Autonomous TMA Pilot Project
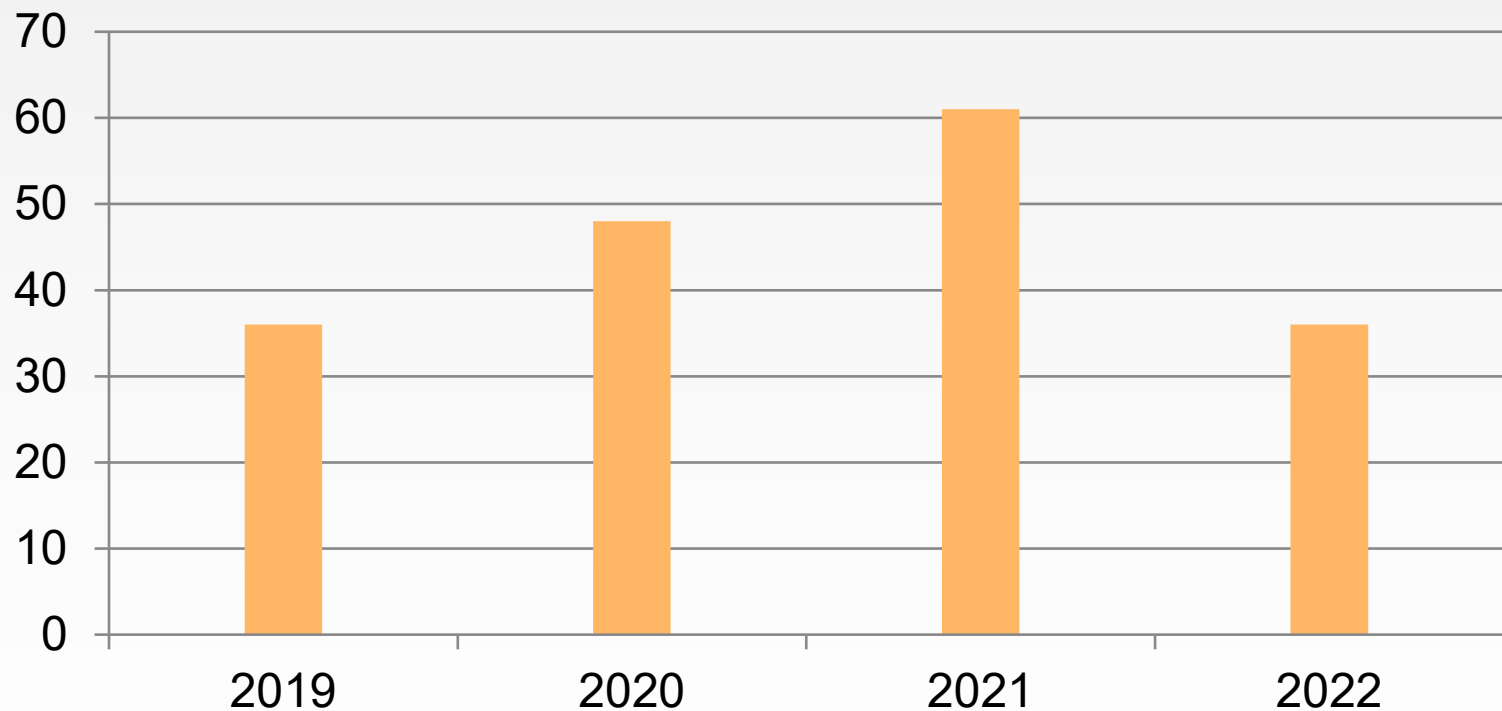
Project Background

MoDOT TMA Crashes

What is the goal?

Eliminate operator injuries when the rear protective vehicle is impacted by removing the operator from the vehicle.

Functionality

What it can do:

- Leader-Follower system – rear TMA unstaffed
- Follow at various distances up to 1500'
- Pause and catch up
- Function in short duration GPS denied environments
- Turn signals are synced
- Laterally offset from the lead vehicle up to 12'

What it can't do:

- Platoon to the project at highway speeds
- Follow through signals and intersections
- Throughout the pilot project a safety driver will be in the follower

Performance Specifications

- Frontal collision avoidance
- Seamless function in GPS denied environments
- E-stop & failsafe systems
- Longitudinal accuracy of +-15'
- Lateral accuracy of +-6"
- Follow distance adjustment required
- Pause and catch up function
- V2V non-line of sight functionality
- TMA impact recognition and brake application
- Arrow board and turn signal coordination
- Vehicle take over functionality
- Operator friendly user interface

Contract with Kratos Defense and Security Solutions

- **$550K to retrofit two MoDOT trucks**
  - Funded with Federal Statewide Planning and Research (SPR) Funds
  - International trucks w/ Manual for Assessing Safety Hardware (MASH) TMA

- **No payment until it performs**
  - Training, component testing & verification
  - 32 Hour closed road test
  - 250 Hour live work zone test

