High-Efficiency Control Systems for Connected Class 8 Trucks

PI: Dr. Greg Shaver

Presented by:
Alex Taylor & Cody Allen
Research Assistants, PhD Candidates
at the Purdue University Herrick Labs
What is NEXTCAR?

**NEXT**-Generation Energy Technologies for
Connected and
Automated
On-Road Vehicles

**Goals**
- **Energy Consumption**: 20% reduction over a 2016/2017 baseline vehicle
- **Emissions**: No degradation relative to baseline
- **Utility**: Must meet current safety and regulatory standards and customer acceptability
- **Incremental cost**: $1000-$3000 per vehicle
Changing the Status Quo

**STATUS QUO**

Two separate and independent efforts for improving vehicle energy efficiency:

- Independent Vehicle Dynamic Control
- Powertrain Optimization

**NEXTCAR**

Program vision is to maximize energy efficiency through a cooperative effort from all communities including Transportation, Vehicles and Powertrain.
Assessing Technology Potential

- What if a vehicle had **perfect information** about
  - Its route and topography
  - Environmental conditions
  - Traffic conditions
  - Traffic behavior
  - Condition of its powertrain and after treatment systems (if any)
  - The quality of its fuel (if used)
  - ......and everything else

- And it **cooperates** with all the vehicles around it in order to reduce its energy consumption,

- With **perfect control** and optimization?
Assessing Technology Potential

- What if a vehicle had **perfect information** about:
  - Its route and topography
  - Environmental conditions
  - Traffic conditions
  - Traffic behavior
  - Condition of its powertrain and after treatment systems (if any)
  - The quality of its fuel (if used)
  - ......and everything else

- And it **cooperates** with all the vehicles around it in order to reduce its energy consumption,

- With **perfect control** and optimization?
Benefits

- Order of magnitude safety improvements
- Reduced congestion
- Reduced emissions and use of fossil fuels
- Improved access to jobs and services
- Reduced transportation costs for users
- Improved accessibility and mobility
Benefits

- Order of magnitude safety improvements
- Reduced congestion
- Reduced emissions and use of fossil fuels
- Improved access to jobs and services
- Reduced transportation costs for users
- Improved accessibility and mobility

How much energy could be saved?
NEXTCAR Projects - Total of $32M

University of California – Berkeley
General Motors
University of Michigan
University of California – Riverside
Michigan Technological University
Southwest Research Institute
Pennsylvania State University
The Ohio State University
University of Minnesota
University of Delaware
Purdue University
NEXTCAR Projects – Total of $32M

University of California – Berkeley
General Motors
University of Michigan
University of California – Riverside
Michigan Technological University
Southwest Research Institute
Pennsylvania State University
The Ohio State University
University of Minnesota
University of Delaware
**Purdue University**

Connected & Automated Class 8 Trucks
Our Project - Thesis Statement

- **Engine and transmission** fuel efficiency improvements have remained **isolated from** emerging **Connected and Automated Vehicle (CAV)** applications

- Use a collaborative vehicle and powertrain solution to **reduce fuel consumption** and CO$_2$ emissions by **up to 20% in diesel-powered Class 8 trucks**
  - Must demonstrate on trucks by end of project

- Target < $3,000 incremental vehicle cost at mass production scales
Trucking Industry Statistics

Average Annual Vehicle Miles Traveled of Major Vehicle Categories

- Class 8 Truck: 68,000
- Transit Bus
- Refuse Truck
- Para. Shuttle
- Delivery Truck
- School Bus
- Police
- Light Truck
- Light-Duty Vehicle
- Car
- Motorcycle

Annual Miles per Vehicle
Trucking Industry Statistics

Average Annual Fuel Use of Major Vehicle Categories

- Class 8 Truck: 12,900
- Transit Bus
- Refuse Truck
- Para. Shuttle
- Taxi
- Delivery Truck
- School Bus
- Police
- Light Truck
- Light-Duty Vehicle
- Car
- Motorcycle

GGEs per year
(Gasoline Gallon Equivalent)
Indiana is a Critical Freight Corridor

- $750 billion in freight moves to, from or through Indiana annually
- 1.5 billion tons of freight travel though Indiana, making it the fifth busiest state for commercial freight traffic. By 2040, freight flow is expected to increase by 60 percent.
Our Project - Team Members

Project Sponsor

ARPA-E

Project Partners

Purdue University

Cummins

Peloton

NREL

PACCAR

ZF
Our Project - Team Members

Faculty:

Pl: Dr. Greg Shaver  Dr. Neera Jain  Dr. Dan DeLaurentis  Dr. Darcy Bullock  Dr. Srini Peeta

Students:
- 5 Graduate Students
- 3 Undergraduate Students
Purdue NEXTCAR - 3 Concepts for 20% Fuel Savings
What technology exists today?

- Cummins, Inc: **ADEPT**
  - 6% fuel savings using Predictive Cruise Control, SmartTorque2, SmartCoast
  - 2 kilometers of lookahead information including grade
  - Eliminate unnecessary downshifts
  - Leverage gravity & vehicle momentum

Diagram:
- Connectivity
- Powertrain
What technology exists today?

