Connected Commercial Electric Vehicle Research for Intelligent Energy Management and Emissions Reductions

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CTS Transportation Environment and Energy (E&E) in Transportation Research Council
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University of Minnesota
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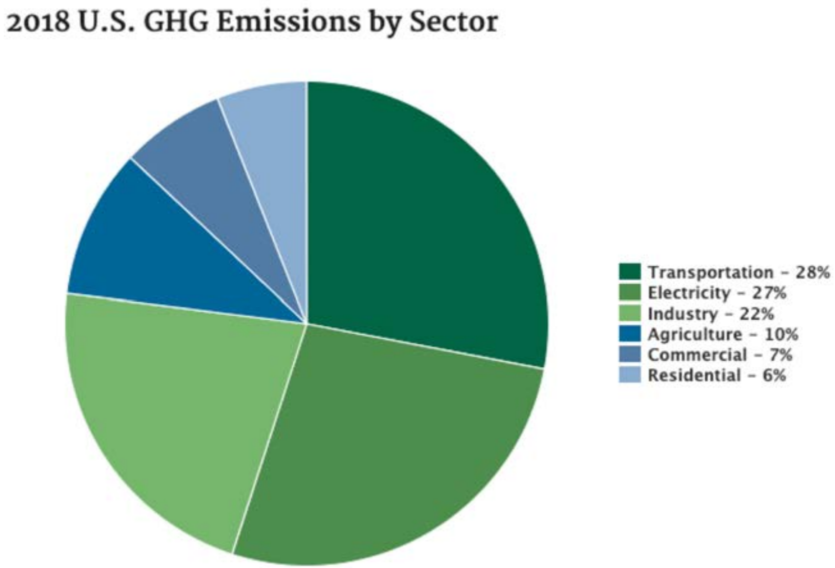
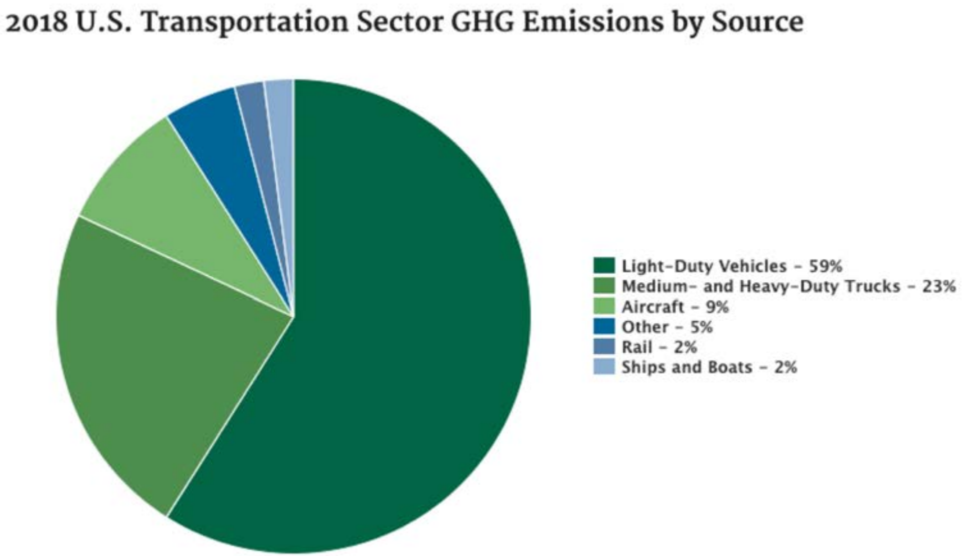
Vehicle Transport and CO_2 Emissions

