Mobility and Energy Improvements Realized through Prediction-Based Vehicle Powertrain Control and Traffic Management (ti101)

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2020 DOE Vehicle Technologies Office Virtual Annual Merit Review (AMR), June 1-4, 2020

Colorado State University

Overview

- Timeline
  - Project start date 11/30/2018
  - Project end date 12/31/2020
  - 66% completed
- Budget
  - Govt. Share: $628,663
  - Cost Share : $207,168
  - Total : $835,831

- Barriers (U.S. DRIVE – VMSATT 2019 Roadmap)
  - Data collection
  - Artificial intelligence and machine learning for CAV development
  - Quantify with real-world data the energy savings benefits of optimized advanced vehicle controls
- Partners
  - Colorado State University (CSU, lead)
  - Western Michigan University (WMU)
  - National Renewable Energy Laboratory
  - Northern Colorado Clean Cities Coalition
  - Denver Metro Clean Cities Coalition

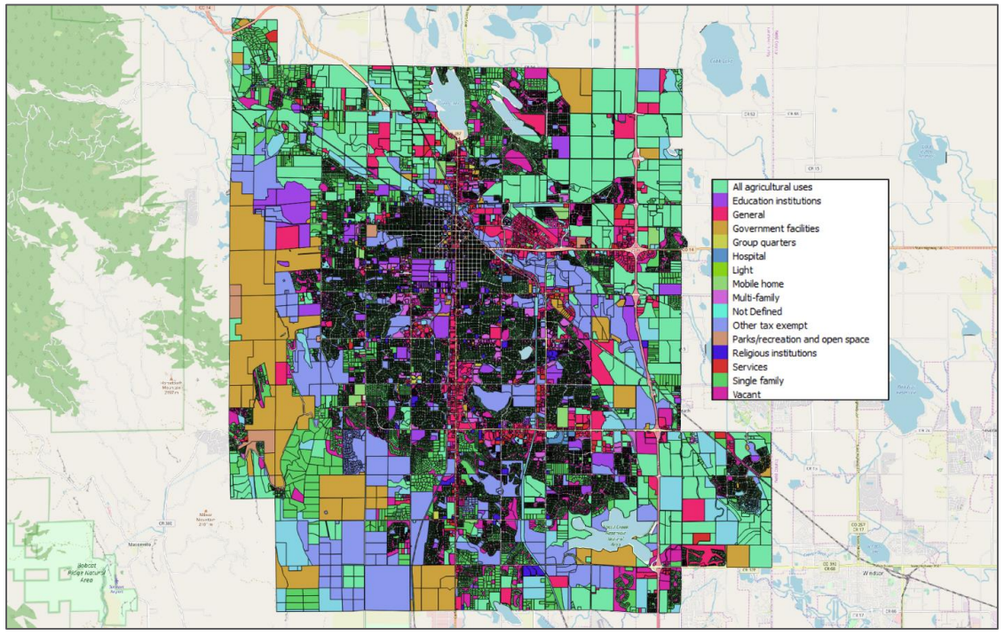
Acknowledgements

- Thomas H. Bradley, Ph.D., Professor, Colorado State University (CSU)
  - Aaron Rabinowicz, Samantha White
- Zachary D. Asher, Ph.D., Assistant Professor, Western Michigan University (WMU)
  - Tushar Gaikwad, Farhang Motallebiaraghi
- Suren Chen, Ph.D., Professor, Colorado State University (CSU)
  - Kaisen Yao
- Edwin Chong, Ph.D., Professor, Colorado State University (CSU)
- Venu M. Garikapati, Ph.D., Project Leader, National Renewable Energy Lab. (NREL)
- Eric Wood, Research Scientist, National Renewable Energy Laboratory (NREL)
- Jacob R. Holden, Research Engineer, National Renewable Energy Laboratory (NREL)
- Diego Lopez, Northern Colorado Clean Cities Coalition
- Bonnie Trowbridge, Denver Metro Clean Cities Coalition

Relevance

To reduce travel time and travel time variance while minimizing energy consumption and human health-specific emissions exposure due to transportation.

Map of Fort Collins, CO by land use classification



Objectives

A data driven approach requires development of a set of coordinated traffic, vehicle (FE and emissions), and infrastructure data using connected vehicle probe data collection techniques.

