h) \) is estimated as the constant average headway between vehicles after the fourth vehicle in the queue and continuing until the last vehicle that was in the queue at the beginning of the green has cleared the intersection.

- Saturation flow rate \( (s) \) is defined as the flow rate per lane at which vehicles can pass through a signalized intersection. It represents the number of vehicles per hour per lane that can pass through a signalized intersection if the green signal was available for the full hour.
Flight Experiments at MLK and Clifton Signal

- Record multiple traffic video using UAV and record GoPro video with traffic lights in the frame
- Create an event in UAV and GoPro videos by flashing a light to synchronize the videos
- Process the traffic videos using computer vision algorithm to compute parameters of interest
- Validate results from computer vision algorithm against Jamar TDC-8 counter
## Results for MLK and Clifton Signal[~4.15 pm]

<table>
<thead>
<tr>
<th>Test case</th>
<th>Angle from the road θ</th>
<th>Distance from road (ft) d</th>
<th>Altitude (ft) a</th>
<th>Number of green signals</th>
<th>Headway Lane 1</th>
<th>Jamar Headway Lane 1</th>
<th>Saturation Flow rate Lane 1</th>
<th>Jamar Saturation Flow rate Lane 1</th>
<th>Percent Error in Saturation Flow Rate Lane 1</th>
<th>Headway Lane 2</th>
<th>Jamar Headway Lane 2</th>
<th>Saturation Flow rate Lane 2</th>
<th>Jamar Saturation Flow rate Lane 2</th>
<th>Percent Error in Saturation Flow Rate Lane 2</th>
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<td>45</td>
<td>150</td>
<td>150</td>
<td>6</td>
<td>2.27</td>
<td>2.24</td>
<td>1581.5</td>
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<td>-0.41</td>
<td>2.28</td>
<td>2.24</td>
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<td>1603.5</td>
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<td>2</td>
<td>50</td>
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<td>2.16</td>
<td>2.25</td>
<td>1661.7</td>
<td>1598.7</td>
<td>0.17</td>
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<td>50</td>
<td>150</td>
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<td>2.38</td>
<td>2.45</td>
<td>1508.4</td>
<td>1465.9</td>
<td>-1.47</td>
</tr>
</tbody>
</table>

### Lane 1 headway data

- Headway: h= 2.27 s
- Saturation flow rate = 1581.5 veh/hr/lane

### Lane 2 headway data

- Headway: h= 2.24 s
- Saturation flow rate = 1604.1 veh/hr/lane
Interrupted Traffic Flow: Queuing Study at US-50

- Capacity is defined as the maximum number of vehicles that can reasonably be expected to pass through the intersection under prevailing traffic, roadway, and signalization conditions during a 15-min period.

- **Undersaturated traffic flow** - When the capacity of intersection is more than the demand at certain point of time, it means that the intersection is able to service all vehicles arriving and leaving the intersection during the green and red light phases.

- **Oversaturated traffic flow** - When the capacity of intersection is less than the demand at certain point of time, it is termed as oversaturated traffic flow and the intersection is not able to service all vehicles arriving the intersection during red and green light phases.

- The time required for the queue to dissipate represents the queue service time.
Oversaturated Intersection on US-50

- When the intersection is oversaturated, it is quite possible that the tail of the queue may not be visible in the video frame. So, a new metric “Level of Service (LOS)” is used to predict intersection delays.

Note: - The increment and decrement on y-axis has been shown as straight lines w.r.t signal change but in real scenario it will not be linear, it is a function of arrival and departure of vehicles at the intersection.

<table>
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<tr>
<th>LOS</th>
<th>Signalized Intersection</th>
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<tr>
<td>A</td>
<td>≤10 sec</td>
</tr>
<tr>
<td>B</td>
<td>10–20 sec</td>
</tr>
<tr>
<td>C</td>
<td>20–35 sec</td>
</tr>
<tr>
<td>D</td>
<td>35–55 sec</td>
</tr>
<tr>
<td>E</td>
<td>55–80 sec</td>
</tr>
<tr>
<td>F</td>
<td>&gt;80 sec</td>
</tr>
</tbody>
</table>

Source: HCM
Aerial Mapping
Construction Monitoring
UCII UAV Workflow

**CAPTURE**

**PROCESS**

**ANALYZE/VISUALIZE**

Professional photogrammetry software for drone based mapping

UCII Common Operating Platform

*insert one line about COP*
Flow Chart for Mapping/Modelling Mission Planning and SOPs
(Captures interactions between hardware, software, and flight ops)

2) Camera Settings:
- Sensor Width (mm)
- Real Focal Length (mm)
- Image Width (pixels)
- Image Height (pixels)

1) Structure Specifics and Flight Purpose:
- Height of Structure (m)
- Max GSD Structure Roof (cm/px)
- Min % Overlap on Structure (%)
- GCPs, MTPs needed?
- RTK needed?

