High-Efficiency Control Systems for Connected Class 8 Trucks

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Presented by:

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at the Purdue University Herrick Labs

U.S. DEPARTMENT OF ENERGY

arpa-e CHANGING WHAT'S POSSIBLE

What is NEXTCAR?

NEXT-Generation Energy Technologies for

Connected and

Automated

On-**R**oad Vehicles

Goals

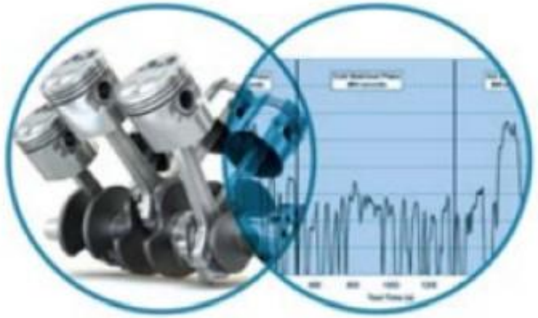
- **Energy Consumption**: 20% reduction over a 2016/2017 baseline vehicle
- **Emissions**: No degradation relative to baseline
- **Utility**: Must meet current safety and regulatory standards and customer acceptability
- **Incremental cost**: $1000-$3000 per vehicle

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?

[1]

Herrick Laboratories PURDUE UNIVERSITY

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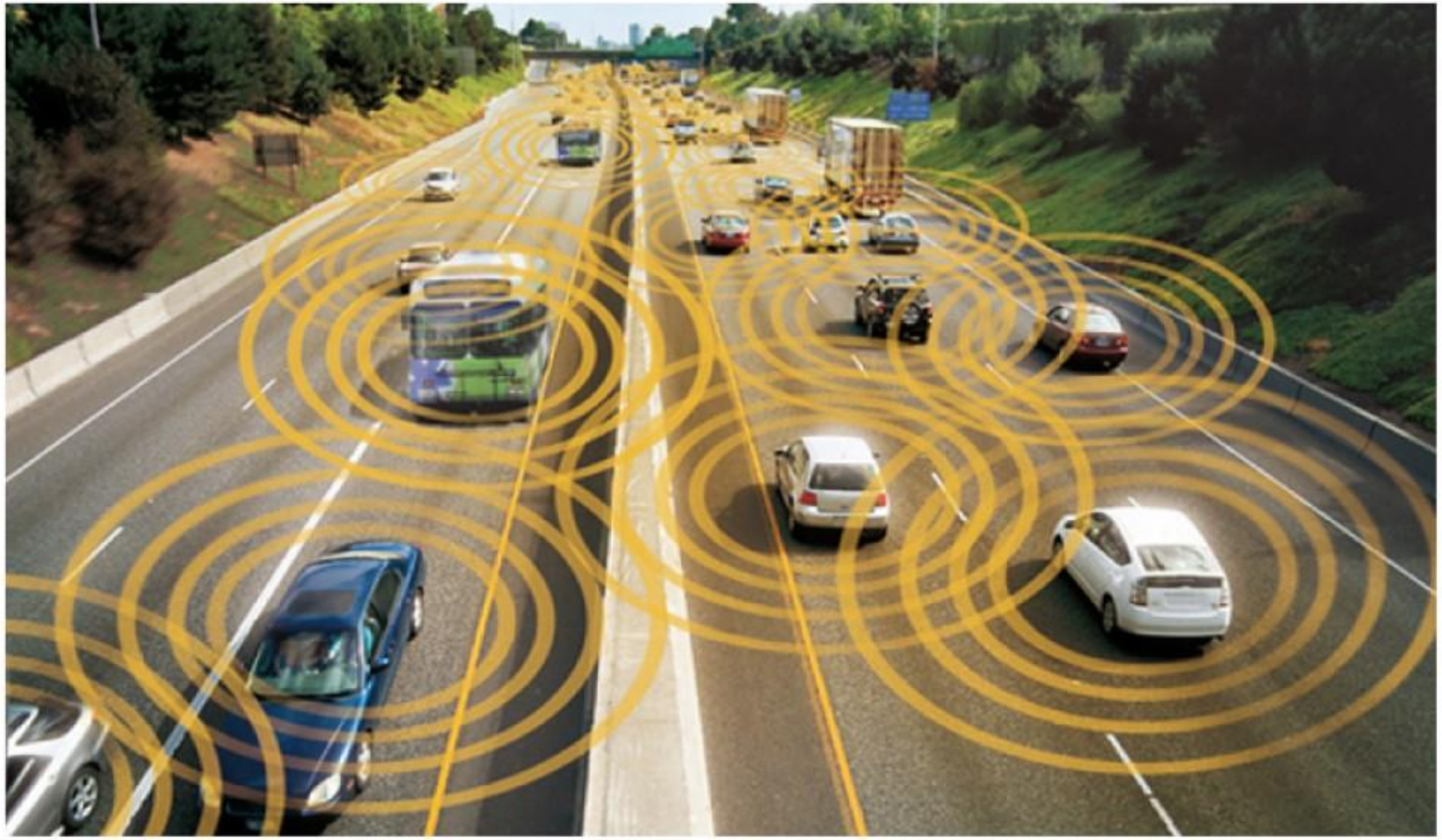
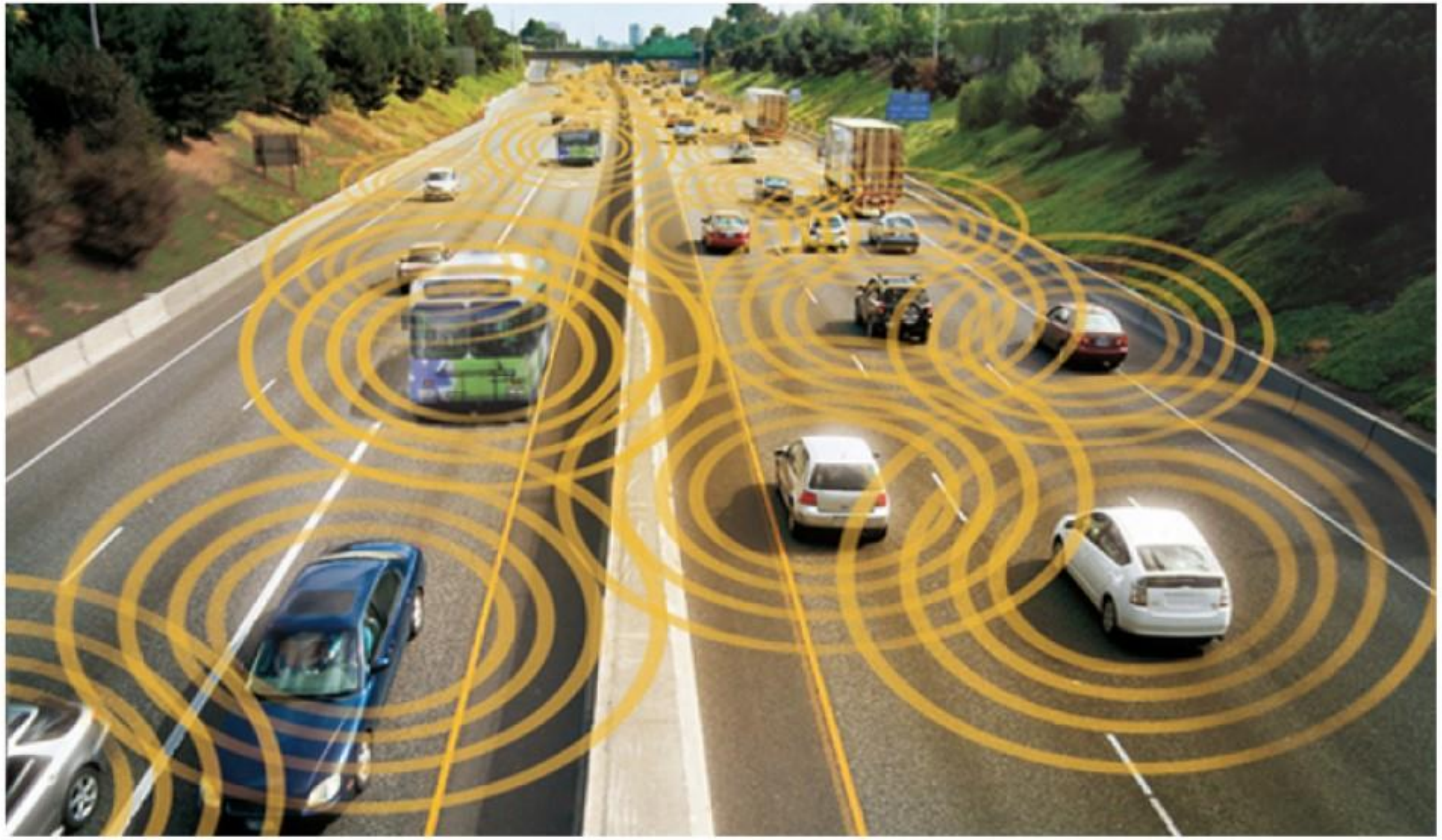


[1]