Optimize traffic management systems *and* connected/automated vehicle powertrain control to test scenarios demonstrating the synergistic benefits of system-level data sharing, infrastructure management and CAV controls optimization.

Measure and evaluate the multi-objective results using a transportation system level metric of *Mobility Energy Productivity*. The results of these studies are then tested for their extensibility through a partnership with the City and County of Denver, CO.

Milestones

Milestones for Budget Period 1 (CY 2019)

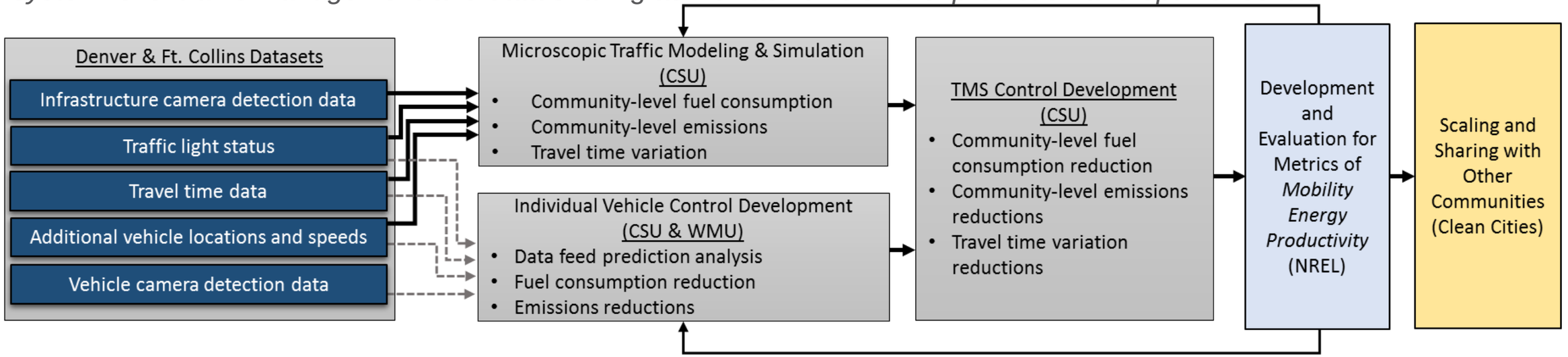
Milestones	Type	Description	Status
FE and emissions data gathered for all considered vehicle classes	Technical	At least one set of emissions and FE data associated with each vehicle class of interest is collected	Pass
Data collection	Technical	All data collection tasks are completed	Pass
Direct, quantitative comparison of simulation and experiment – traffic	Technical	A direct, quantitative comparison of simulation and experiment for the microscopic traffic simulation toolset is completed	Pass
Direct, quantitative comparison of simulation and experiment – vehicles	Technical	A direct, quantitative comparison of simulation and experiment for the vehicle fuel economy and emissions simulation toolset is completed	Pass
Model Validation	Go/No Go	Models are determined to be fit for use for quantification and optimization.	Pass

Milestones for Budget Period 2 (CY 2020)

Milestones	Type	Description	Status
Optimization operational for vehicles demonstrated	Technical	Optimization of one or more design variable for the metric of Mobility Energy Productivity for the vehicle EMS model demonstrated	Pass
Optimization operational for transportation system model demonstrated	Technical	Optimization of one or more design variable for the metric of Mobility Energy Productivity for the transportation system model demonstrated	Pass
Optimization comparison	Technical	Direct, quantitative comparison of baseline and optimized transportation system Completed	Ongoing
Simulation of City and County of Denver	Technical	A functional microscopic simulation of key transportation corridors completed	Ongoing
Quantification of Mobility Energy Productivity Metric	Technical	The calculation of Mobility Energy Productivity Metric for a specific use case and optimization completed	Ongoing

Approach

This project proposes a set of hypotheses for improving novel metrics of Mobility Energy Productivity through improved *system level traffic management* and data sharing as well as *vehicle-level prediction and optimal control*.



