Advancing Platooning with Advanced Driver-Assistance Systems Control Integration and Assessment

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Cummins Inc.

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Cummins

Project Overview

Timeline

- Project Start Date: 10/01/2018
- Project End Date: 12/31/2021
- Percent complete: 30%

Budget

- Total Project Budget: $5,000,000
  - Total Recipient Share: $2,500,000
  - Total Federal Share: $2,500,000
  - Federal share of expenditures*: $854,336
  - Recipient share of expenditures*: $978,620

* As of 03/31/2020 (does not include federal lab spending)

Barriers

- Limited platooning assessment under real-world driving conditions
- Integration of ADAS features not well understood
- Interaction of tire conditions with platooning not well understood

Partners

- Cummins (lead)
- National Renewable Energy Lab (NREL)
- Clemson University
- Michelin North America

Project Objectives

1. Assess the impact of real-world driving conditions on truck platooning fuel saving
2. Assess advanced driver-assistance systems (ADAS) and tire connectivity technology integration
3. Identify barriers to truck platooning

DOE FOA Objective:
Execute field evaluations of multi-truck platoon proof of concepts that assess both the potential fuel savings and barriers that need to be overcome for platooning to be effective.

This will result in:

- understanding truck platooning fuel saving and performance under real-world driving conditions
- assessment of ADAS features and tire connectivity integration
- collection of vehicle and powertrain test data (hard to model) that can inform future research needs
- development of solutions to address barriers if applicable

Project Approach

Budget Period 1 (2019)

✓ Technology Integration

- ✓ Baseline CACC*/Platooning control integration and tuning
- ✓ ADAS and Tire connectivity integration
- ✓ Data loggers and new sensors integration
- ✓ Development of data logging pipeline and storage
- ✓ Route selection and real-world test factor characterization
- ✓ Test plan development
- ✓ **Go/No-Go: ACC Interfaced with Baseline Platoon Controller**

Budget Period 2 (2020)

☐ Technology testing

- ✓ Test plan refinement (COVID-19 impact)
- ☐ (in progress) 2 truck platooning test under real-world driving conditions
- ☐ Assess the impact of real-world driving conditions on fuel saving
- ☐ Assess the impact of real-world driving conditions on powertrain operation
- ☐ Identify barriers through test data analysis
- ☐ **Go/No-Go: 2-Truck Platoon Data Analysis Completed**

Budget Period 3 (2021)

☐ Technology solutions

- ☐ 3 truck platooning test
- ☐ Quantify the impact of real-world driving conditions on platooning
- ☐ Quantify the impact of ADAS integration
- ☐ Quantify the impact of tire connectivity
- ☐ Identify and demonstrate solutions if applicable

*CACC: Cooperative Adaptive Cruise Control

Project Accomplishments and Progress

All three trucks are instrumented:

- **Trailing Truck**: Data Logger, Fuel Measurement, CACC* platooning system, tire connectivity
- **Lead Truck**: Data Logger, Fuel Measurement, tire connectivity, ADAS**
- **Control Truck**: Data Logger, Fuel Measurement

Truck	Control	Lead & Trail
Truck Model	INTERNATIONAL 2020 LT625 6X4 (LT62F)	
Application	General Freight Long Haul Sleeper	
GVW	67000 lb	
Engine	Cummins X15 Efficiency Series, EPA 2017, 430HP @ 1800 RPM, 1450/1650 lb-ft	
Transmission	Eaton Endurant 12-Speed Fully Automated Manual Overdrive	
Rear Axle Ratio	2.79	
Steer Tire	Bridgestone R283A ECOPIA 295/75R22.5 100 psi	Michelin X Line Energy 275/80R22.5 100 psi
Drive Tire	Bridgestone M710 ECOPIA 295/75R22.5 100 psi	Michelin XDA Energy 275/80R22.5 100 psi
Trailer Tire	Bridgestone R283A ECOPIA 295/75R22.5 100 psi	Michelin X Line Energy 275/80R22.5 100 psi
Collision Mitigation	Bendix Wingman Fusion with Adaptive Cruise Control and Lane Departure Warning	
Powertrain Features	RSG, GDP, LBSC, Predictive Cruise Control, VAM, PTP, Smart Torque, Smart Coast, ISD	
Fan Drive	Two Speed Direct Drive	
Trailer Model	2020 Great Dane 53' Van - Underbody skirts	

* Cooperative Adaptative Cruise Control
** Advanced Driver Assistance System

Accomplishments and Progress (cont.)