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



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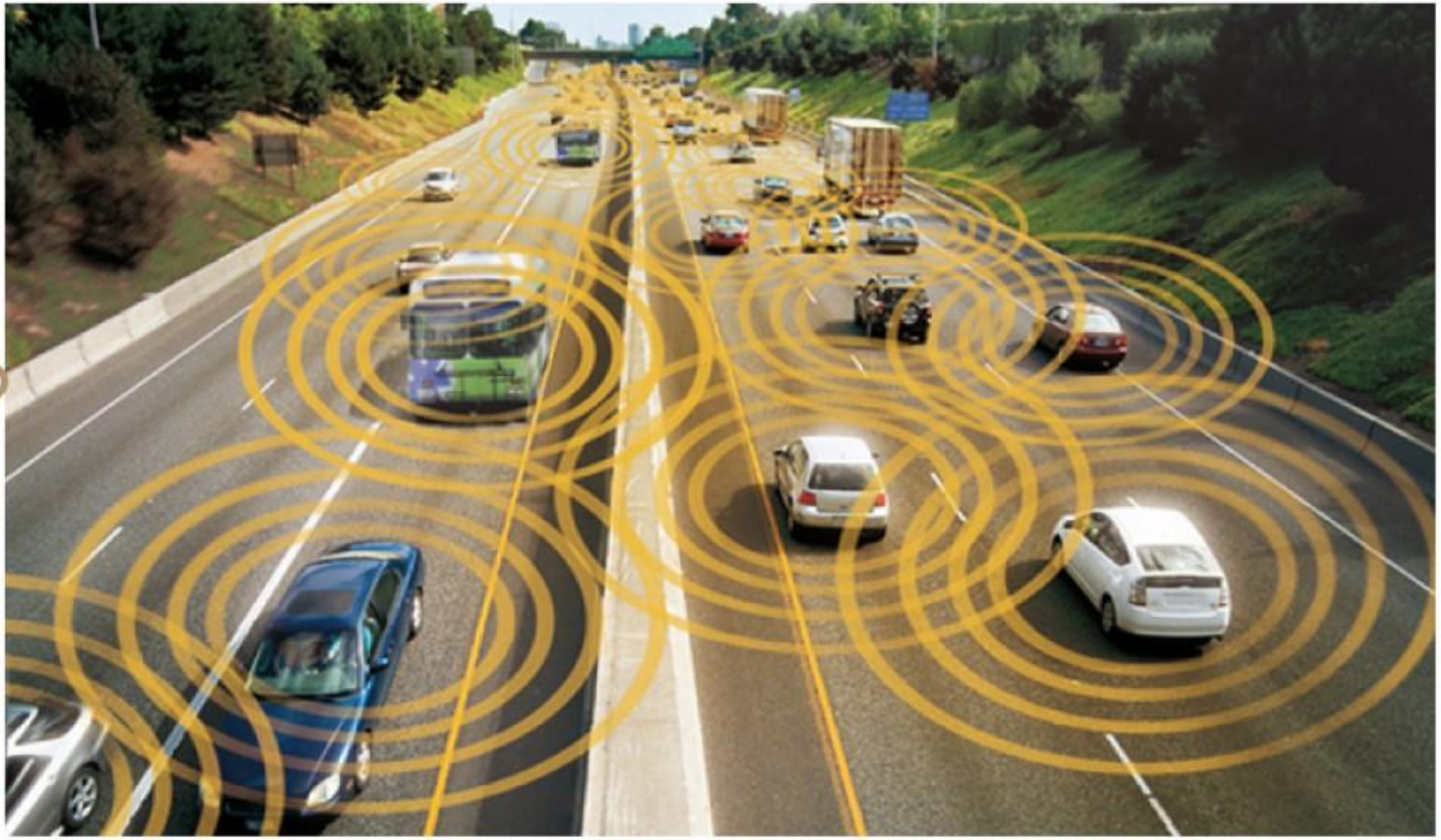

[1]

→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 Kickoff Meeting

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Purdue University

Connected & Automated Class 8 Trucks

Our Project – Thesis Statement

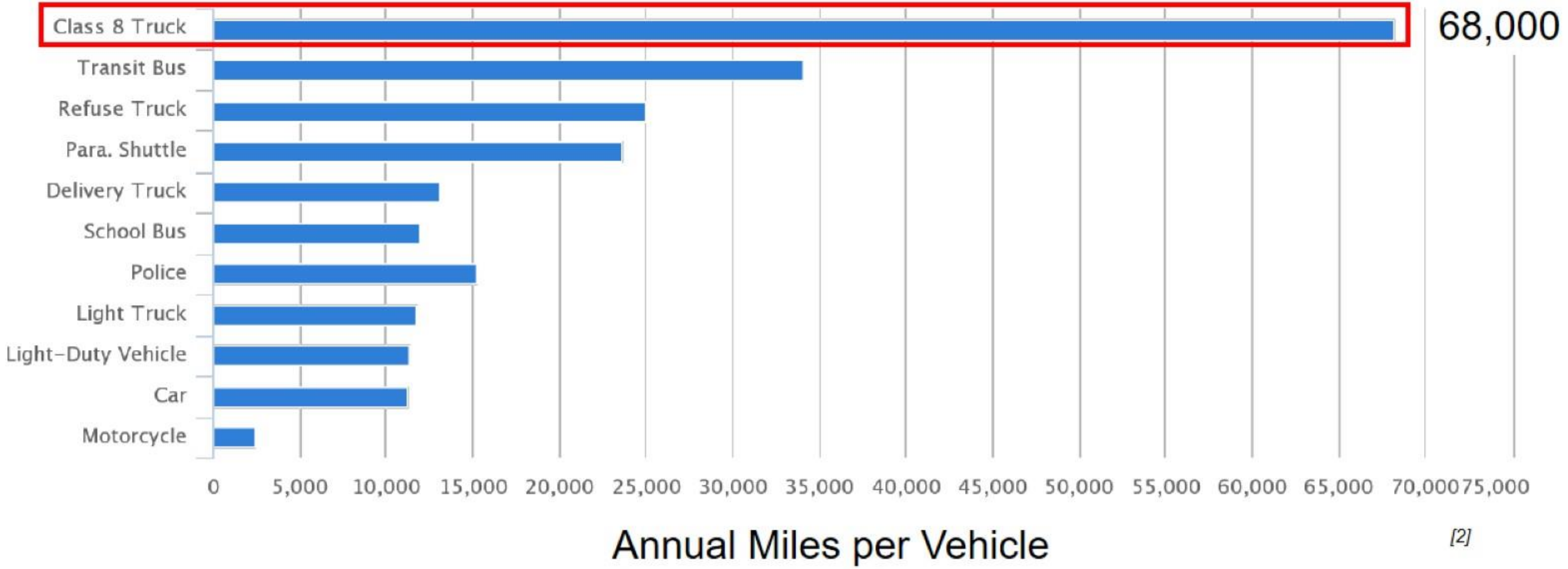
- **Engine** and **transmission** fuel efficiency improvements have remained **isolated from** emerging **Connected and Automated Vehicle (CAV) applications**

- 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

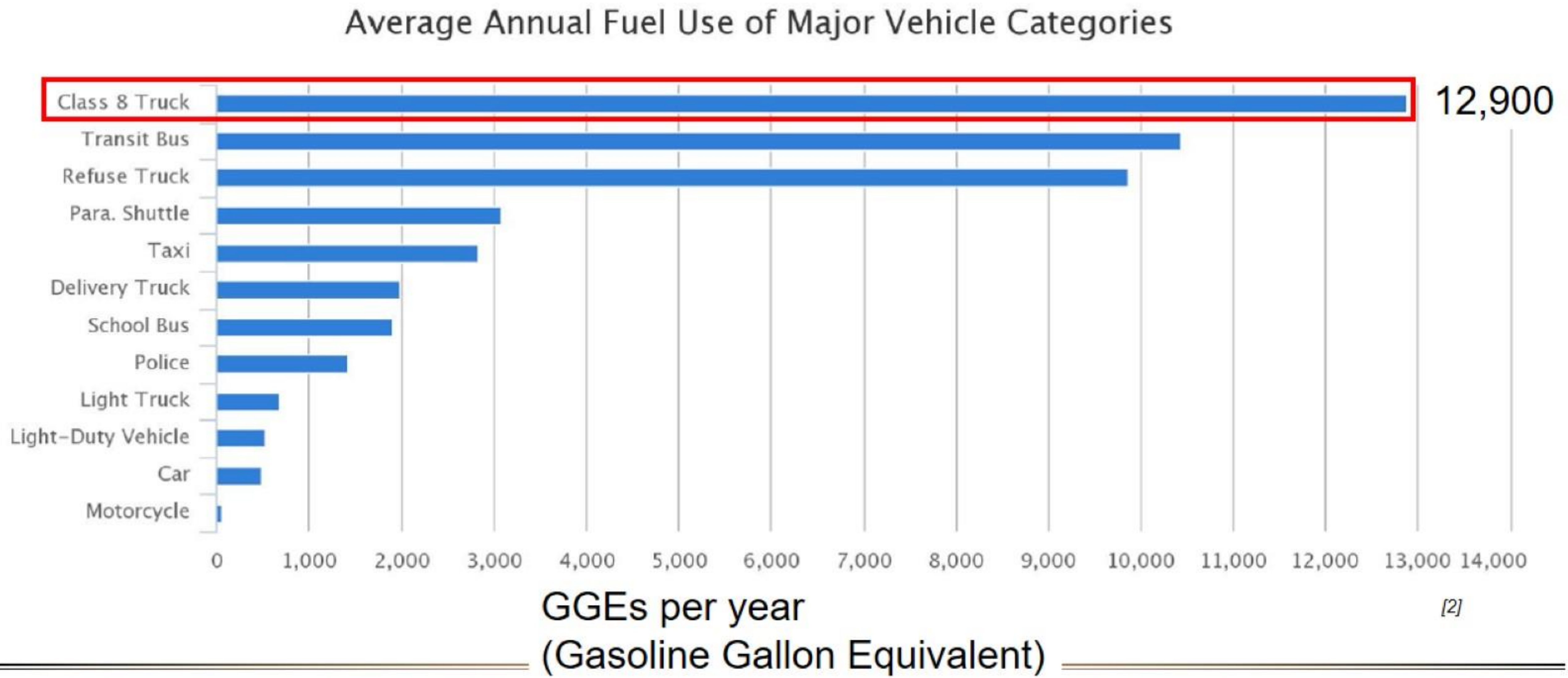
Trucking Industry Statistics

Average Annual Vehicle Miles Traveled of Major Vehicle Categories



[2]