Real-world datasets + Optimized microscopic simulations + optimized optimal CAV control

Evaluated using multi-objective metrics of transportation system quality

Approach

- Problem and scope definitions
  - The problem of **traffic congestion along major transportation corridors** of the municipality (College Ave. Fort Collins, Spear Blvd. Denver) and the potential to use TMS and CAVs to improve throughput on these corridors without modification of the physical roadway.
  - The problem of **the interface between bus rapid transit (BRT) and traffic at intersections** (Mason St. Ft Collins, Colfax Ave. Denver). BRT uses dedicated lanes to skip queues and congestion along major transportation corridors, but BRT must still participate in signalized intersections at cross streets. Enabling prioritization and vehicle-level energy management control of these BRT vehicles is hypothesized to improve metrics of mobility energy productivity.
  - The problem of **through-town Class 8 freight truck transport** (Shields Ave., Fort Collins, I-70/Colorado Blvd, Denver). Due to the growth of Class 8 truck transport, these municipalities face noise pollution, emissions, human health, and safety considerations due to a high volume of Class 8 trucks moving through town on surface streets. Enabling signal prioritization (which also enables platooning) and vehicle-level energy management control for these high-energy consumption, high emissions vehicles is hypothesized to improve metrics of mobility energy productivity

Technical Accomplishments and Progress

- Data collection and synthesis
  - Along key routes and for samples of all vehicle types
    - LD Diesel
    - LD Gasoline
    - BRT Diesel
    - Class 8 Diesel
  - Multi-channel data is collected and processed to make coherent datasets

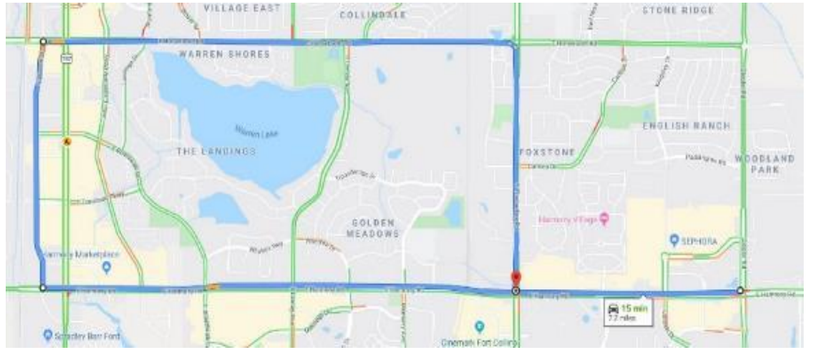
These datasets are then used as inputs to the model validation and testing processes

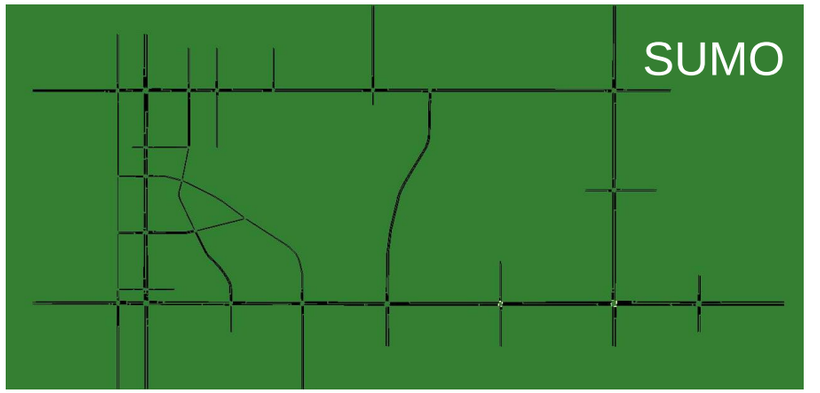
Data Streams Successfully Measured via Probe Vehicles and Assembled into a Coherent Dataset

Data Treatment	Description	Data Stream
Driver Inputs	Steering, accelerator and brake pedal traces, drive mode selection, turn signal, etc.	VEH
Vehicle Performance	Vehicle speed, engine load and speed, transmission gear, accelerations, etc.	VEH
Vehicle Position and Motion	GNSS position and motion information	COMM
Object Tracks	Relative locations and classifications of detected and tracked objects	ADAS, COMM
Lane Information	Information about vehicle position and trajectory relative to the vehicle's current lane	ADAS, COMM
Condition Information	Lighting and weather conditions in the vehicle environment	ADAS, COMM
Signal Phase and Timing	Phase and timing information for traffic signals	COMM
Segment Speeds	Average vehicle speeds for segments of road	COMM
Lead Vehicle	Relative position and motion of the vehicle most immediately in front of the ego vehicle	ADAS, COMM
Historical Speeds	Speeds which vehicles have historically travelled at specific locations	VEH, COMM