3) UCII Flight Ops Calculator:
- GSD on ground (cm/px)
- Height of Flight (m)
- % Overlap on Ground (%)

4) Mission Checks:
- Is the flight-time acceptable?
- Does the altitude over the structure avoid any potential obstructions?
- Does mission consist of more than 99 waypoints? (GSPro)

5) Upload to UAV and Fly Mission

6) Pix4DMapperPro (2D and 3D modelling)

Form a template used in other future SOPs: Traffic Monitoring, Bridge/Facility Inspection, Construction Monitoring, etc.
Construction and Aerial Mapping
D10 SR266 (Earth Excavation Project)

Mission Overview
• Mapped Area: >200 Acres
• The construction area was divided into 4 areas.
• This aided in:
  • Flying the UAV for short period of time.
  • Logistics.

Purpose
Volume of earth that was excavated and filled was measured using the 3D Point Cloud and DSM.
Mission Overview

• **Mapped Area:** >14 Acres
• The construction area was divided into 5 areas.
• This aided in:
  • Flying the UAV for short period of time, and maintain desired GSD
  • Logistics.

Purpose

Area of pre-splits in the intersection was measured using point clouds and marking surfaces using Pix4D.
Construction and Aerial Mapping
D10 Norwood Landslide Mapping

Mission Overview

• **Mapped Area:** >2 Acres

• his aided in:
  • Flying the UAV for short period of time, and maintain desired GSD
  • Logistics

Purpose

Area of pre-splits in the intersection was measured using point clouds and marking surfaces on Pix4D.

Point Cloud of Land Erosion at the Landslide site

3D Model of Landslide, Newport, OH
Facility and Bridge Inspection
Facilities and Bridge Inspection

Explanation of GSD & Overlap in Images

**Ground Sampling Distance (GSD)** is the actual size of the ground corresponding to an individual pixel.

\[
\text{GSD}_{\text{average}} = \frac{H \text{ (m)} \times Sw \text{ (mm)} \times 100}{Fr \text{ (mm)} \times Im_{\text{width}} \text{ (px)}}
\]

- \(H\): Height of flight (m)
- \(Sw\): Camera Sensor Width (mm)
- \(Fr\): Real focal length (mm)
- \(Im_{\text{width}}\): Width of Image (px)

**Overlap** percentage between images is the amount by which one image includes the area covered by the next image. There are two types of overlap values:

1. **Side Overlap**: Refers to the percentage of overlap between different flight leg.
2. **Front Overlap**: Refers to the percentage of overlap between one image and the next, taken by the drones when flying in the same direction.

Experiments were run to ensure desired overlap of images on top of structures was achieved.
Facilities and Bridge Inspection
Crack Detection Experiments

- **Aim & Procedure:**
  - Experiment was conducted in-lab to check the effect of distance when documenting cracks.
  - Experiments were done using the DJI X5s, and DJI Z30 (using different zoom levels)
  - Images of the crack comparator card was taken using the M210 drone at varying distances from 2ft to 100ft.
  - The theoretical GSD value of the images were calculated according to the camera used and distance of capture.
  - A heat map of the theoretical GSD and distance was created.
  - The images are being analyzed to check if the calculated GSD value and the observations in the photograph agree.

![Crack Comparator Card used for reference](image-url)
## Crack Detection Experiments

**Facilities and Bridge Inspection**

<table>
<thead>
<tr>
<th>Distance (ft/m)</th>
<th>Camera</th>
<th>Z30</th>
<th>X5S</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (0.6096m)</td>
<td>0.348m/px</td>
<td>0.173m/px</td>
<td>0.069m/px</td>
</tr>
<tr>
<td>3 (0.9144m)</td>
<td>0.511m/px</td>
<td>0.260m/px</td>
<td>0.104m/px</td>
</tr>
<tr>
<td>4 (1.2192m)</td>
<td>0.665m/px</td>
<td>0.347m/px</td>
<td>0.139m/px</td>
</tr>
<tr>
<td>5 (1.524m)</td>
<td>0.869m/px</td>
<td>0.437m/px</td>
<td>0.178m/px</td>
</tr>
<tr>
<td>6 (1.8288m)</td>
<td>1.043m/px</td>
<td>0.521m/px</td>
<td>0.205m/px</td>
</tr>
<tr>
<td>7 (2.1336m)</td>
<td>1.217m/px</td>
<td>0.608m/px</td>
<td>0.249m/px</td>
</tr>
<tr>
<td>8 (2.4384m)</td>
<td>1.391m/px</td>
<td>0.695m/px</td>
<td>0.278m/px</td>
</tr>
<tr>
<td>9 (2.7432m)</td>
<td>1.555m/px</td>
<td>0.783m/px</td>
<td>0.310m/px</td>
</tr>
<tr>
<td>10 (3.048m)</td>
<td>1.718m/px</td>
<td>0.868m/px</td>
<td>0.347m/px</td>
</tr>
<tr>
<td>11 (3.453m)</td>
<td>1.882m/px</td>
<td>1.001m/px</td>
<td>0.389m/px</td>
</tr>
<tr>
<td>12 (3.858m)</td>
<td>2.046m/px</td>
<td>1.134m/px</td>
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<tr>
<td>13 (4.263m)</td>
<td>2.210m/px</td>
<td>1.267m/px</td>
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<tr>
<td>14 (4.669m)</td>
<td>2.374m/px</td>
<td>1.399m/px</td>
<td>0.512m/px</td>
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<tr>
<td>15 (5.074m)</td>
<td>2.538m/px</td>
<td>1.532m/px</td>
<td>0.553m/px</td>
</tr>
<tr>
<td>16 (5.480m)</td>
<td>2.702m/px</td>
<td>1.665m/px</td>
<td>0.594m/px</td>
</tr>
</tbody>
</table>