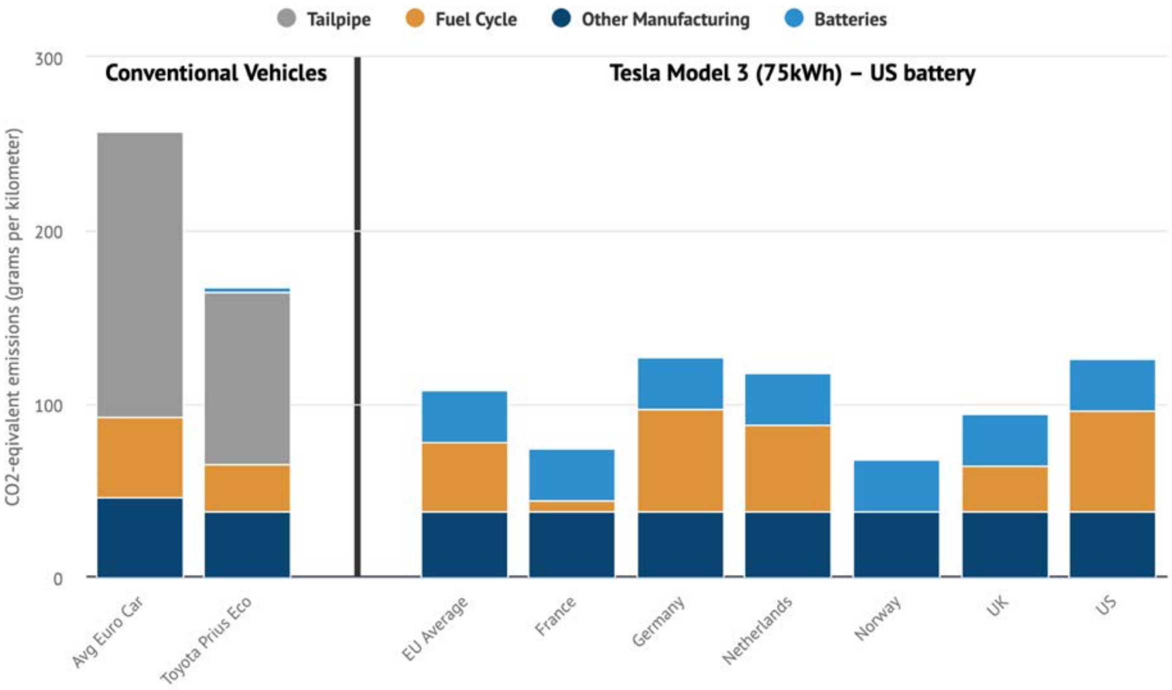




https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions

Medium and heavy duty trucks account for only ~4% of the vehicle population

Electrification can lower net CO_2 emissions

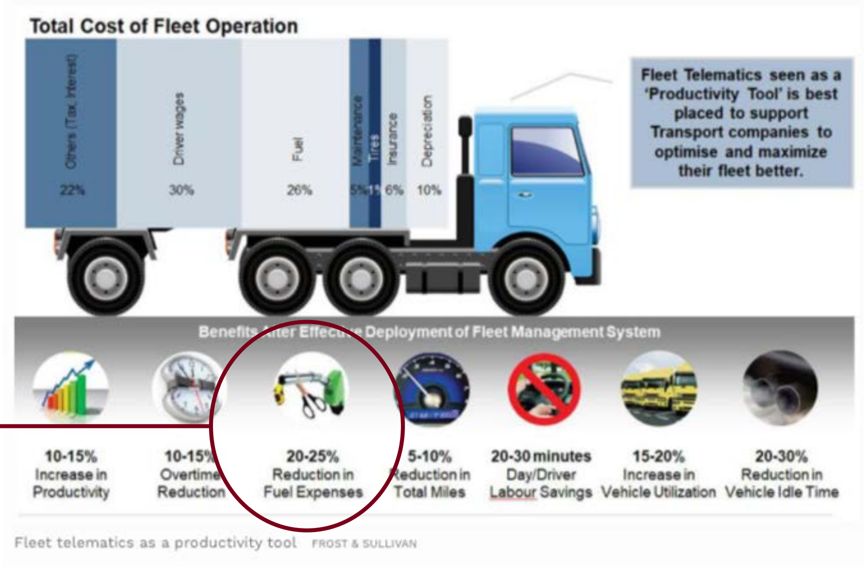


https://www.carbonbrief.org/factcheck-how-electric-vehicles-help-to-tackle-climate-change

However, due to lifecycle energy use, it is not a panacea

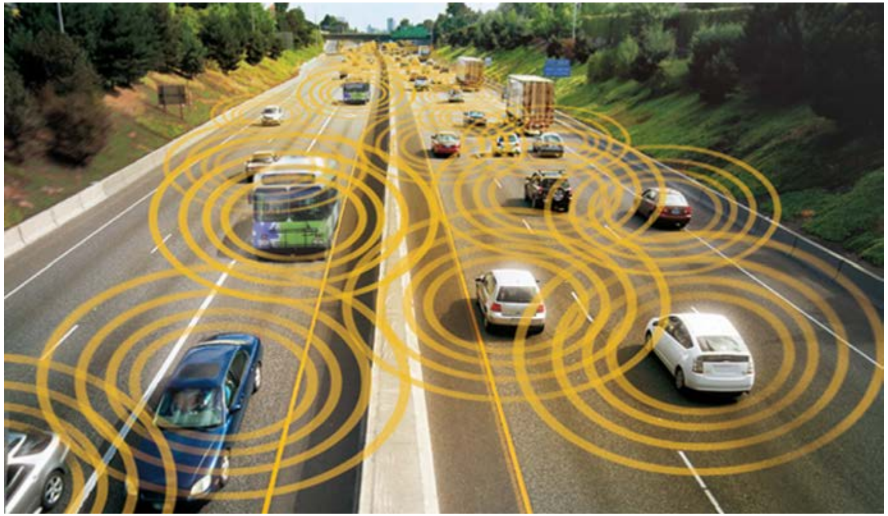
Telematics and Data Analysis

- Commercial truck sales down significantly in 2020
- Telematics market is growing
  - 29.3 million vehicles in 2020
  - 10% annual increase
  - $17.1B market in the US
- Reductions in fuel use proportional to CO_2 reductions



https://www.forbes.com/sites/sarwantsingh/2020/06/03/commercial-vehicle-sales-are-ailing-so-why-is-the-connected-truck-telematics-market-still-in-good-health/#2daa316f7e12