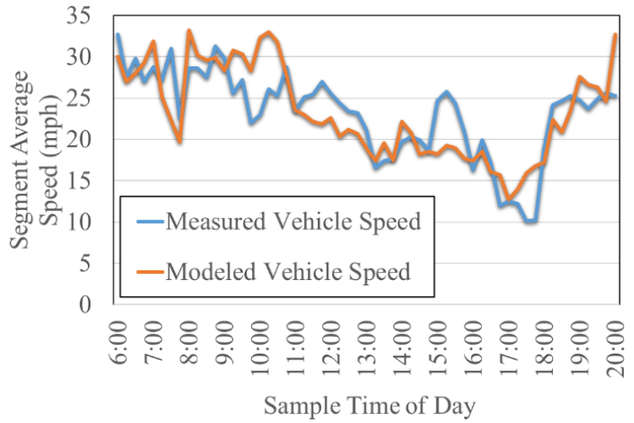
Rabinowicz, A., et al., “Synchronous and Open, Real World, Vehicle, ADAS, and Infrastructure Data Streams for Automotive Machine Learning Algorithms Research” SAE 2020-01-0736

Technical Accomplishments and Progress



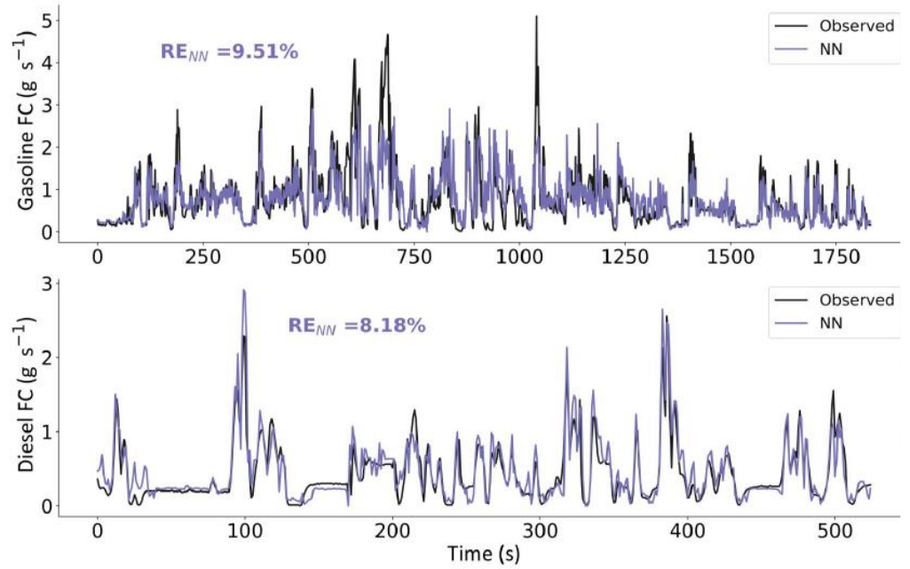


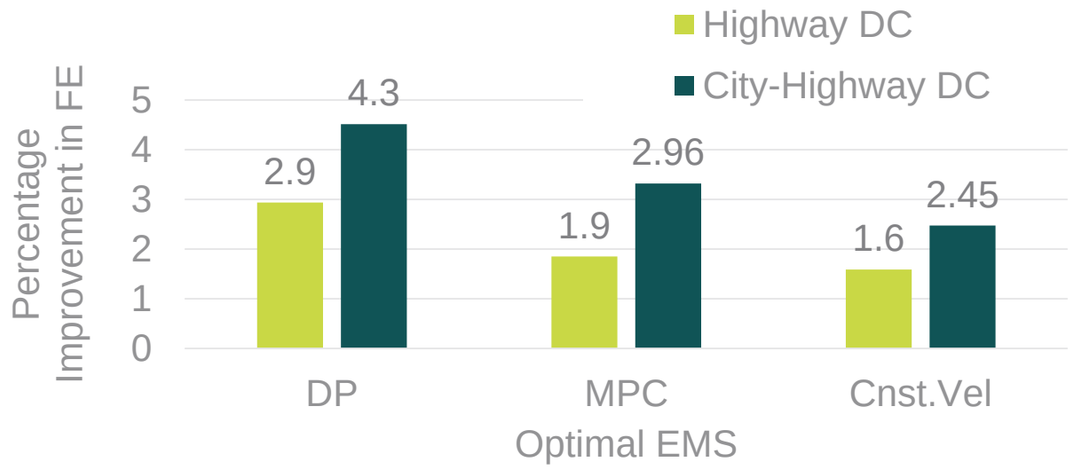
- Microscopic Traffic Simulation
  - Performed in SUMO and CORSIM
  - Modeling of two artery networks
    - Harmony Rd.
    - College Ave. & Mason St.
  - Validated to real-world datasets across multiple metrics of performance
    - Temporal dynamics, Segment speeds, Travel times
- Throughput can be very mildly improved (1-2%) through rigorous SPAT optimization
  - Tradeoffs are omni-present (throughput vs. emissions, FE vs. emissions, uptown vs. crosstown throughput)