	Fuel Saved (speed of 65 mph & weight of 67000lb)	
Distance Target	**Lead Truck**	**Trailing Truck**
CACC @ 0.6 sec	1.70% +/- 0.96%	7.07% +/- 0.78%
CACC @ 1.0 sec	0.23% +/- 0.98%	6.52% +/- 0.66%
CACC @ 2.3 sec	N/A	5.34% +/- 1.07% (w.r.t Lead)
ACC @ 2.3 sec	N/A	4.01% +/- 0.96% (w.r.t Lead)

- Baseline platoon system is tuned and validated for upcoming 2020 on-road tests:
  - Fuel saving trend is aligned with previously published results under test track conditions guided by SAE J1321 standard.

Accomplishments and Progress (cont.)

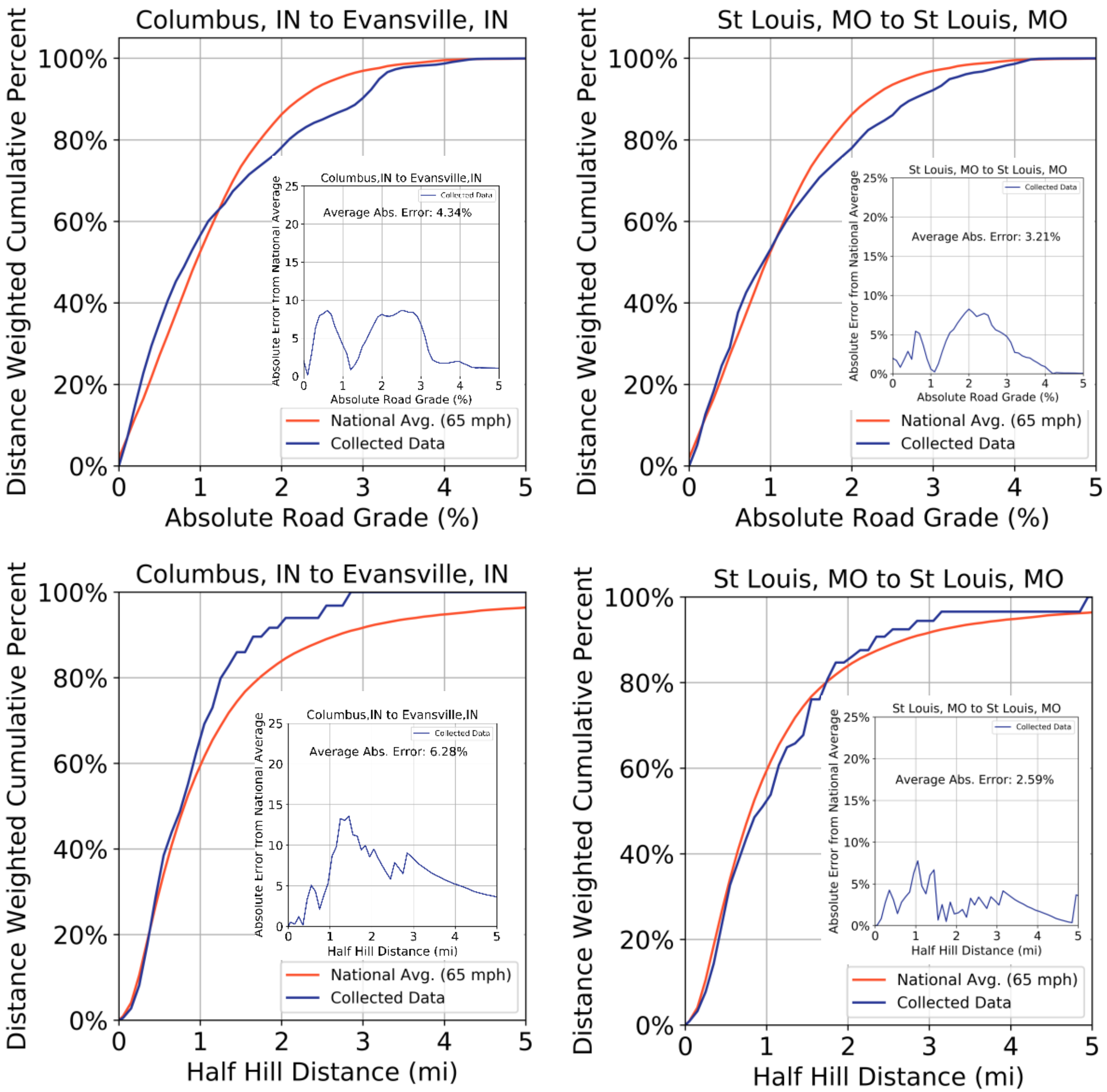
- Completed analysis of test factors to enable a multi-variate design of experiments