Trucking Industry Statistics

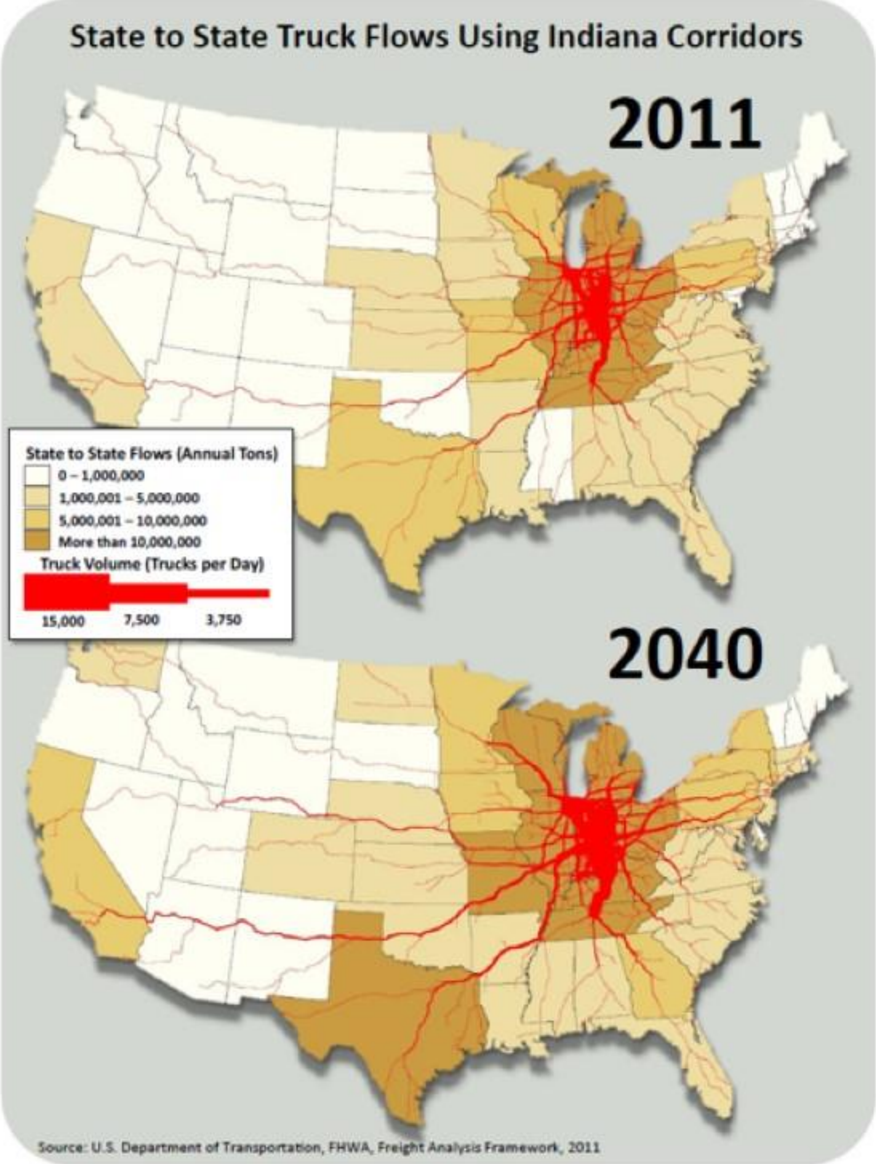


[2]

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

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Project Partners

PURDUE UNIVERSITY

Cummins

Peloton

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

PACCAR

ZF

Our Project – Team Members

PURDUE UNIVERSITY

Faculty:

PI: Dr. Greg Shaver

Dr. Neera Jain

Dr. Dan DeLaurentis

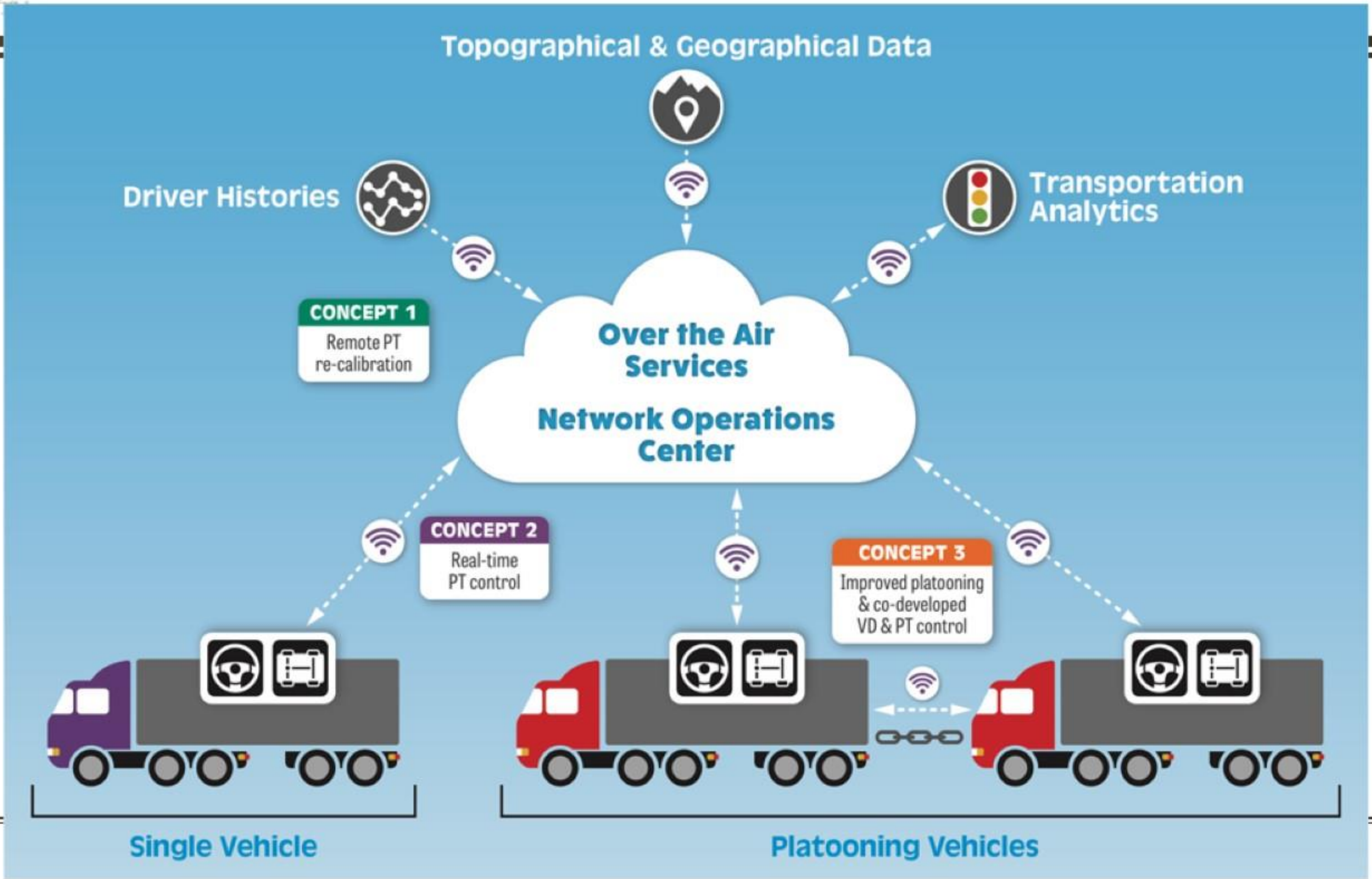
Dr. Darcy Bullock

Dr. Srini Peeta

Students:

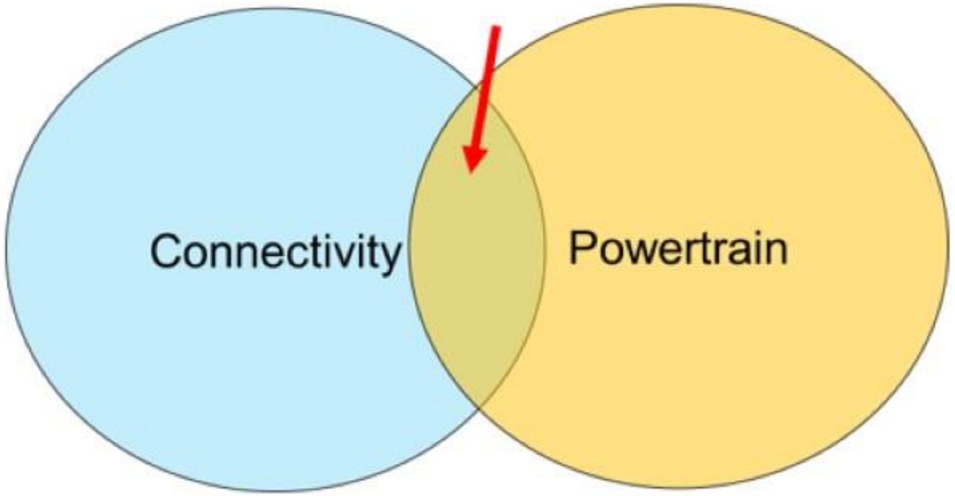
- 5 Graduate Students
- 3 Undergraduate Students

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



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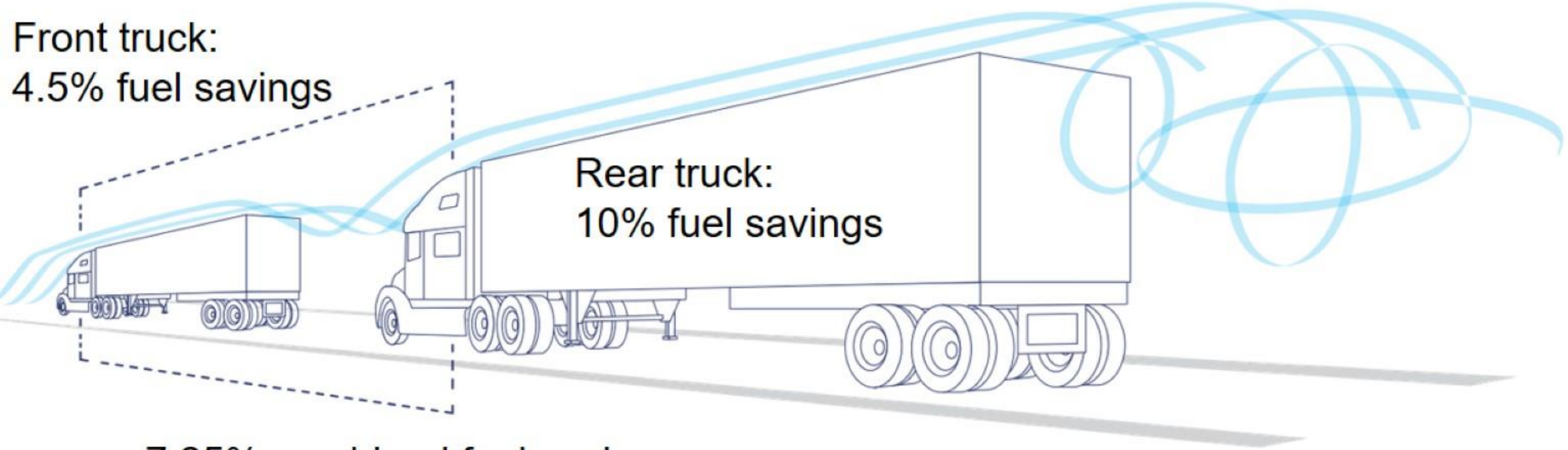
What technology exists today?