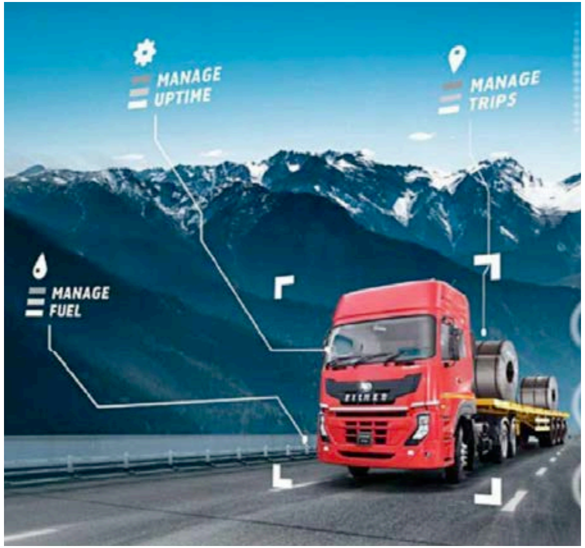
Telematics: Part of the Connectivity Landscape



Vehicles will use greater levels of connectivity in the future
V2V, V2I, V2C, V2X

Vehicle Data Vision

- Collect more and diverse datasets
- Data can be used for:
  1. Analysis for design feedback
  2. Predictive diagnostics
  3. In-use powertrain improvement
- Develop rule-based data approaches to:
  - Improve fuel economy for PHEVs
  - Optimize on-route fast charging
  - Predict EV range on-route
  - Adjust shifting control to minimize energy use



https://www.magzter.com/article/Automotive/Commercial-Vehicle/Safe-Drive-With-Telematics

Connectivity Enables Vehicle Electrification

- Range in EVs is limited
- Depends heavily on:
  - Ambient temperature
  - HVAC loads
  - Mass
  - Driving behavior

- Connectivity can provide range confidence
- Charge optimization
- Route planning and load distribution

Technology Description

Cloud

Inputs

High time resolution data
- Vehicle speed
- Powertrain parameters
- GPS location

Exogenous parameters
- Map
- Traffic density

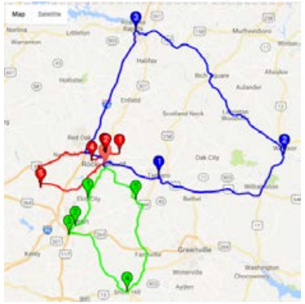
Outputs

Powertrain recommendations
- EV mode on/off
- Hybrid mode setting
- REx engine on/off
- REx engine power
- Pure EV fast charge duration

Vehicle

resource-limited vehicle

Infrastructure



Delivery Routing

Charging Requirements

Portfolio of Connected Vehicle Projects

2017

ARPA-E NEXTCAR
Connected Delivery Vehicles

2018

MnDOT
Snowplow Fuel
Consumption

LRRB/MnDOT
Hybrid
Fleet Vehicles

2019

DOE STTR
Route Optimization
of PHEVs

DOE/Volvo
Energy Management of
Class 8 Electric Trucks

2020

DOE
Heavy-Duty EV
Implementation Tool

DOE/Exergi Predictive
EV Delivery Truck
Range Prediction

2021

Cloud-Connected Last Mile Delivery Vehicles

- Aim: Improve the fuel economy of range extender (REx)-equipped electric delivery vehicles through real-time powertrain optimization using two-way vehicle-to-cloud (V2C) connectivity
- Goal: Greater than 20% energy efficiency improvement of a baseline 2016 E-Gen delivery vehicle integrating routing, V2C and physics-aware data analytics

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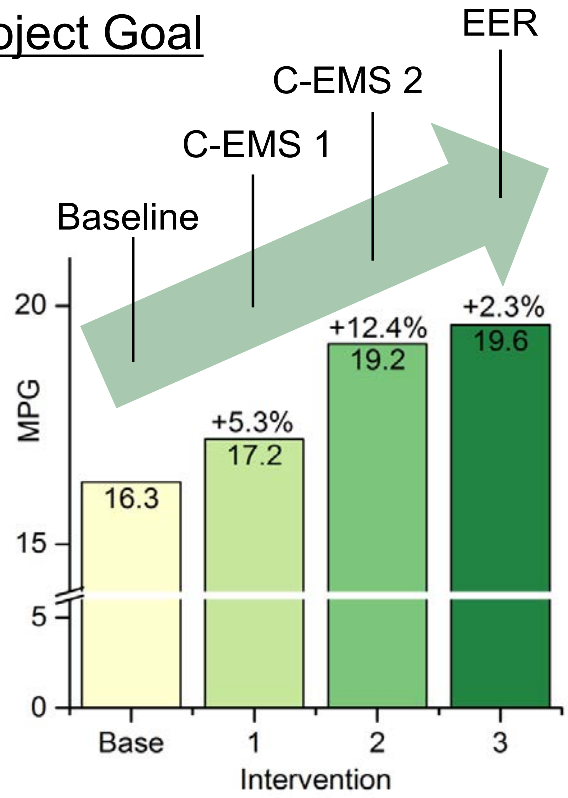
Connected Energy Management