- Defined the requirements to:
  - select routes,
  - refine logging parameter list,
  - calculate route and performance indexes, and
  - define test conditions
- Test factors sorted by priority and allocated to road or track testing or modelling for results

	Rating of Importance to Customer	10	10	8	6	8	4	
		1	2	3	4	5	6	
Test Category	Test Factor	Importance to Line Haul Trucking	Platooning Fuel Saving Impact	Platooning Operation Impact	Past Test Data Availability	Feasibility of Testing	Maturity of Alternative Methods to Assess Platooning e.g. Simulation	Total
Traffic	Highway traffic induced speed fluctuation	9	9	9	9	1	9	350
Route	Terrain (Flat/non-Flat (>1%))	9	9	9	9	3	3	342
Vehicle Configuration	GVW Differences (within platoon)	9	9	9	9	3	1	334
Traffic	Lane change (1)	3	9	9	9	9	3	330
Powertrain Calibration	ADEPT enabled/disabled on Lead	9	9	1	9	9	3	326
Environmental Conditions	Road Surface Condition	3	9	9	9	3	9	306
Tire	Tire wear (new/worn)	3	9	9	9	3	9	306
Platooning Operation	Following Time / Distance Gap	9	9	9	1	3	3	294
Vehicle Configuration	Trailer Aero Treatments	9	9	1	3	9	3	290
Environmental Conditions	Weather conditions (tempt/wind) (2)	9	9	3	9	1	3	278
Platooning Operation	2 vs 3 trucks	3	9	9	3	3	9	270
Tire	Tire inflation pressure	9	3	3	9	3	9	258
Tire	Tire Performance (Traction vs LRR)	3	3	3	9	9	9	246
Traffic	Vehicle cut in front / behind of Lead	3	3	9	3	9	3	234
Route	Curvature	3	9	3	3	3	9	222
Platooning Operation	Lead driver speed control (CC vs non-CC)	3	3	3	9	9	1	214
Vehicle Configuration	Tractor Type (Daycab/Sleeper)	3	9	1	9	1	3	202
Traffic	Aerodynamic impact of surrounding vehicles (3)	1	9	1	3	3	9	186
Powertrain Calibration	Engine Rating Difference	3	3	3	3	9	1	178
Route	Road Speed Limit (High / Low vehicle speed)	3	3	1	3	9	3	170
Environmental Conditions	Altitude	3	3	1	9	3	3	158
Vehicle Configuration	Final Drive Ratio	1	1	3	9	3	1	126
Vehicle Configuration	Truck Weight Class	1	3	1	9	1	3	122