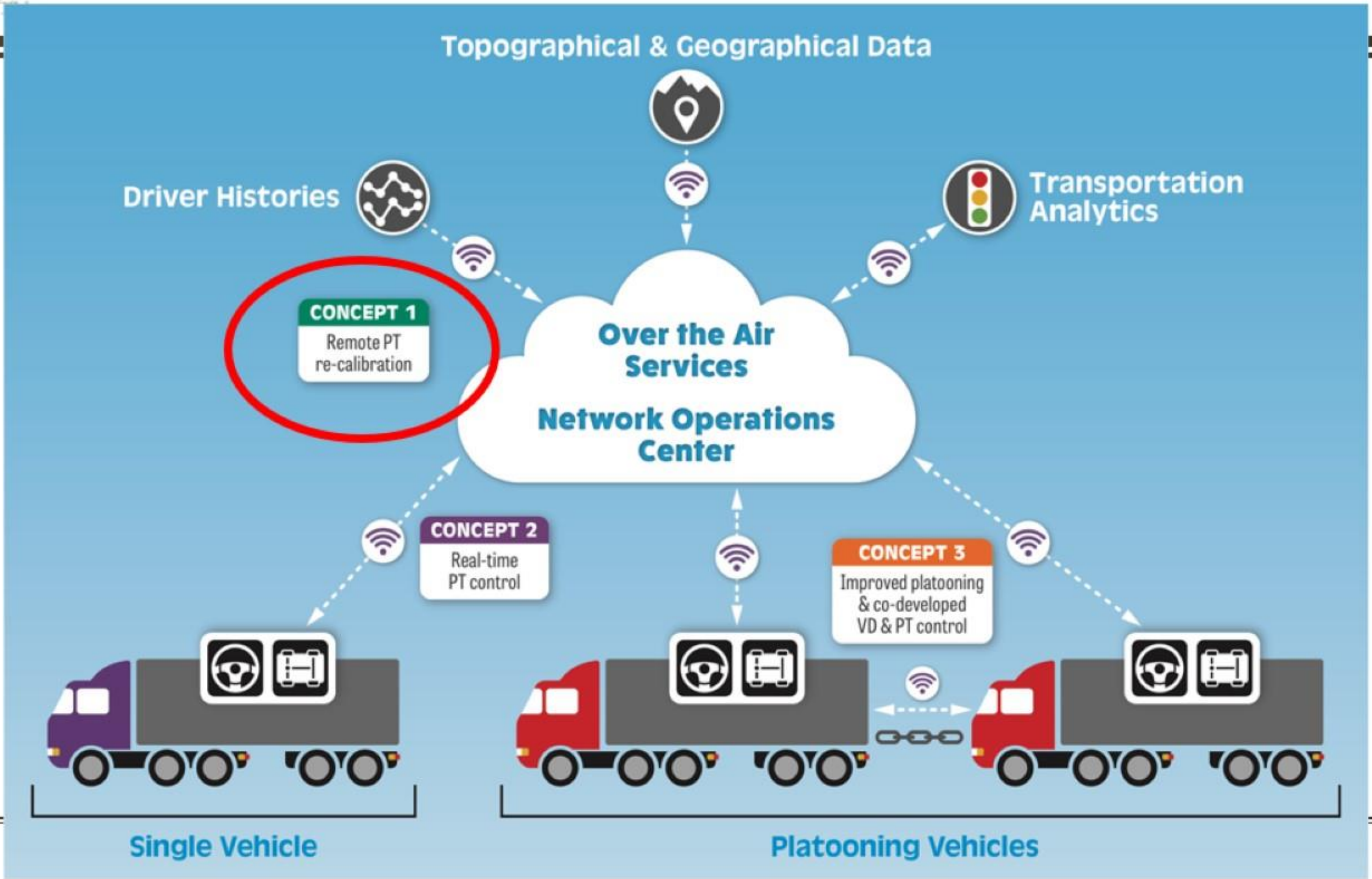
- **Peloton Technology, Inc: Platooning**



7.25% combined fuel savings

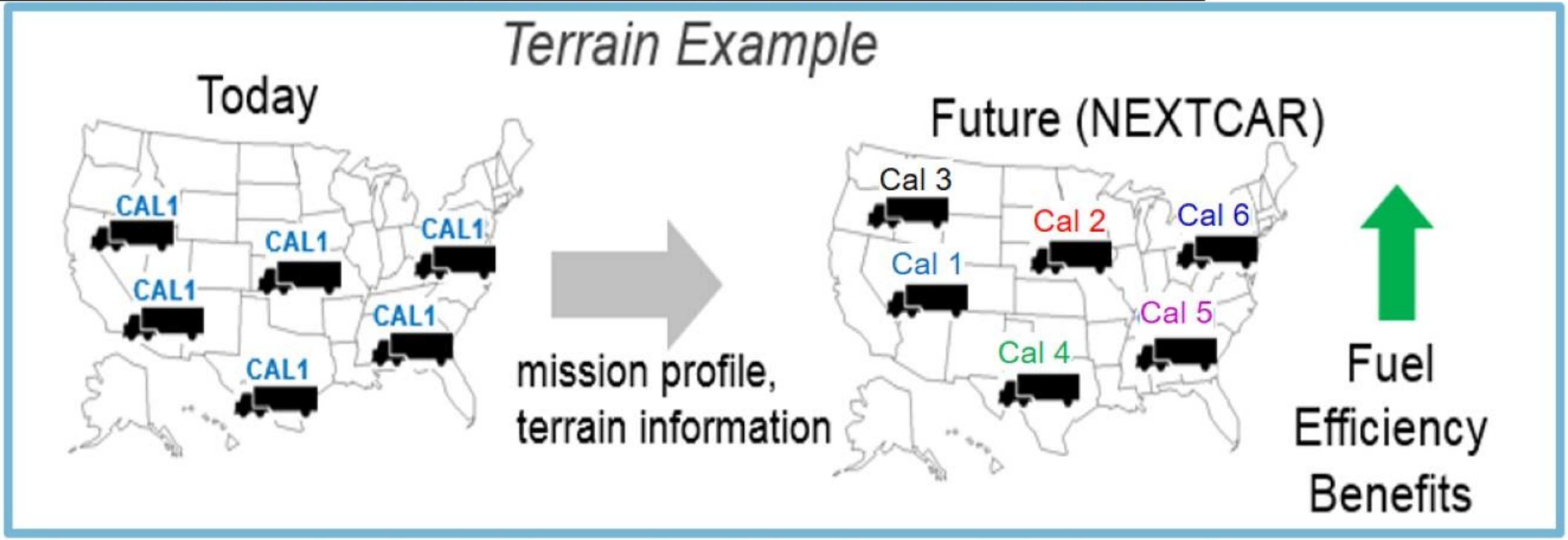
[3]

Purdue NEXTCAR – 3 Concepts for 20% Fuel Savings



Purdue NEXTCAR – 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 – Concept 1

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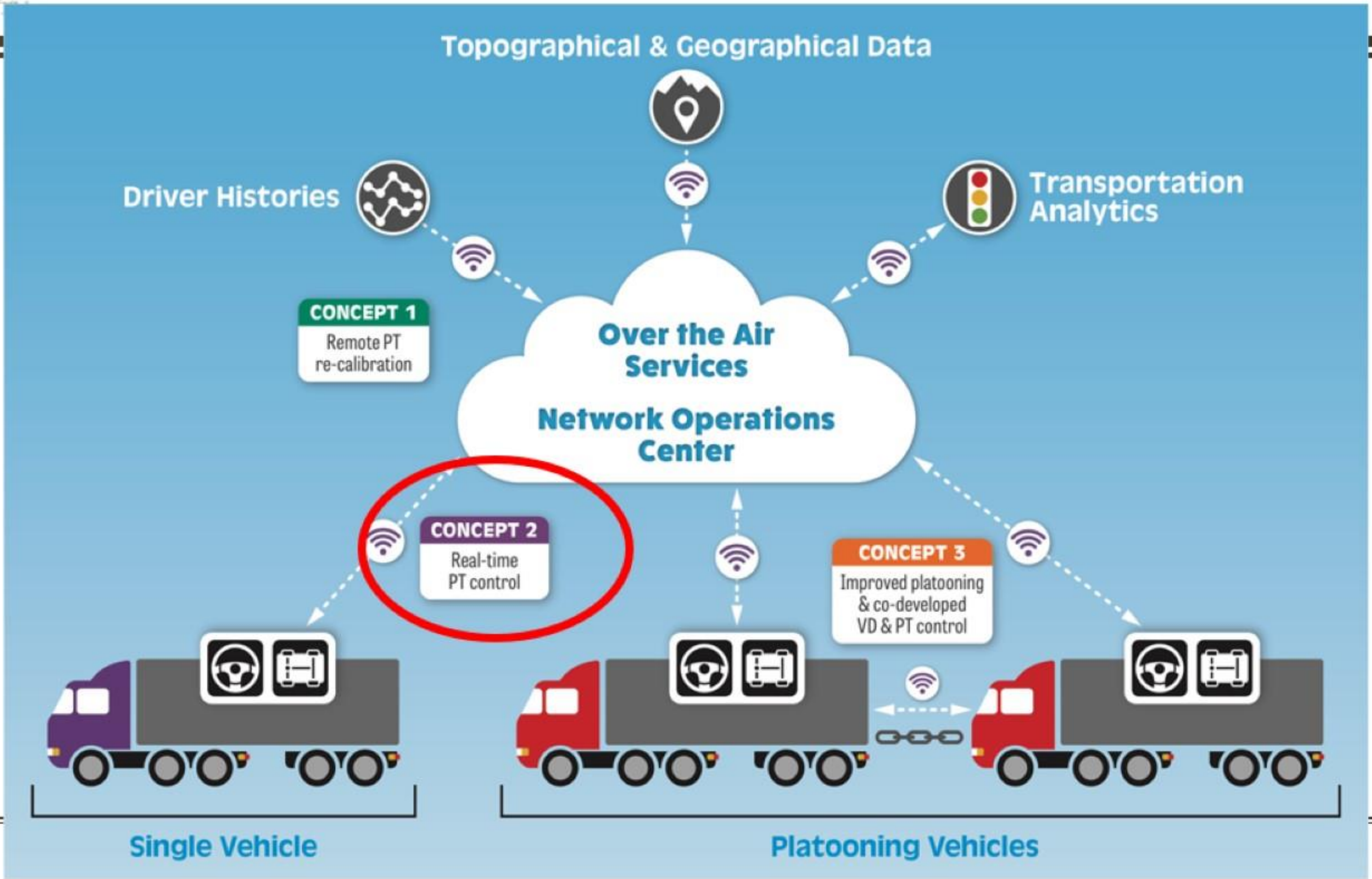
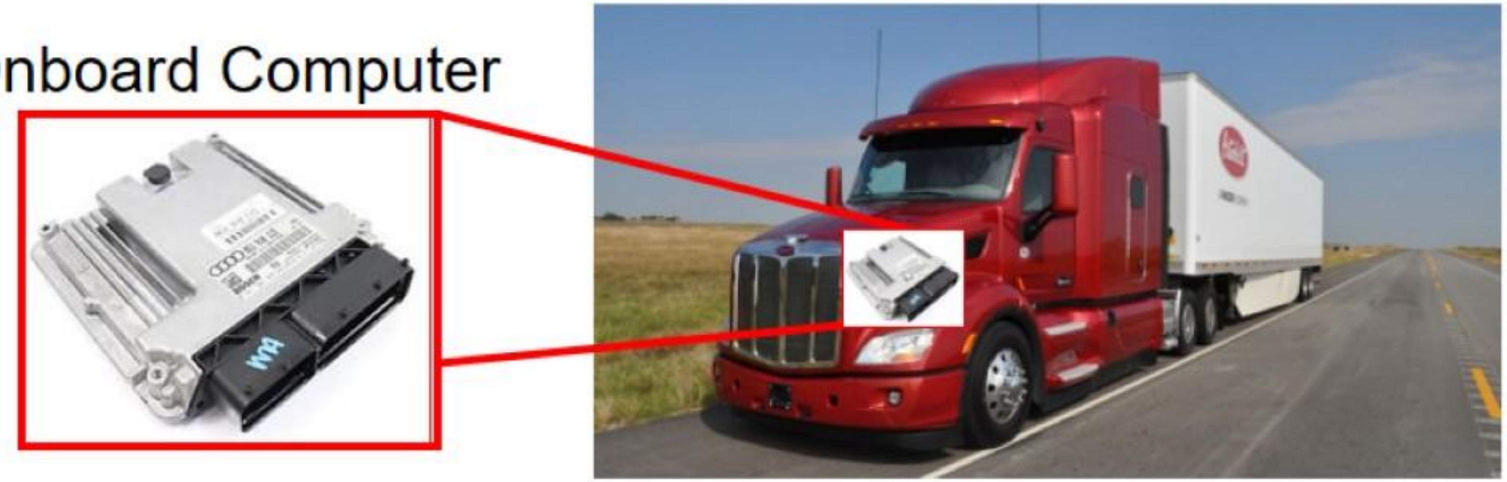