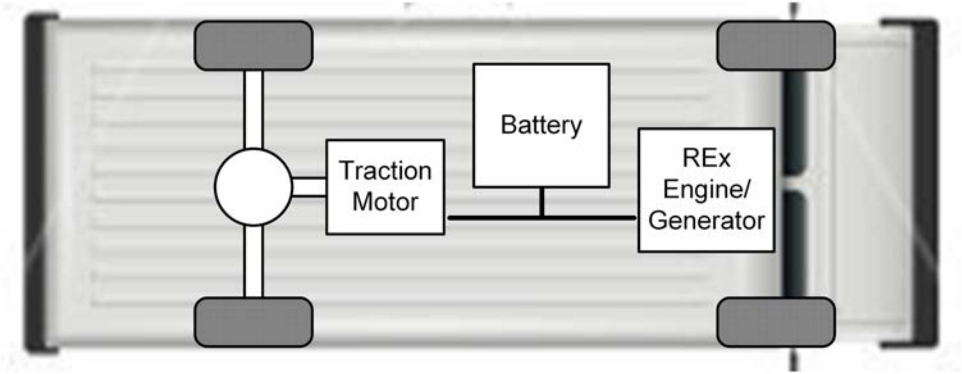
- **Two Interventions:** C-EMS and Energy Efficient Routing (EER)
- EER – Reduced energy use between set origin-dest. pairs with time penalty
- C-EMS – Minimized fuel consumption through practical rule-based algorithms

Project Goal



Workhorse E-Gen Vehicle

- E-GEN Vehicles are range-extended PHEVs
  - 20 kW BMW I-3 REx
  - 60 kW-hr battery
  - 1 kW-hr/mile average energy use
  - ~ 60 mile all electric range
- UPS Fleet
  - Currently 125 vehicles
  - Desired end SOC = 10%
  - Driver sets route distance (L_{set})



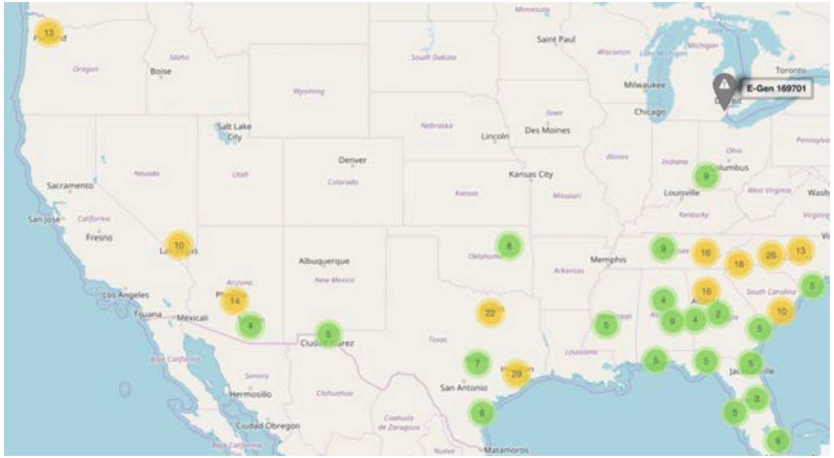
Rule-Based Control for SOC Minimization

- Vehicle data mined at 0.2 Hz for 16 months from >100 in-use UPS E-GEN vehicles

- Varied locations
- Different route types

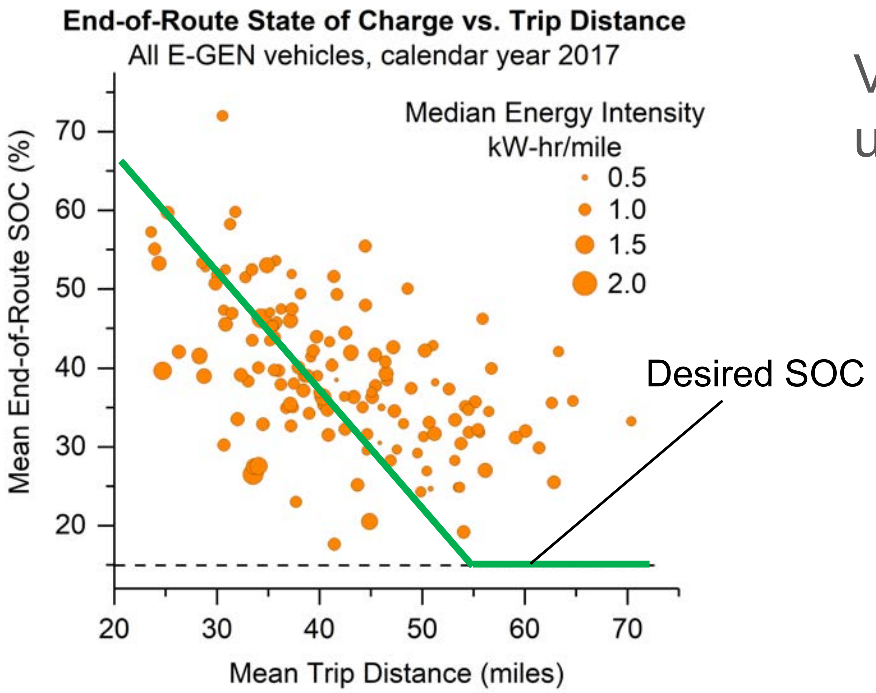
METRON™

Telematics and Asset Tracking Software



Goal: Vehicle returns to depot each day with 10% battery state of charge (SOC), <u>minimize REx use</u>