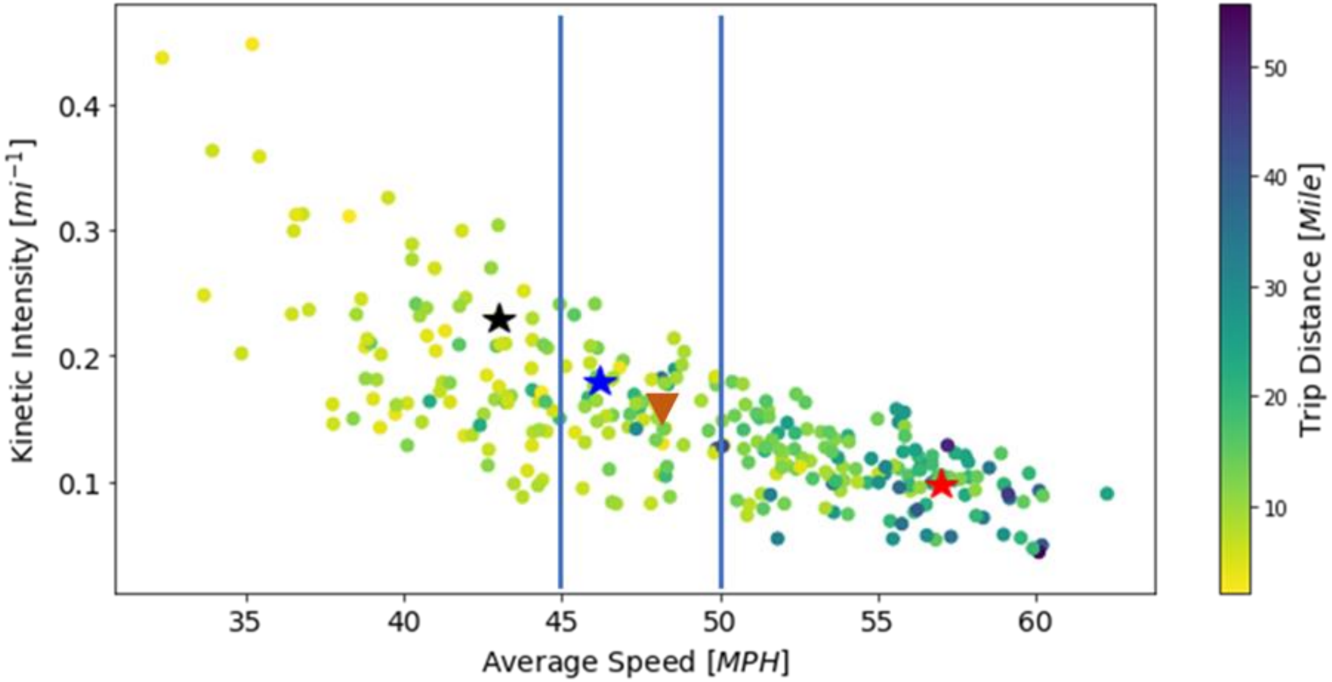
Accomplishments and Progress (cont.)

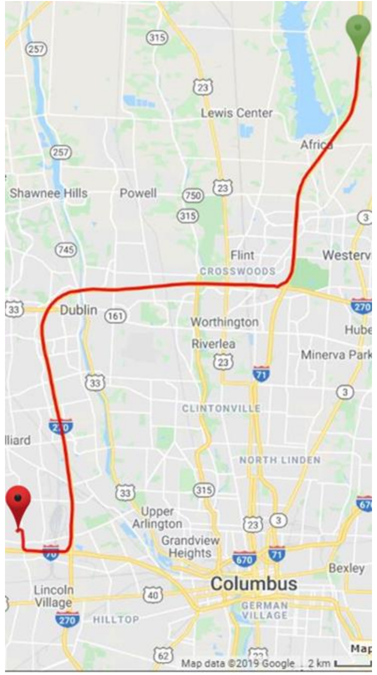
- Routes are selected per road grade national statistics*:
  - Columbus, IN -> Evansville, IN
  - St. Louis, MO -> Sikeston, MO -> St. Louis, MO
- Selection was based on statistical similarity of the routes to the national road grade data.
- The impact of ADAS features on lead truck is assessed as a part of this test.