System Overview: Leader Vehicle
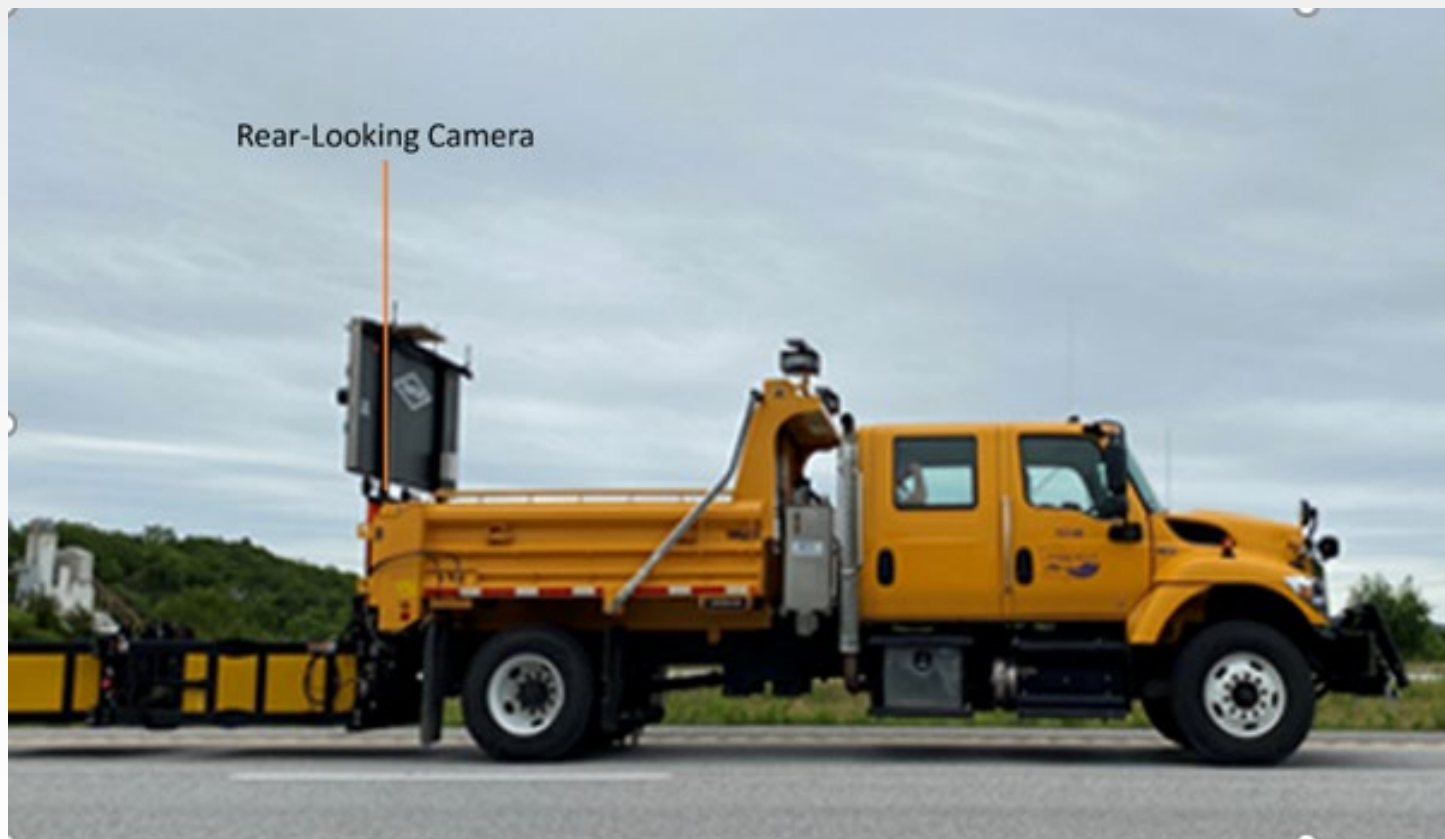
System Overview: Leader Vehicle

System Overview: Leader Vehicle

System Overview: Follower Vehicle

System Overview: Follower Vehicle

System Overview: Operation

- E-crumbs - GPS

- Dead Reckoning (DR)

  - More that 45 seconds initiates an A-stop

- A-stop

  - Obstacle (can be cleared by operator)

- E-stop

  - Shuts down the truck

Project Timeline

- 2017 May - RFP #1 - 4 proposals - no contract
- 2018 January - RFP #2 – 5 proposals
- 2018 March – Contract executed with Kratos for KC District pilot project
- 2018 April – MoDOT dump trucks to Florida
- 2019 April – MoDOT dump trucks back to MO
- 2019 April-May – Verification and 32-hour testing
- 2019 June – 250-hour Live Work Zone test

Project Timeline

- 2019 June – System issues in GPS denied environment
  - Stopped Live WZ testing
- 2019 September – Kratos installed upgrades to correct issues – Performed verification and 32-hour testing
- 2020 March – Project on hold due to pandemic
- 2020 August – Solution to move equipment in lead truck to crew cab with physical barrier
- 2021 January – MoDOT lead dump trucks to Florida
- 2021 March – MODOT dump trucks back to MO
- 2021 April – Follower truck down due to mechanical issues