Purdue NEXTCAR – Concept 2

- Cloud based optimization, improved control of the powertrain

Onboard Computer



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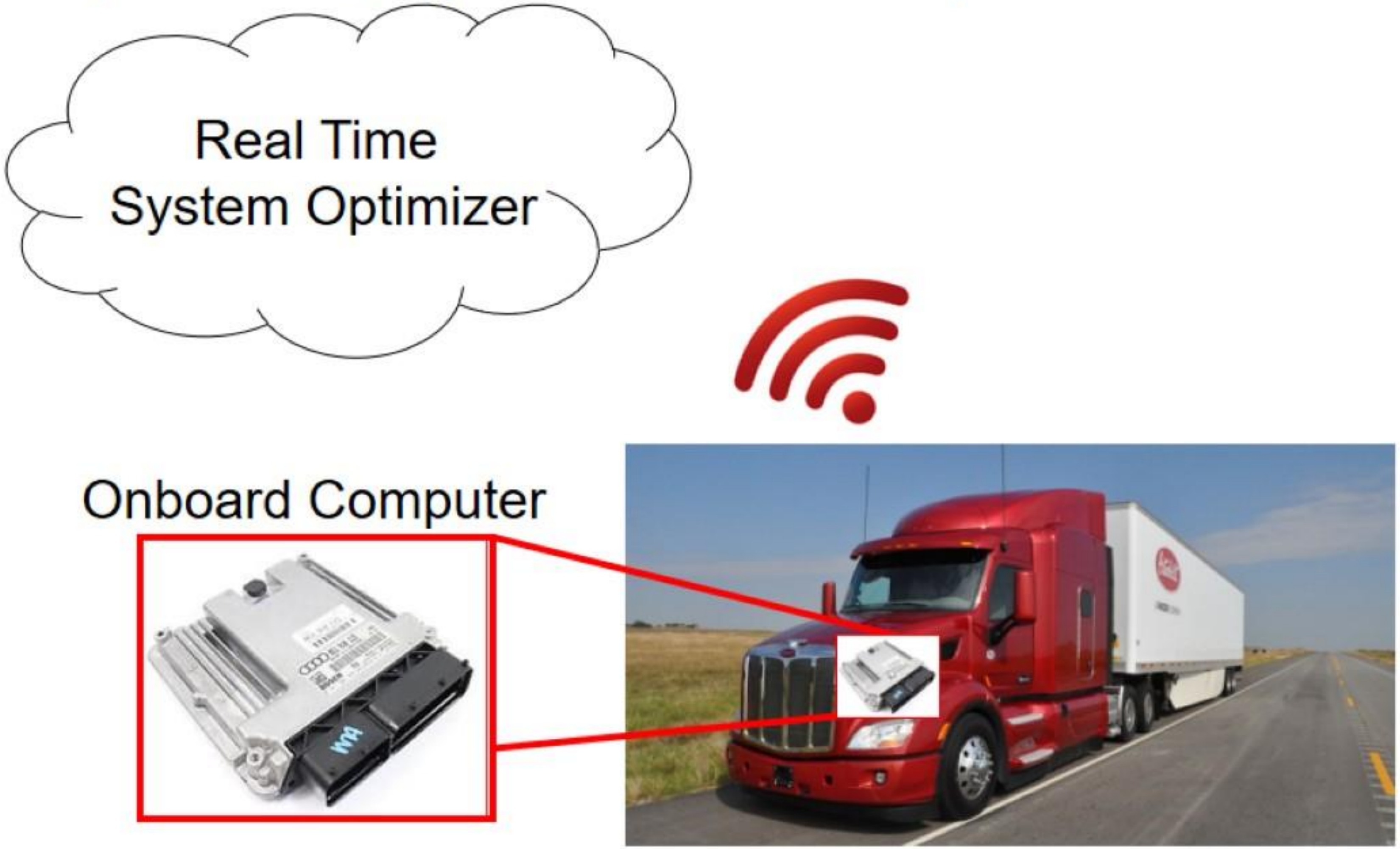

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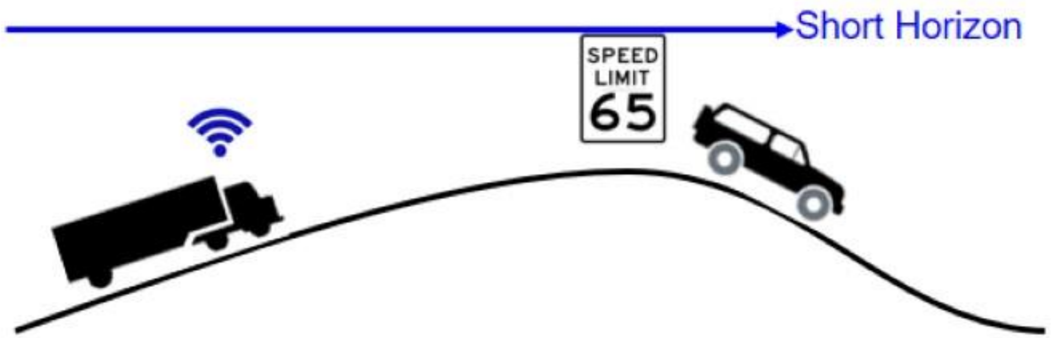