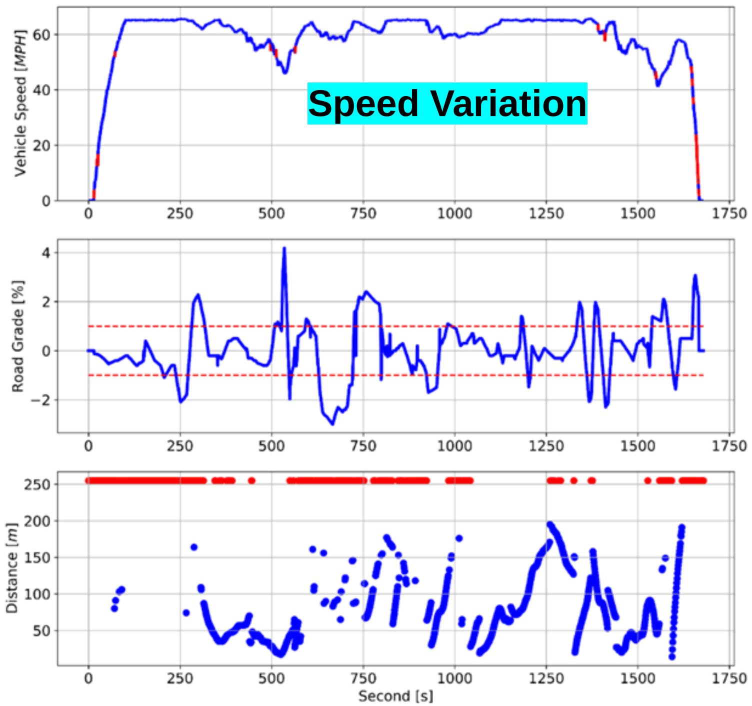


* *Analysis by NREL*

Accomplishments and Progress (cont.)





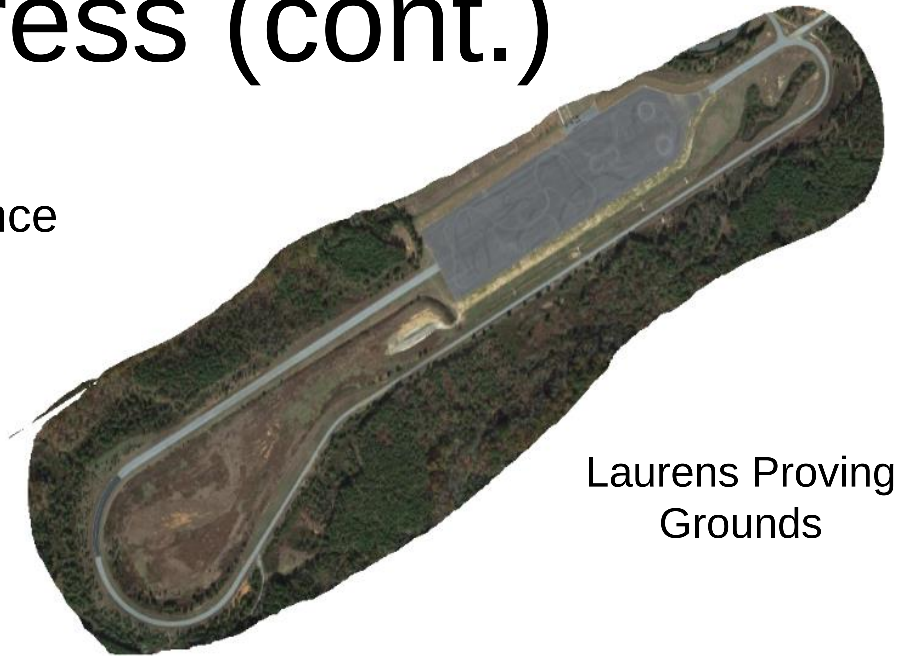


- NREL Fleet DNA data was analyzed to identify a statistically representative highway transient driving profile for truck platooning evaluations*.
- The speed profile was imposed on the lead truck to assess the impact of highway traffic. This test was conducted on test track to collect repeatable data. The data is under analysis.
- The impact of weight variation is considered as a part of this test.