- Peloton Technology, Inc: Platooning

Front truck: 4.5% fuel savings

Rear truck: 10% fuel savings

7.25% combined fuel savings
Purdue NEXTCAR - 3 Concepts for 20% Fuel Savings

- Driver Histories
- Transportation Analytics
- Topographical & Geographical Data

**CONCEPT 1**
Remote PT re-calibration

**CONCEPT 2**
Real-time PT control

**CONCEPT 3**
Improved platooning & co-developed VD & PT control

Network Operations Center

Over the Air Services

Single Vehicle

Platooning Vehicles

3/7/2018
Connectivity-enabled, remote powertrain calibration

- Tune engine calibration using connectivity-enabled information
- Impacts vehicle performance and fuel consumption
- Two-way communication between cloud and powertrain
Connectivity-enabled, remote powertrain calibration

- Tune engine calibration using connectivity-enabled information
- Impacts vehicle performance and fuel consumption
- Two-way communication between cloud and powertrain
Connectivity-enabled, remote powertrain calibration

- Tune engine calibration using connectivity-enabled information
- Impacts vehicle performance and fuel consumption
- Two-way communication between cloud and powertrain
Cloud based optimization, improved control of the powertrain
Cloud based optimization, improved control of the powertrain

Real Time System Optimizer

Onboard Computer
Short Horizon Example

- Road geometry
- Speed of preceding vehicles
- Speed limit

Short Horizon Algorithms

Optimal instantaneous spacing between vehicles
Purdue NEXTCAR – Concept 2

Long Horizon Example

- Road geometry
- Instantaneous traffic
- Future traffic patterns
- Weather
- Speed limits
- Etc.

Long Horizon Algorithms

Optimal speed profile over the route
Purdue NEXTCAR - Concept 2

**Engine/Aftertreatment Optimization Example**

- Engine state
- Aftertreatment state
- Upcoming operating conditions
- Etc.

**Engine/AT Optimization Algorithms**

Optimal system parameters (injection timing, air handling, etc.)
Purdue NEXTCAR - 3 Concepts for 20% Fuel Savings
Platooning 101

- Improved Vehicle Coordination & Platooning
Platooning 101

- Improved Safety

- Radar & connectivity based braking system removes *driver reaction time*
Peloton Technology, Inc: Platooning
Platooning 101

1. Peloton Technology, Inc: Platooning
Peloton Technology, Inc: Platooning
Platooning 101

Active Braking:
Reduce braking time from 1.5 to 0.03 seconds to reduce stopping distances & end-of-queue accidents

- Platooning will save lives, increase efficiencies, and reduce NOx & soot pollution
- Drivers steer, but rear truck acceleration/braking is automated
- Active braking systems are linked, allowing safe following distances to 40 feet
Purdue NEXTCAR – Concept 3

- Improved Vehicle Coordination & Platooning

  - The platooning gap is hard to regulate when either truck is near the torque limit
  - Gap is hard to maintain when trucks shift gears independently
Purdue NEXTCAR – Concept 3

- Improved Vehicle Coordination & Platooning

  - The platooning gap is hard to regulate when either truck is near the torque limit
    » Solution: Powertrain control optimized for platooning

  - Gap is hard to maintain when trucks shift gears independently
    » Solution: Coordinated shifting
From Concepts to Fuel Savings On-Trucks

Algorithm Development

Simulations

Engine Testing

Truck Testing
Simulations - Vehicle & Powertrain

Corridor (Lat/Lon/Grade) CSV File

Vehicle Model Engine Speed & Torque Engine Model After-Treatment Model

SpeedGoat DAQ/Control System

Log Data
Possible Corridors for Testing in Indiana

Connected Corridor
Data taken with equipment from Purdue Civil Engineering colleagues
Centimeter level precision

US 231 near Purdue
- Traffic Signal Locations

Speed Limits (MPH)

Herrick Labs
Simulations - Vehicle & Powertrain

- Corridor (Lat/Lon/Grade) CSV File
- Vehicle Model
- Engine Speed & Torque
- Engine Model
- After-Treatment Model
- SpeedGoat DAQ/Control System
- Log Data
Engine Testing “Hardware in Loop”

- Corridor (Lat/Lon/Grade)
- CSV File
- Vehicle Model
- Engine Speed & Torque
- SpeedGoat DAQ/Control System
- Log Data
- Engine & Dyno in Test Cell

3/7/2018
Simulate real-time Class 8 Truck operation on Indiana (or other) corridors

- 15 Liter Cummins X15 Engine
  - 450 Horsepower @ 1800 RPM
  - 1750 ft-lbs of Torque
On-Road Truck Testing

- Two Model Year 2018 Peterbilt 579 trucks
- Must demonstrate fuel savings on-road by end of 3 year project
Herrick Labs - Engine Test Cells

- Industry Collaboration
- Undergraduate Students
- High School Students
Thank you

Dr. Greg Shaver: gshaver@purdue.edu
Alex Taylor: taylorah@purdue.edu
Cody Allen: cmallen3@purdue.edu
Sources


[3] Peloton Technology Website