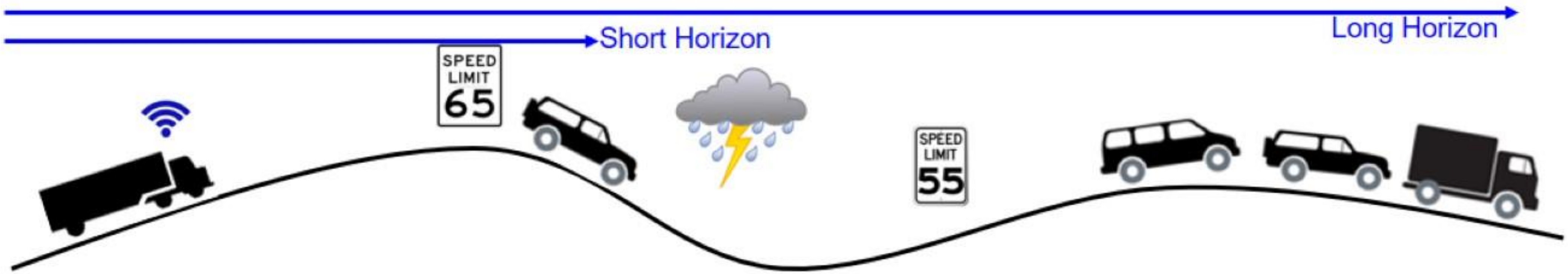
Short Horizon Example

-Road geometry
-Speed of preceding vehicles
-Speed limit

→ **Short Horizon Algorithms** →

Optimal instantaneous spacing between vehicles

Purdue NEXTCAR – Concept 2



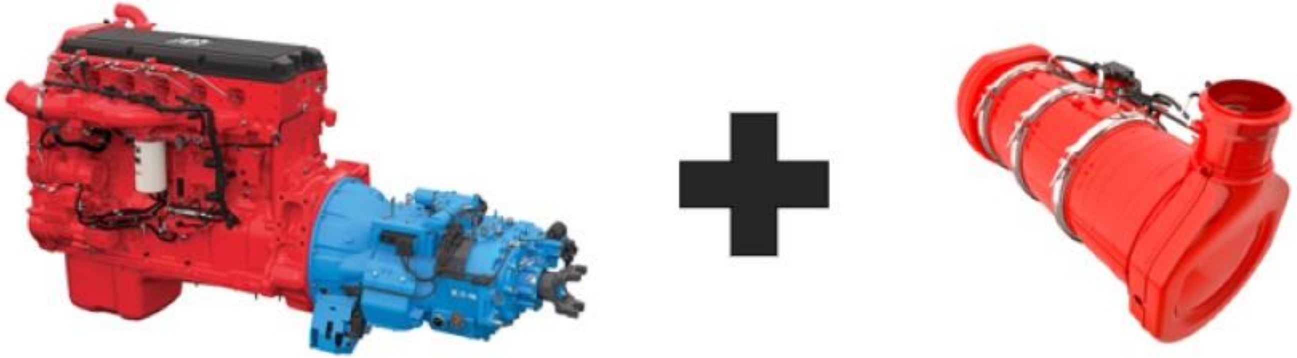
Long Horizon Example

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

→ **Long Horizon Algorithms** →

Optimal speed profile over the route

Purdue NEXTCAR – Concept 2



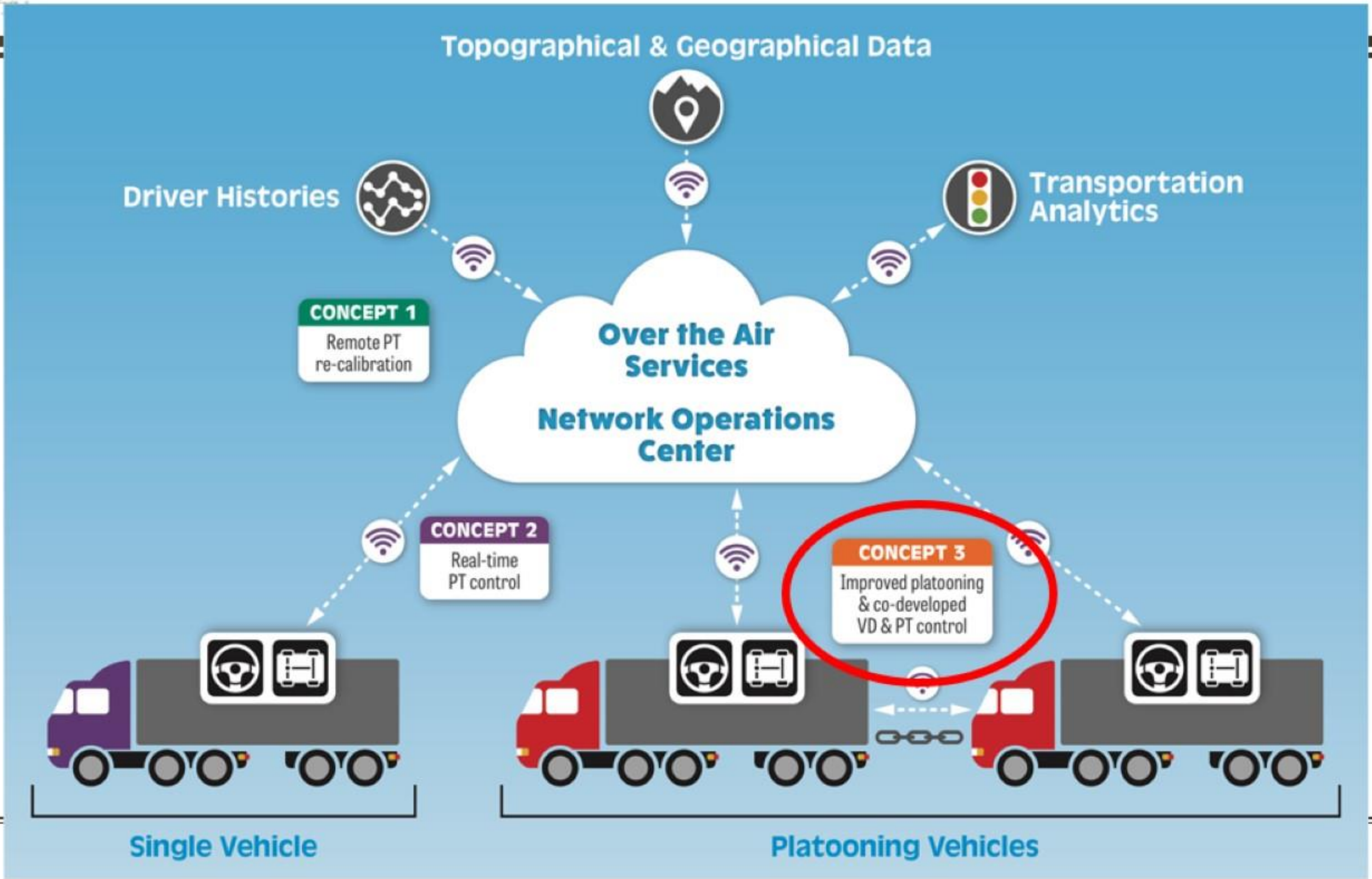
Engine/Aftertreatment Optimization Example

-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

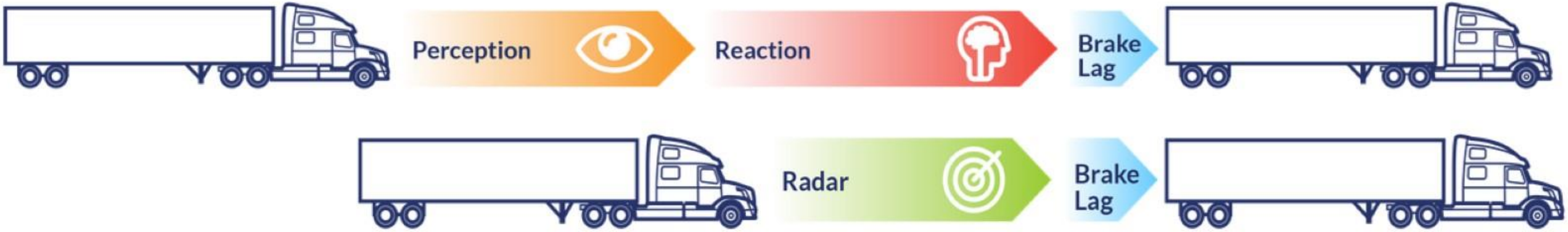
- Radar & connectivity based braking system removes **driver reaction time**

Platooning 101

- **Peloton Technology, Inc: Platooning**

[3]

- **Peloton Technology, Inc: Platooning**



[3]

Platooning 101

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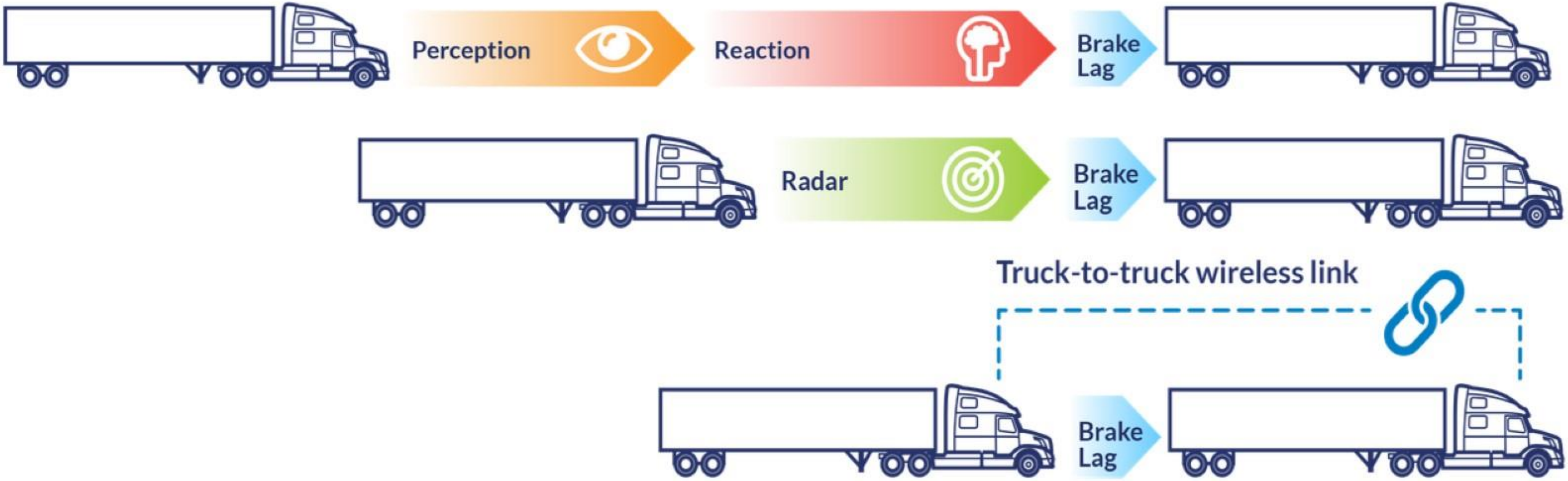

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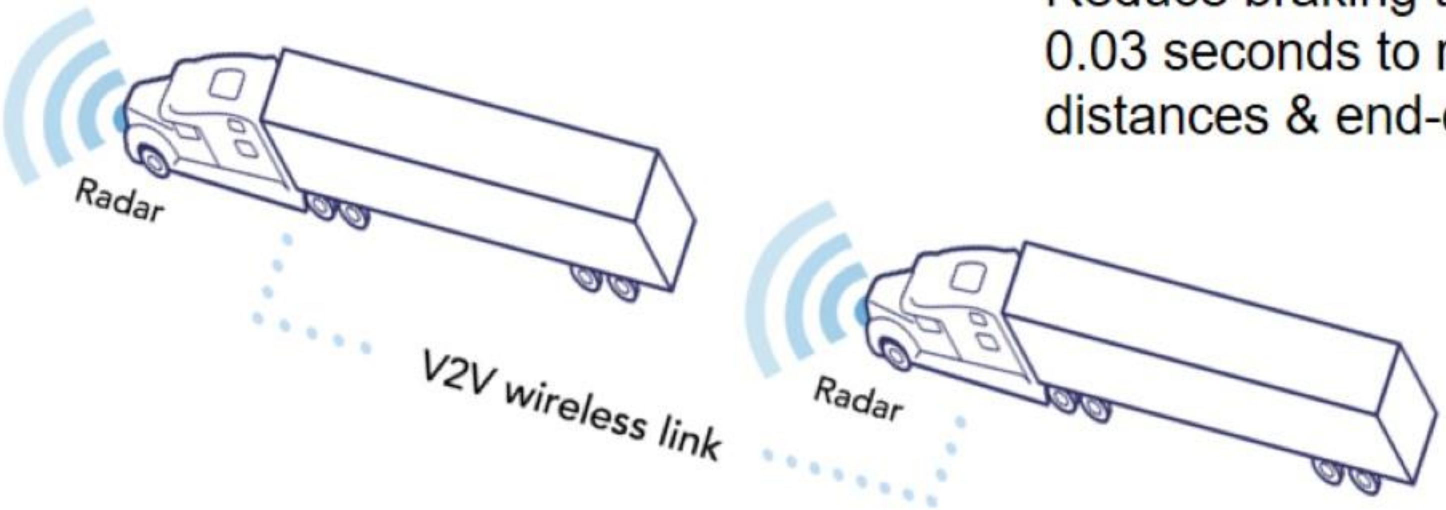
Platooning 101