** Analysis by NREL*

Accomplishments and Progress (cont.)

Tire Connectivity



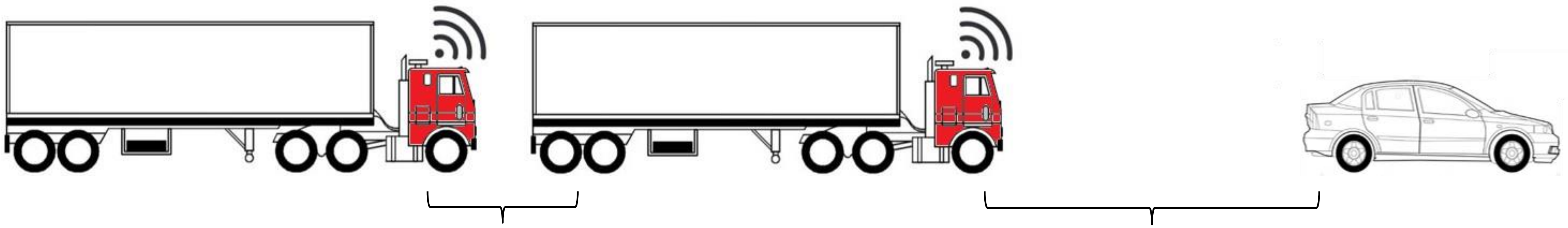
Laurens Proving Grounds

- Michelin has conducted vehicle braking tests to quantify the importance of tires when platooning on wet roads. Test parameters included:
  - Road types (asphalt, concrete)
  - empty and fully loaded trailers
  - Disk and drum brakes
  - different brand tires,
  - tier wear: new, half and fully worn
- Tire is a 1st order parameter when determining vehicle stopping distance on wet roads since:
  - Tire choice impacts the stopping distance as much as other vehicle parameters
  - Tire adherence capability decreases significantly as the tire wears
- To increase platooning time on wet roads, adherence capability of the tires as a function of their type and state must be known to determine the platooning distance between trucks and platooning order.
- **Testing of tire to vehicle connectivity:** TMS sensors mounted on the tires successfully transmitted tire temperature and inflation pressure. The same system will be used to transmit information about the tire adherence capabilities during subsequent phases of the project.

**Slide from Michelin North America*

Accomplishments and Progress (cont.)

- Design of distributed Model Predictive Control (MPC) to boost energy and powertrain efficiency of Multi-Truck Cooperative Operation during Platooning/CACC
  - Leverages connectivity for look-ahead data and coordination with other vehicles with estimation of uncertainty in traffic prediction



