High-Efficiency Control Systems for Connected Class 8 Trucks

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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

[1]
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

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Assessing Technology Potential

**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
Assessing Technology Potential

Benefits

• Order of magnitude safety improvements
• Reduced congestion
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How much energy could be saved?
NEXTCARE 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
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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
Trucking Industry Statistics

Average Annual Fuel Use of Major Vehicle Categories

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

(Gasoline Gallon Equivalent)

3/7/2018
India is a Critical Freight Corridor

- $750 billion in freight moves to, from or through Indiana annually.

- 1.5 billion tons of freight travel through 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 logo]

Project Partners

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[Peloton logo]
[NREL logo]
[Paccar logo]
[ZF logo]
Our Project - Team Members

Faculty:
- PI: 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

\[ \text{GROSS VEHICLE WEIGHT} + \text{DYNAMIC DRAG} + \text{ROAD GRADE} = \text{RPM SWEET SPOT} \]
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

Concept 1: Remote PT re-calibration
Concept 2: Real-time PT control
Concept 3: Improved platooning & co-developed VD & PT control
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

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Purdue NEXTC AR – Concept 1

- 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
Purdue NEXTCAR - 3 Concepts for 20% Fuel Savings
Cloud based optimization, improved control of the powertrain
Cloud based optimization, improved control of the powertrain

Real Time System Optimizer

Onboard Computer
Purdue NEXTCAR - Concept 2

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/After treatment 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

10% FUEL SAVINGS

4.5% FUEL SAVINGS
Platooning 101

- Improved Safety

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

Perception  Reaction  Brake Lag

Radar  Brake Lag
Platooning 101

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

1. Algorithm Development
2. Simulations
3. Engine Testing
4. Truck Testing

Purdue University
Cummins
Peloton
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

3/7/2018
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

Herrick Labs

Speed Limits (MPH)
Engine Testing “Hardware in Loop”
Engine Test Bed @ Purdue’s Herrick Labs

- 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
Thank you

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Sources


[3] Peloton Technology Website