**Lens = 15mm**

<table>
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<th>Lens = 45mm</th>
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<tbody>
<tr>
<td>2 (0.6096m)</td>
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<td>3 (0.9144m)</td>
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<tr>
<td>4 (1.2192m)</td>
</tr>
<tr>
<td>5 (1.524m)</td>
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<td>6 (1.8288m)</td>
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<td>12 (3.858m)</td>
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<tr>
<td>13 (4.263m)</td>
</tr>
<tr>
<td>14 (4.669m)</td>
</tr>
<tr>
<td>15 (5.074m)</td>
</tr>
<tr>
<td>16 (5.480m)</td>
</tr>
</tbody>
</table>

- **GSD values (mm/px)**
- **Distance values (ft/m)**
- **Camera options: M210, Z30, X5S**
Facilities and Bridge Inspection

ODOT HQ, Columbus

Cross-referring both visual and thermal orthomosaics would allow an inspector to make an informed decision about a structure.

Possible wear in insulation due to its proximity to a drain hole.

Visual Inspections using visual orthomosaic

Thermal Inspections using thermal orthomosaic
Facilities and Bridge Inspection
ODOT HQ, Columbus: Inspection Using Pix4D Mapper

One can draw surfaces on **Pix4D Visual Point Cloud** to view the individual visual images of the area, covered in the surface, for improved inspection.

One can draw surfaces on **Pix4D Thermal Point Cloud** to view the individual thermal images of the area, covered in the surface, for improved inspection.
Processed Visual Orthomosaics can be uploaded to Pix4D Cloud. Inspectors can add annotations and share their results amongst their peers.

Processed Thermal Orthomosaics can be uploaded to Pix4D Cloud. Inspectors can add annotations and share their results amongst their peers.
Facilities and Bridge Inspection
Northwood Garage, Toledo

Observations:
1. Presence of moisture/Highly emissive surface(wear in roof)/Non-uniform heating.
2. Absence of moisture/Non-uniform heating.
3. Absence of moisture in concrete.
4. Grass with moisture.
5. Grass without moisture.

Confirmations:
The garage was not uniformly heating. In certain areas of garage (the darker shades on the roof) the heating pipes were not functional.
Northwoods Garage, D2
Facilities and Bridge Inspection
Study at Jeremiah Morrow Bridge, Oregonia

Inspector mode: Pilot controls UAV, Inspector controls camera
Facilities and Bridge Inspection
Study at Jeremiah Morrow Bridge, Oregonia

Initial 3D Point Cloud of the bridge

Initial Visual façade of the bridge
2 Types of UAS Workflows for Bridge Inspection

If you conduct the inspection BEFORE collecting imagery data:

1. Perform Field Inspection
2. Mark Defects Directly on Bridge
3. Document Inspection with UAS and/or Terrestrial
4. Process Data
5. Analyze Inspection Data
6. Share Inspection Information

If you conduct the inspection AFTER collecting imagery data:

1. Document Structure with UAS and/or Terrestrial
2. Process Data
3. Perform Inspection/Measure Deficiencies
4. Analyze Inspection Data
5. Share Inspection Information

From Final Report 2018-26, Minnesota DOT
## ROI of UAS Operations for Bridge Inspection

**Assumptions:**
- Snooper costs = $3,000/day (with operator)
- Traffic control costs = up to $2,500/day

**While:**
- Drone costs = $300/day; Pilot and Processor costs = $120/hour

**With Fixed Cost:**
- Bridge Inspector cost = $150/hour

<table>
<thead>
<tr>
<th>Structure</th>
<th>Traditional Inspection Cost</th>
<th>UAS Assisted Inspection Cost</th>
<th>Savings +/-</th>
<th>Savings Percentage</th>
<th>Traditional Inspection Hours</th>
<th>UAS Assisted Inspection Hours</th>
<th>Savings +/-</th>
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</thead>
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<tr>
<td>19538</td>
<td>$1,080</td>
<td>$1,860</td>
<td>-$780</td>
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<td>MDTA Bridges</td>
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<td>$21,000</td>
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<td>16</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>62504</td>
<td>$3,660</td>
<td>$1,020</td>
<td>$2,640</td>
<td>72%</td>
<td>16</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>82502</td>
<td>$3,240</td>
<td>$2,400</td>
<td>$840</td>
<td>26%</td>
<td>24</td>
<td>16</td>
<td>8</td>
</tr>
</tbody>
</table>

**Average Cost Savings** 40%

**Average Hours Increase** 2%

From Final Report 2018-26, Minnesota DOT