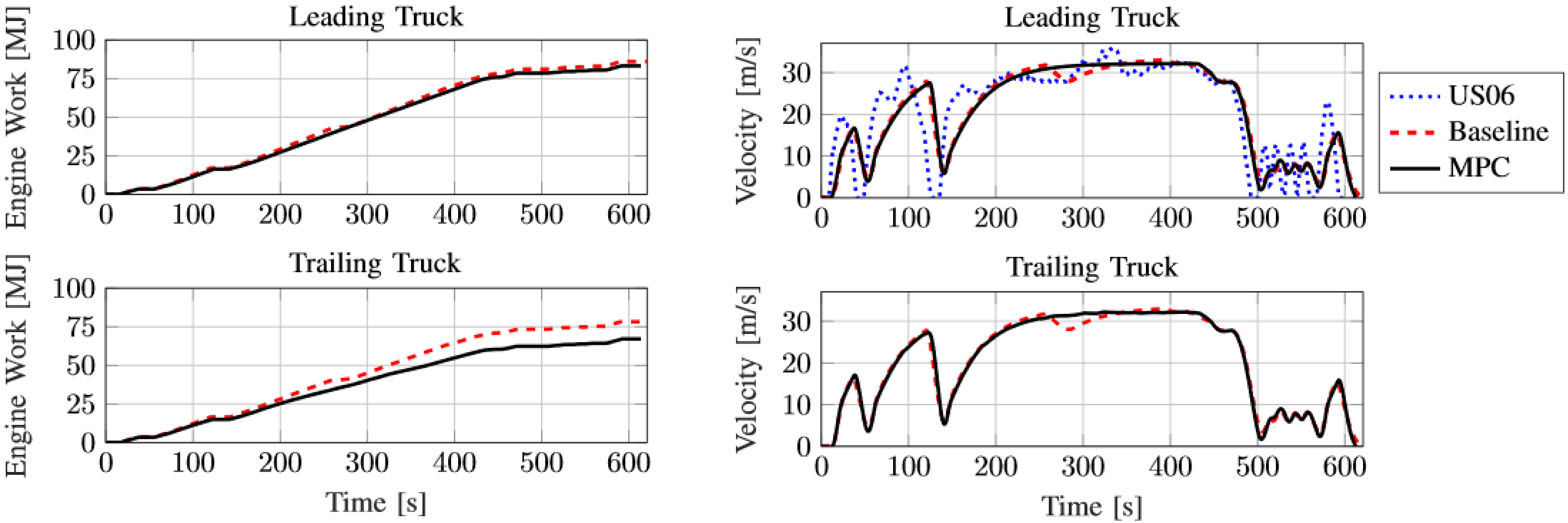
$$s_r(i) = X_r^*(i) \qquad P(s_r(i) \geq s(i) + \underline{d}) = \alpha(i)$$

- Leverages methods developed in EEMS029

**Slide from Clemson University*

Accomplishments and Progress (cont.)

- Showed significant energy saving during traffic operation by distributed MPC (Preliminary Simulation-Pending Validation)*