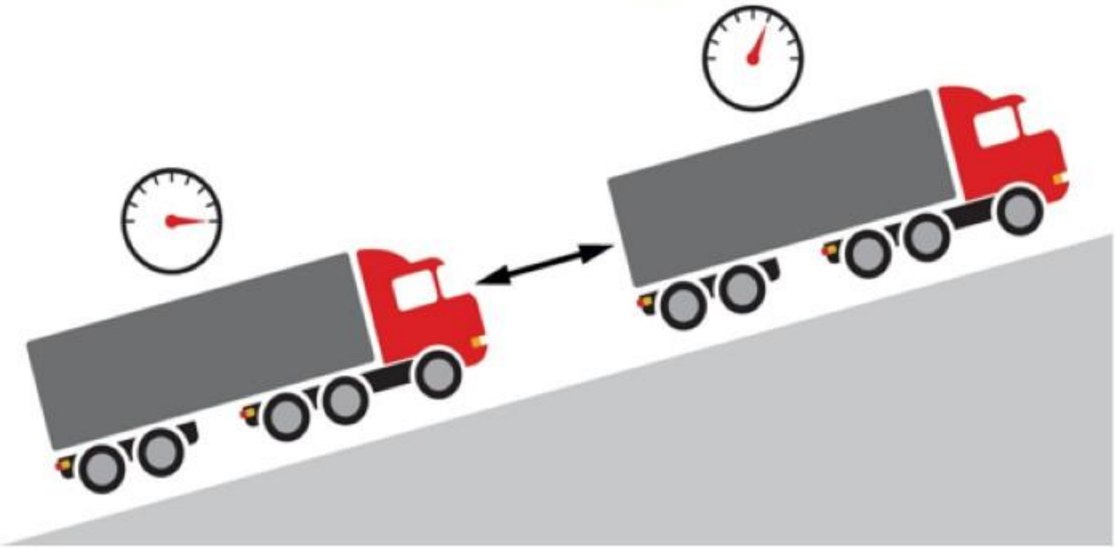


Active Braking:
Reduce braking time from 1.5 to 0.03 seconds to reduce stopping distances & end-of-queue accidents

- 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

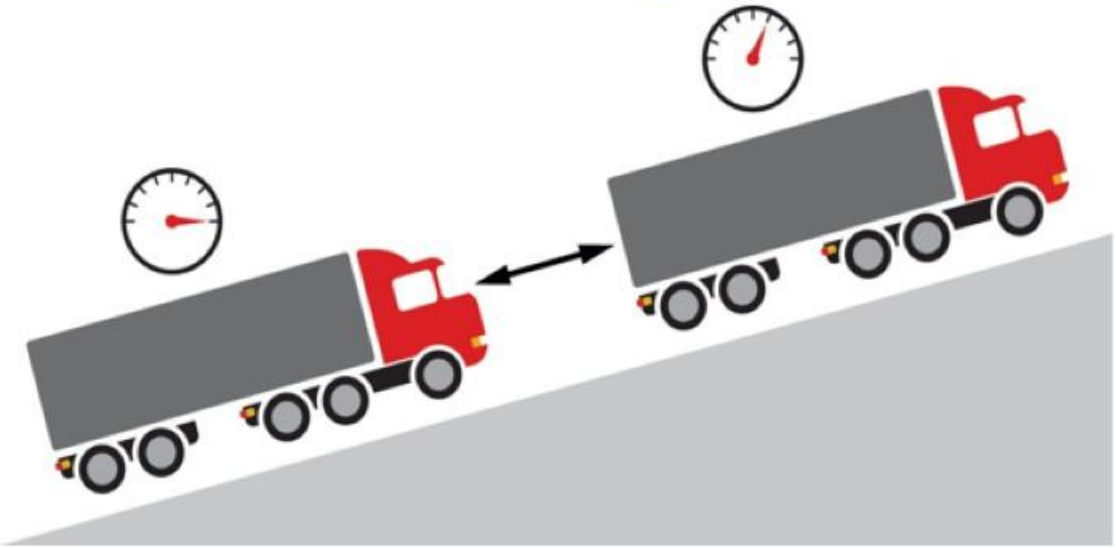


- The platooning gap is hard to regulate when either truck is near the torque limit