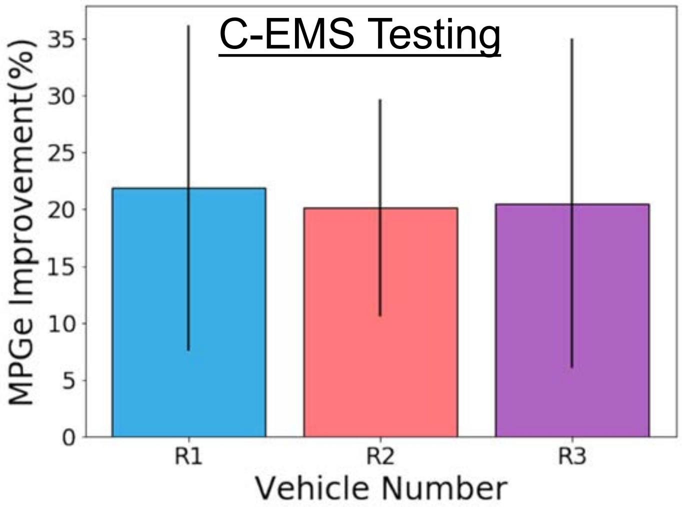
Truck Energy Use



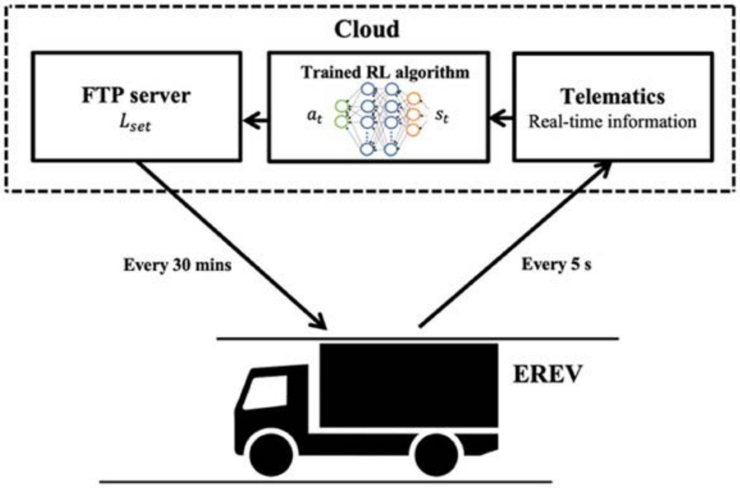
Vehicles above green line use more fuel than desired

Connected Energy Management

- Implemented energy management strategy using reinforcement learning [1,2]
- Enabled over 20% MPGe improvement on actual routes



Testing
R1 = 15 trips
R2 = 9 trips
R3 = 12 trips



[1] Wang, Pengyue, Yan Li, Shashi Shekhar, and William F. Northrop. 2019. "A Deep Reinforcement Learning Framework for Energy Management of Extended Range Electric Delivery Vehicles." In *Proceedings of the 2019 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 1837–42. Hong Kong, China.
[2] Wang, Pengyue and William Northrop. 2020. "Reinforcement Learning Based Energy Management of Multi-Mode Plug-in Hybrid Electric Vehicles for Commuter Route." *SAE Technical Papers* 2020-April (April): 1–9.

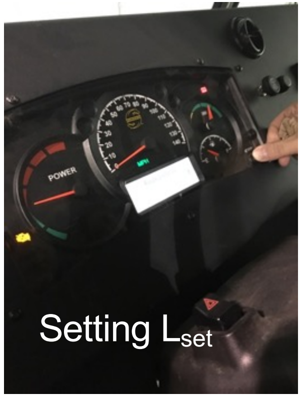
Rule-Based State of Charge Control

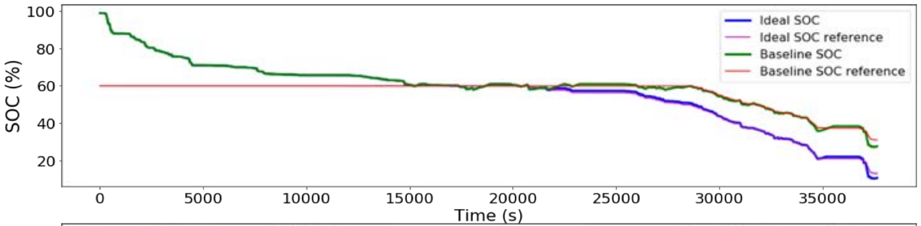
Two rules:

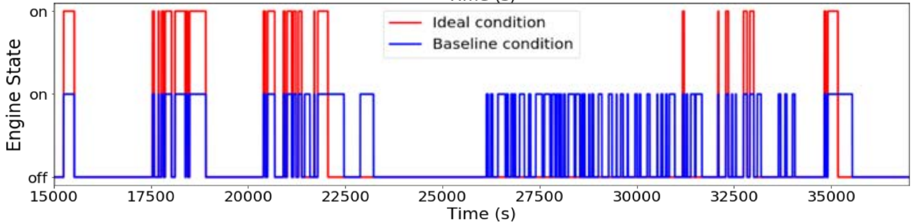
1. If the real-time SOC is lower than the SOC_{ref}, turn engine on
2. If the calculated SOC_{ref} is higher than 60%, set it as 60%

$$SOC_{ref} = 100\% \times \left(1 - 0.9 \times \frac{d}{L_{set}}\right)$$

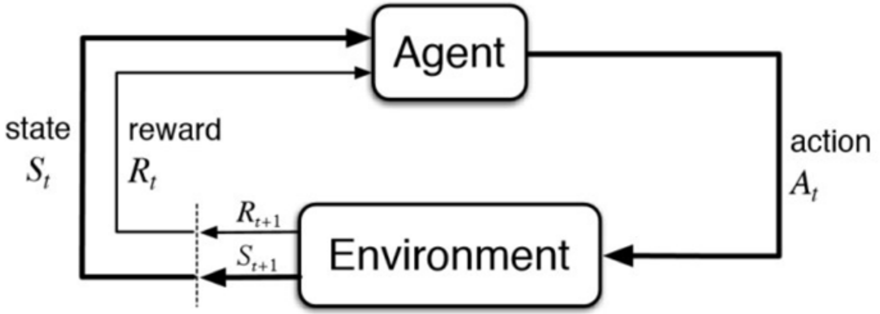
- SOC_{ref} = energy in battery when the vehicle has travelled d miles given the parameter L_{set} (energy-compensated expected trips distance)







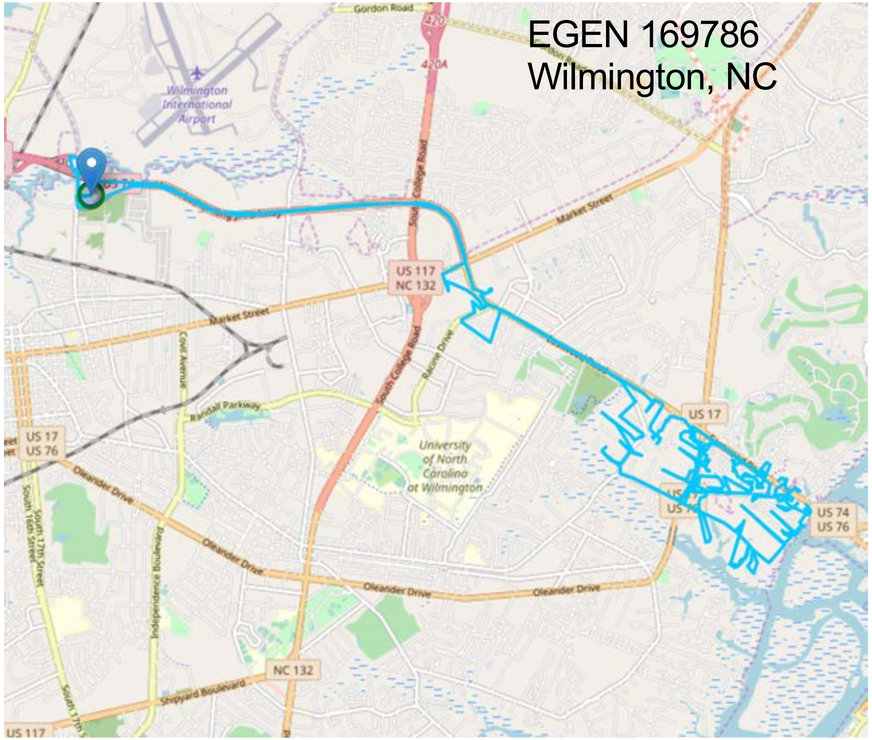
Physics-informed strategy for rule-based control with reinforcement learning



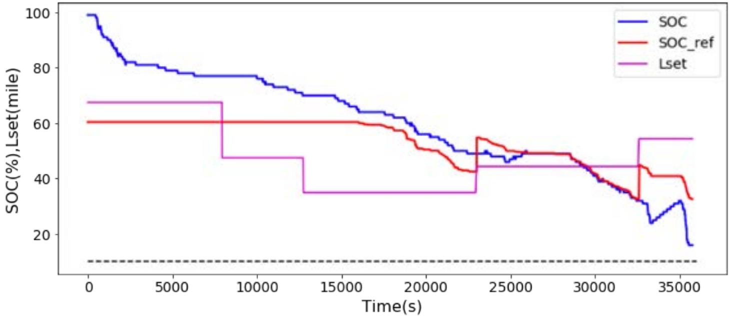
(Richard Sutton, Reinforcement learning: An Introduction)