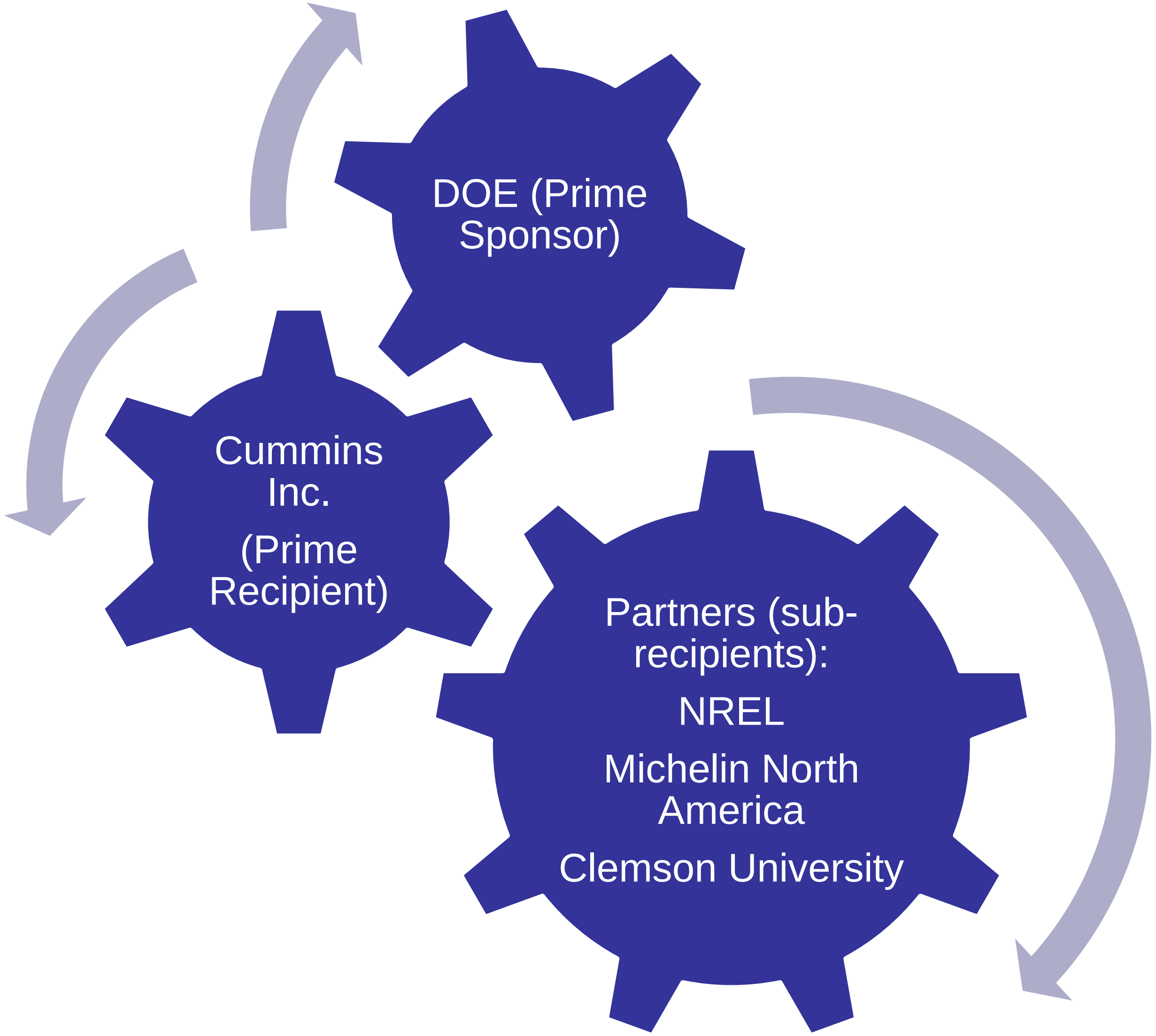


**T. Ard, F. Ashtiani, A. Vahidi, and H. Borhan, "Optimizing gap tracking subject to dynamic losses via connected and anticipative MPC in truck platooning," to appear Proceedings 2020 American Control Conference, 2020.*

**Slide from Clemson University*

Collaboration and Coordination among Project Team

- Biweekly meetings
- Data share through BOX
- Quarterly progress reports
- Publications
- Test data shared with DOE



Overall Impact

- Achievements - budget period 1 (2019)
  - Trucks instrumentation for data logging, fuel measurement, Cooperative Adaptive Cruise Control (CACC) and tire connectivity.
  - Validation of CACC performance for 2 truck platooning completed.
  - Importance of tire conditions demonstrated through truck braking tests.
  - Test plan documentation for real-world 2 truck testing completed.
    - Test factors selected through a selection process.
    - Route selection completed.
    - Traffic characterization completed.
    - Impact of weight distribution and weather conditions characterized.
- Upcoming - budget period 2 (2020)
  - Conduct test plan for 2 truck platooning.
  - Complete fuel saving assessment of 2 truck platooning under real-world driving conditions.
  - Complete barriers identification of the technology through field test data analysis.
- Challenge
  - Covid-19 impacted the timeline of the test plan. Project plan is adjusted to accommodate delays.

Summary

- **Objective:**
  - Assess the impact of real-world driving conditions on truck platooning fuel saving.
  - Assess advanced ADAS and tire connectivity technology integration.
- **Approach:**
  - Conduct platooning tests under real-world driving conditions.
  - Assess the benefits and identify barriers through data analysis.
- **Accomplishment:**
  - Technology integration, tuning and validation for platooning baseline and data logging system completed for 2 truck platoon operation.
  - Real-world driving conditions for line-haul truck application is characterized for route and test factors selection. Test plan for 2020 is developed (collaboration with NREL).
  - Advanced control and tire connectivity solutions are studied for future integration and testing (collaboration with Clemson University and Michelin).
- **Collaboration:**
  - Cummins, NREL, Clemson University, Michelin, IN DOT, Greater Indiana Clean Cities Coalition

Questions?

Contact us by email:

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