Project Timeline

- 2021 November – Second pilot initiated with SW District

- 2022 March – Training and verification testing for SW District pilot

- 2022 April – On road testing began for SW pilot project

- 2022 June – Refresher training for KC pilot project

- 2022 July – On road testing began for KC pilot project

32 Hour Testing April/May 2019

- State Fairgrounds – controlled environment
  - V2V dropouts – MoDOT retrofit issue
  - Radar timeout E-STOP - sky data issue
  - Entering Dead Reckoning (DR) too often – satellite issue
  - Veered off course - excessive CPU usage
  - Follow distance accuracy – hardware issue
  - Delayed E-STOP – excessive CPU usage
  - Lateral accuracy issue – code issue
- Passed 32 test once issues corrected

250 Hour Testing June 2019

- Live work zones on divided highways

- Location accuracy issues driving under bridges

- GPS degradation/DR/follow accuracy issues

- Kratos Solutions:
  - GPS card upgrade – 2.5X satellites
  - GPS antennae upgrade - amplification
  - Roof mounted warning LIDAR

On Road Testing Status

- SW District Pilot Project
  - 125/125 hours completed
  - Continue testing this striping season
  - Focus on challenges with removing the safety driver

- KC District Pilot Project
  - Software issues at end of the striping season
  - Restart testing hours this spring

AMR Leader-Follower System TMA Evaluation

Final Presentation
January 19, 2023

Henry Brown, P.E.
Praveen Edara, Ph.D., P.E., P.T.O.E.
Carlos Sun, Ph.D., P.E., J.D
Zhu Qing, Ph.D.
Ho Jun Baek
Jeffrey Kupko, P.E., P.T.O.E.

(MoDOT 2022a)

Project Overview

- Motivation
  - 150 strikes of moving operations since 2016 (MoDOT 2022b)
  - Eliminate MoDOT worker injuries
- Objectives
  - Evaluate MoDOT's pilot leader-follower TMA program
  - Synthesize DOT practices
  - Identify obstacles to implementation
- Methodology
  - Review of existing literature and DOT practices
  - Interviews with MoDOT personnel
  - Field study
  - Economic analysis

Field Study: Overview

- Observed initialization in parking lot
- Observed during striping operations
  - Springfield (nighttime)
  - Kansas City (daytime)
- Data sources
  - Video
  - Kratos log files
  - Google Earth

User Interface

Leader-Follower System on US 65

Feedback from MoDOT Employees: Overview

- Seven employees
  - 4 Springfield (8/17/22)
  - 3 KC (10/14/2022)
- Conducted individually
- Example topics
  - Roles and training
  - Performance
  - Effects on work zone safety
  - Other possible applications
  - Suggested system improvements

Employee Feedback: Experience and Training

- Experience
  - Trained all three positions
  - Typically focus on one position
  - 16 to 80 hours
  - Some prior KC experience (2019)
- Training adequate
  - Classroom
  - Hands on
    - Closed course
    - Open road
  - Checklist beneficial
- Initial learning curve smooth
- Could operate system efficiently

Employee Feedback: Performance

- Average employee rating 7.1/10
- Mixed opinions on safety
  - Removing driver from follower vehicle
  - Follower driver can focus on traffic
  - Hard for follower to speed up or stop on crests
- Challenges
  - E-crumb errors (varying frequency)
  - Sudden loss of GPS signal
  - Follower sometimes veers to left after DR
  - Need to reconnect if cannot get out of DR
  - Initialization time
  - Some false A-stops

MO 291 over Missouri River

Employee Feedback: Suggested Improvements

- Remote reset for follower
- Additional cameras in follower
- Remote alarm trigger to alert traffic
- Drop pausing e-crumb
- Addition of supplementary system (e.g., lane sensors)
- More information on stoppages for troubleshooting
- More stable stand for tablet
- Closed course for training

Implementation Considerations

- Driverless operation
    - System reset
    - Need for situational awareness (e.g., hills, curves)
    - How to alert drivers?
    - Desired gap distance
- Potential enhancements
    - Remote reset
    - Additional cameras
    - Remote alarm trigger
    - Supplementary guidance system (loss of GPS signal)
    - More stable tablet stand

Conclusions

- Implementation by 4 DOTs
- System generally effective
  - Maintains gap distance (Avg. diff. -3.2' to 15.4') and speed (Avg. diff.   -0.006 mph to -0.39 mph)
  - Remove driver from follower
  - More driver focus on traffic
- Technical challenges
  - GPS signal loss (e.g., bridges, sign trusses)
    - 6.1 to 13.6 DRs/hr
  - Need for performance data

- Non-technical challenges
  - Legislation
  - Procurement
  - Competing priorities
  - Lack of awareness

Next Steps

- SW District Pilot Project
  - Continue testing this striping season
  - Focus on challenges with removing the safety driver

- KC District Pilot Project
  - Restart 250-hour Live Work Zone Testing

Autonomous TMA Pilot Project

Questions?