Agent: The computer algorithm
Environment: low-order physics based model + historical trips
State: Available information for current trip
Reward: A function that rewards low fuel use but penalizes SOC<10%
Action: Change the L_{set} variable

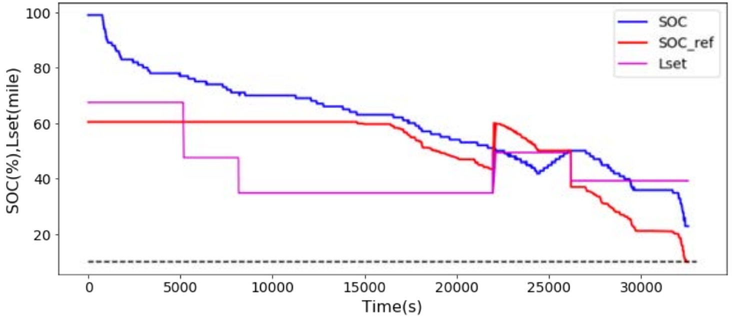
In-Use Example Trip



Trajectories of two UPS delivery trips



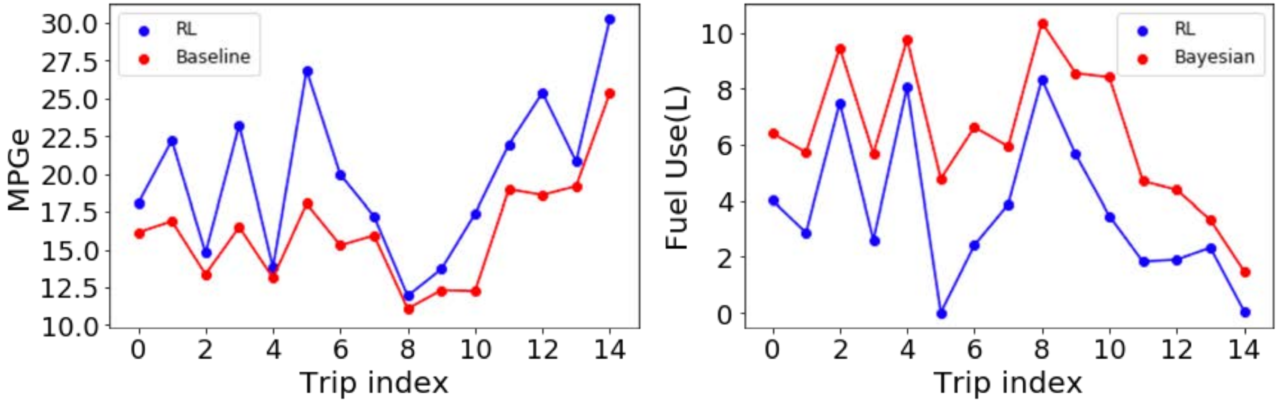
Date: 3/6/19
Distance: 40.59 mile
MPGe: 13.75
Fuel use: 5.67 L



Date: 3/7/19
Distance: 39.14 mile
MPGe: 17.40
Fuel use: 3.48 L

15 trips in total

Savings found over all tested in-use driving days

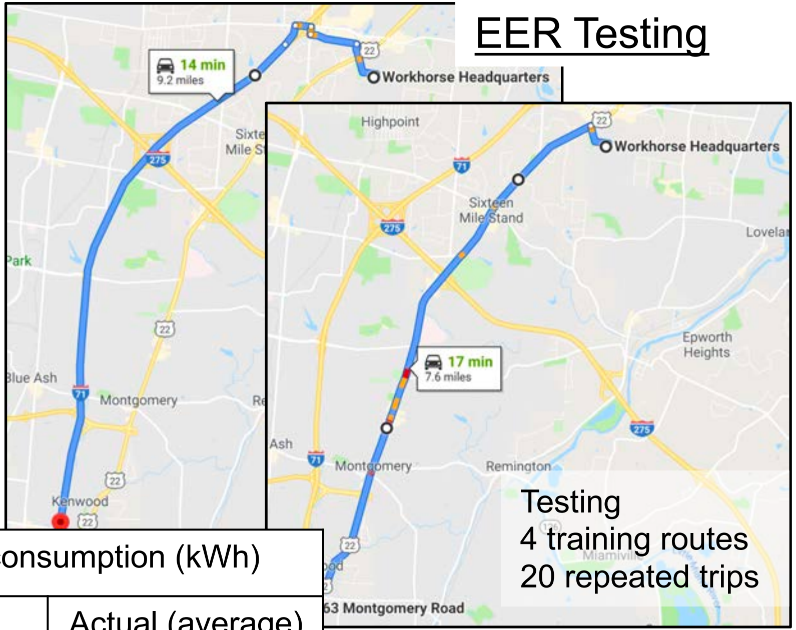


Average MPGe Improvement = 21.8%

Energy Efficient Routing

- Scenario-based energy consumption estimation [1,2]
  - Trajectory-aware path selection algorithm developed
  - Led to estimated 12% energy use reduction with moderate time increase