- 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

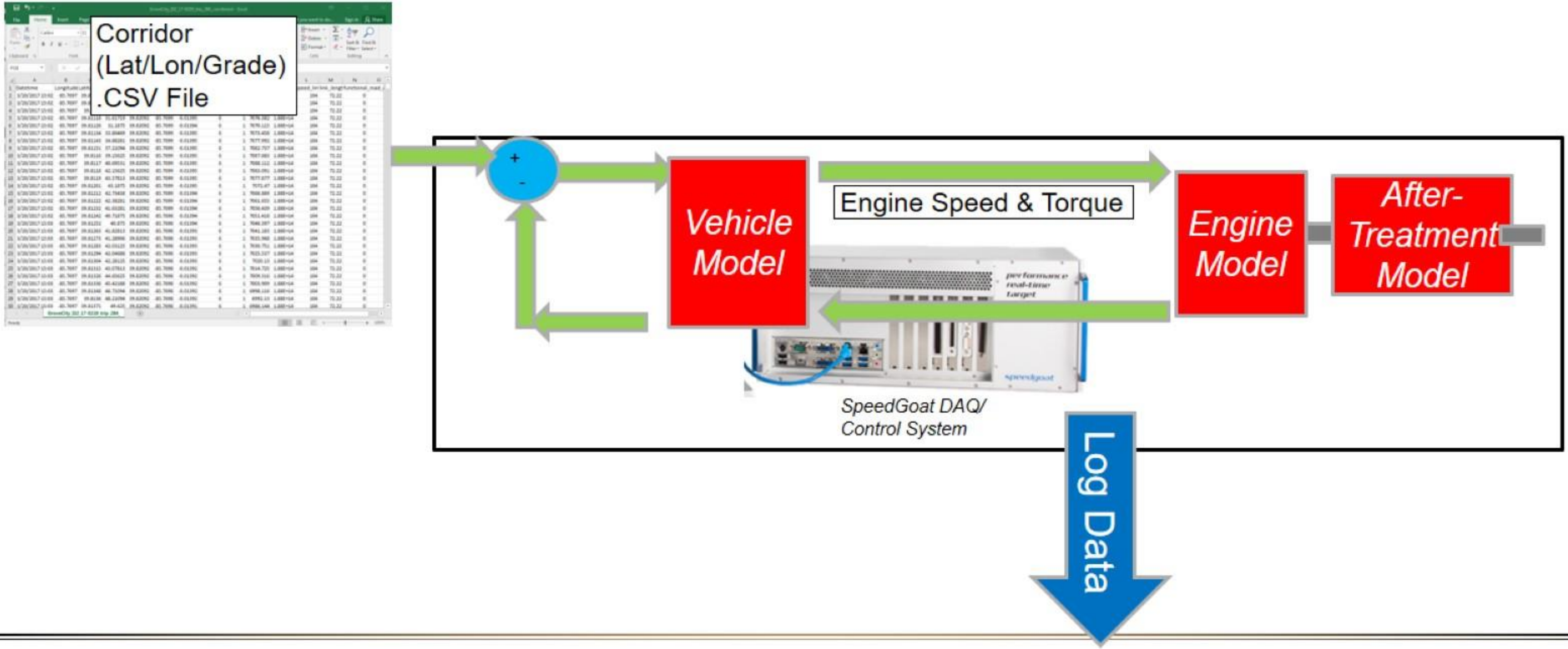
Truck Testing

Engine Testing

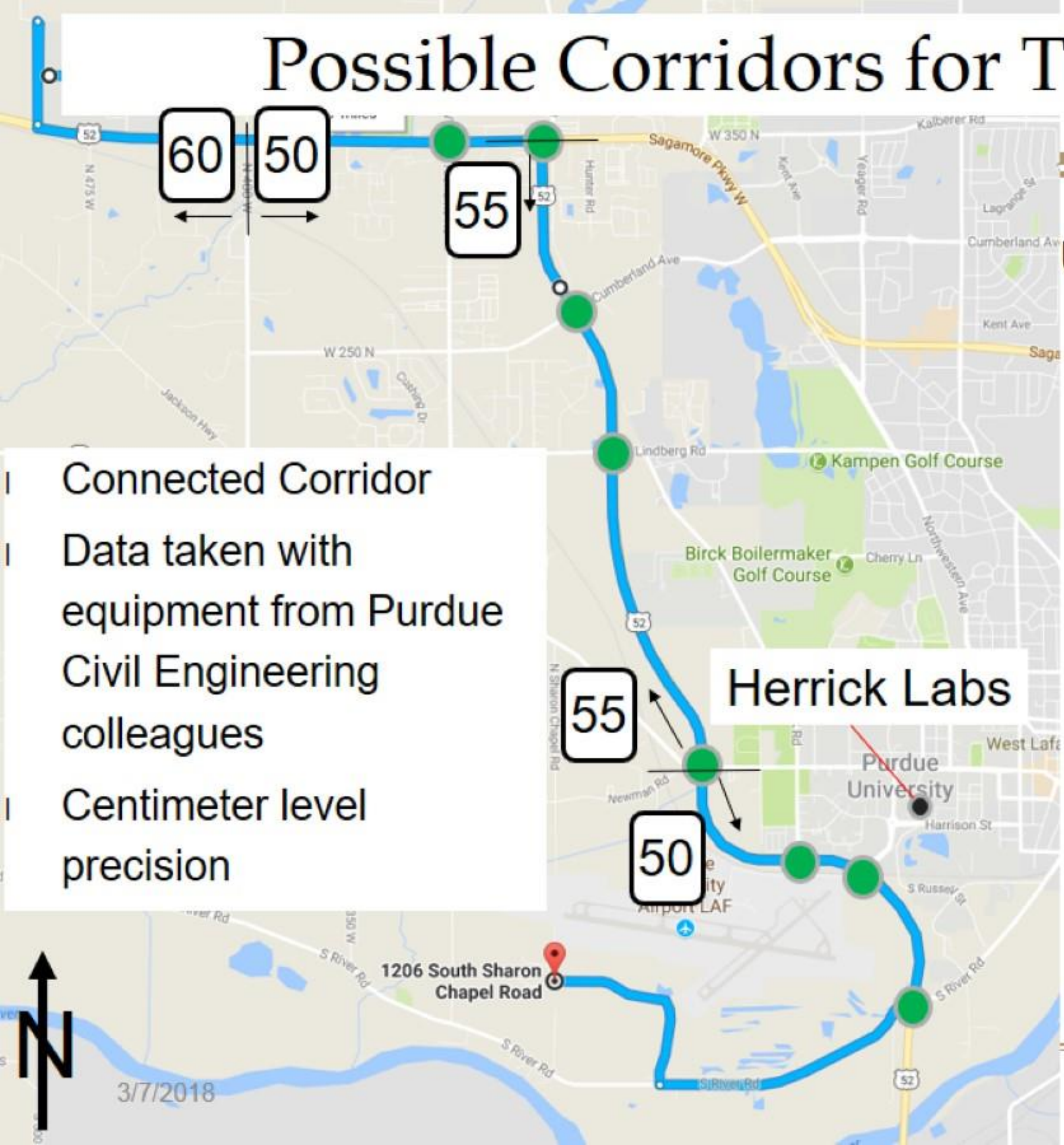
Simulations

Algorithm Development

Simulations – Vehicle & Powertrain



Possible Corridors for Testing in Indiana



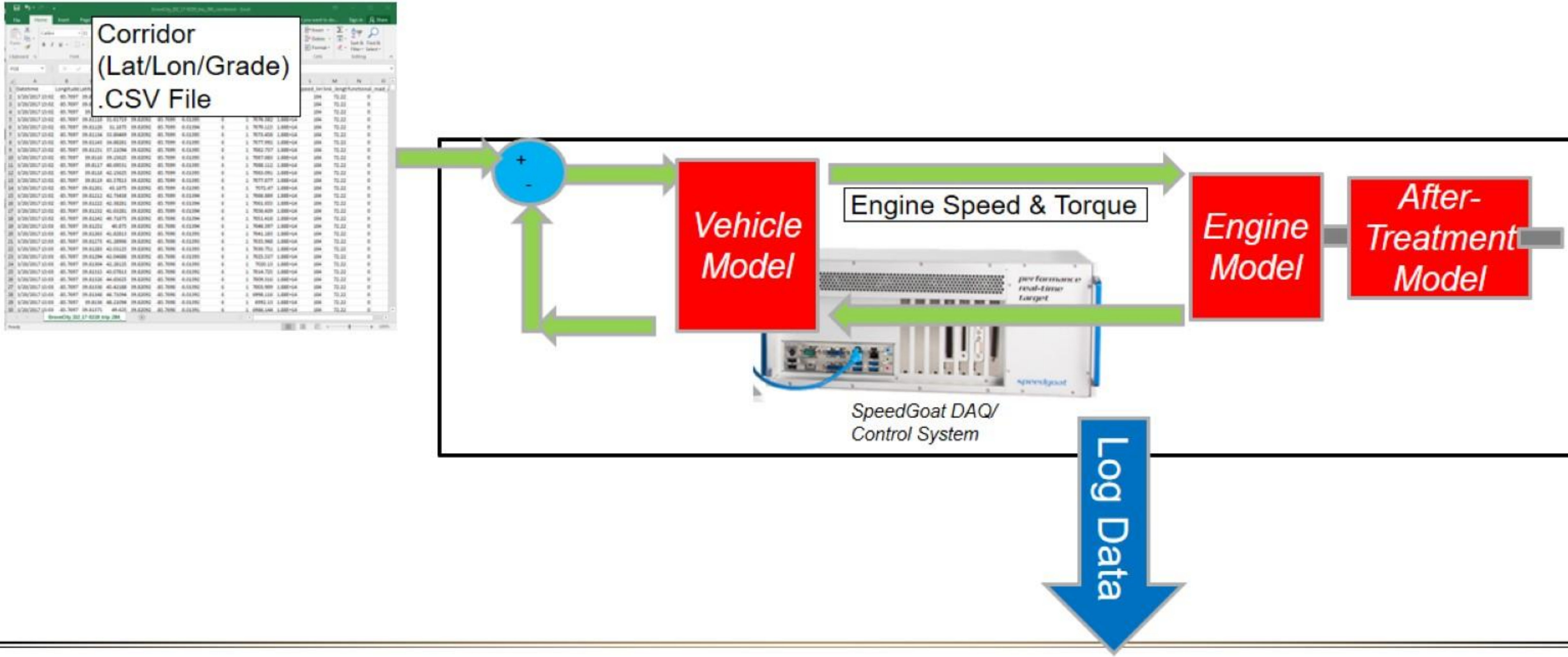
- Connected Corridor
- Data taken with equipment from Purdue Civil Engineering colleagues
- Centimeter level precision

US 231 near Purdue

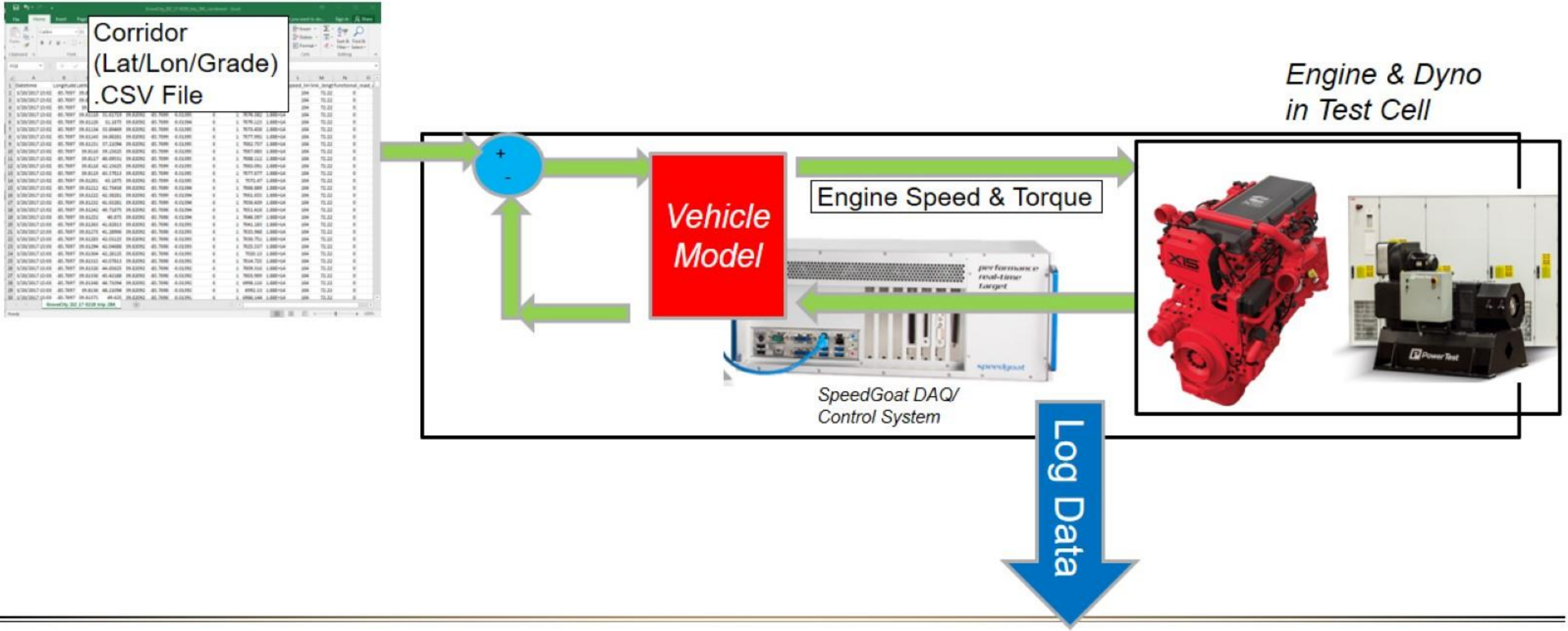
Traffic Signal Locations

Speed Limits (MPH)

Simulations – Vehicle & Powertrain



Engine Testing "Hardware in Loop"



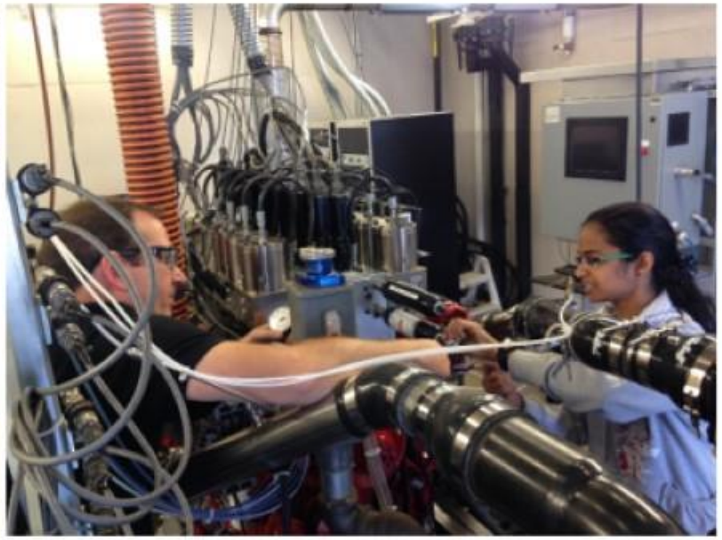
Engine Test Bed @ Purdue's Herrick Labs

- 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

Herrick Labs – Engine Test Cells

- Industry Collaboration
- Undergraduate Students
- High School Students

Thank you

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Sources

- [1] Atkinson C. NEXTCAR Kick-off Meeting. Detroit MI. 2017. https://arpa-e.energy.gov/sites/default/files/2_ARPA-E_NEXTCAR_Kickoff.pdf
- [2] Federal Highway Administration Table VM-1, 'Public Transportation Fact Book', 2015
- [3] Peloton Technology Website
- [4] 'ADEPT Aftermarket Kit for ISX15 Engines', Cummins Brochure