EER Testing

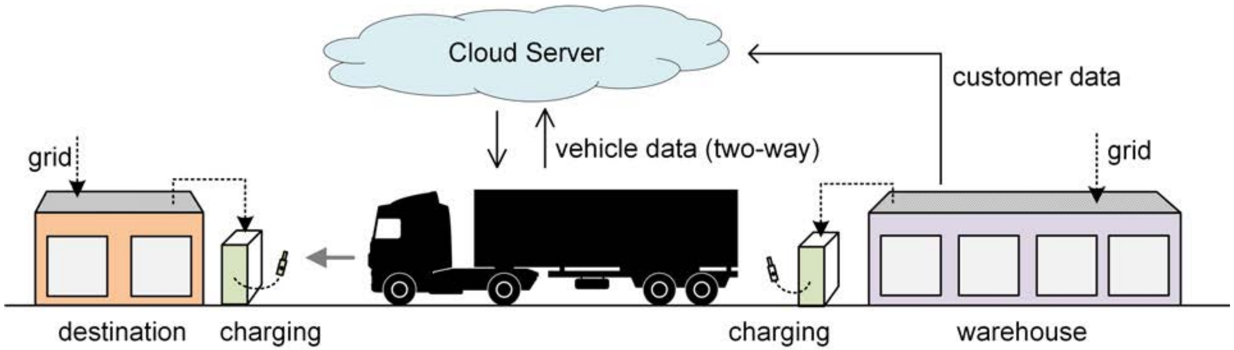


	Time		Energy consumption (kWh)	
	Predicted	Actual (average)	Predicted	Actual (average)
Fastest	14 min	14 min 23 sec	8.54	8.27
Energy-efficient	17 min	16 min 30 sec	5.43	5.09

[1] Li, Yan, Shashi Shekhar, Pengyue Wang, and William Northrop. "Physics-guided energy-efficient path selection: a summary of results." In *Proceedings of the 26th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems*, pp. 99-108. ACM, 2018.

[2] Li, Yan, Pratik Kotwal, Pengyue Wang, Shashi Shekhar, and William Northrop. "Trajectory-aware Lowest-cost Path Selection: A Summary of Results." In *Proceedings of the 16th International Symposium on Spatial and Temporal Databases*, pp. 61-69. ACM, 2019.

Intelligent Energy Management System for Class 8 Regional Delivery



- Physics-based model + data (vehicle + exogenous)
- Predictive charging strategy for given route
- Energy efficient routing to save energy
- Optimal charger location for a fleet of EV trucks

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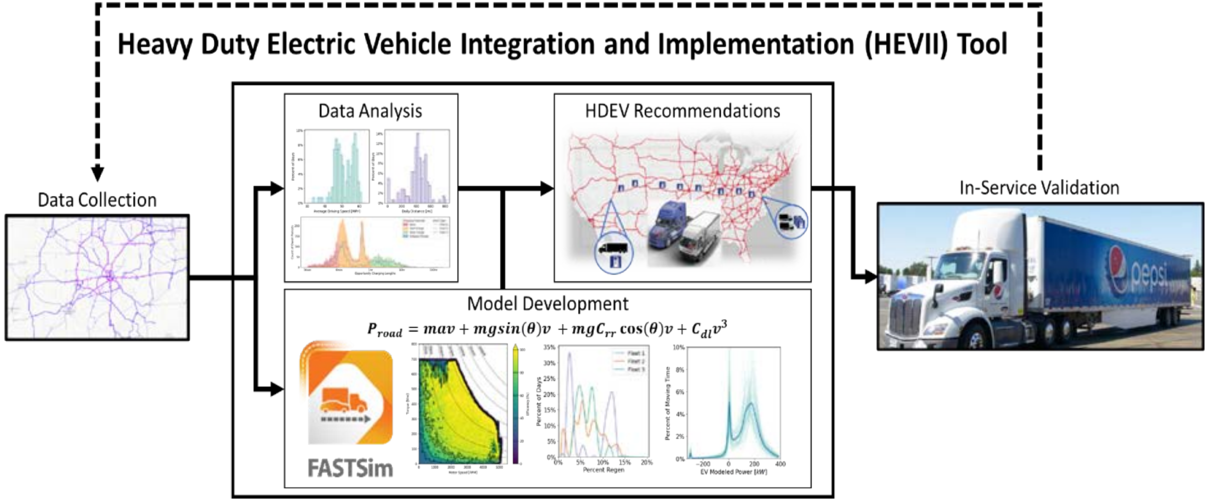
H-E-B

Development of a Heavy-Duty Electric Vehicle Integration and Implementation (HEVII) Tool



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GEOTAB

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- Analysis of two regional Class 6-8 commercial vehicle fleets.
- Novel mass prediction algorithm using fleet trajectory data to estimate EV range
- Develop an integrated charger location estimation tool
- Validate the developed tool

Summary

- Medium and heavy vehicles have high carbon impact
- Electrification can significantly reduce emissions
- Telematics and connectivity is growing
- Connectivity can be used to enable electrification
- Research is using data to lower energy use, improve range confidence for commercial EVs

Thank You!

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