Technical Accomplishments and Progress

- Vehicle-level optimal energy management is performed using predictive powertrain control
  - Fuel economy and emissions assessments are performed using ANN fits to PEMS datasets (n=13)
  - Prediction of future vehicle operation is used to optimize vehicle powertrain control for FE and emissions
  - Various optimization schemes realize a 2% - 4% improvement in FE

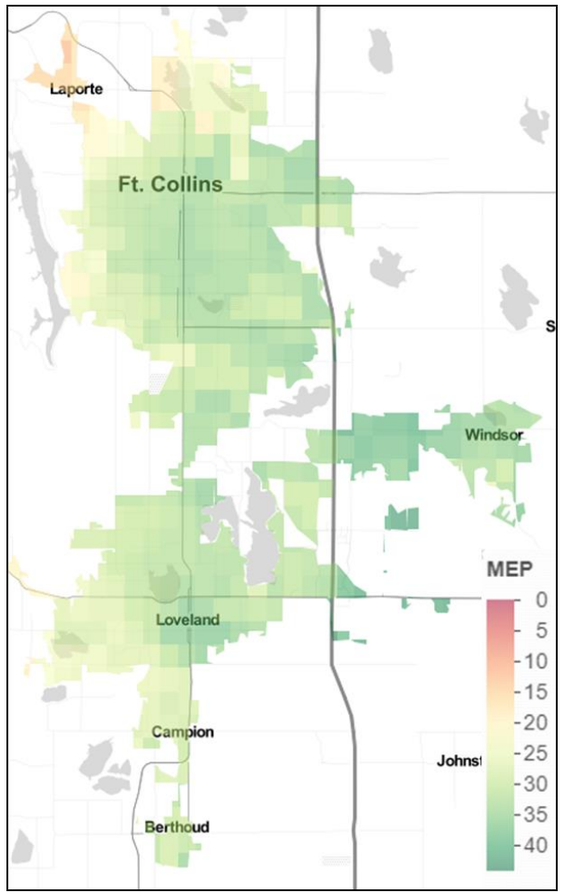




Chenna, S., et al., “On the Use of Artificial Neural Networks to Model In-Use Fuel Consumption and Tailpipe Emissions from Light-Duty Vehicles” submitted to Atmospheric Pollution Research, 2020
Gaikwad, T., et al. “Vehicle Velocity Prediction Using Artificial Neural Network and Effect of Real World Signals on Prediction Window,” SAE 2020-01-0729

Technical Accomplishments and Progress

- Costs and benefits are traded off in a metric at transportation system level (Mobility Energy Productivity)
  - MEP is a spatially realized metric of accessibility, assessing the number of jobs, goods, and service opportunities which are available within prescribed travel times from a location.
  - Allows for tradeoffs among considerations of
    - Transportation system efficiency
    - Vehicle efficiency and cost to operate
    - System-level emissions/energy consumption



Remaining Challenges and Barriers

Remaining challenges are the processes of integration and synthesis

Outcomes will include:

- Quantifying the value of making TMS data publicly available for light-duty vehicles
- Roadmaps for realizing FE, emissions and safety benefits of CAV BRT/Class 8 in suburban networks
- Evaluation of the scalability of TMS/EMS integration in Denver, CO
- Outreach to commercial and government stakeholders

Collaboration and Coordination

Project Coordination among Awardees

- **Colorado State University Engines and Energy Conversion Laboratory** – data acquisition and synthesis, fuel economy and emissions modeling
- **Colorado State University Center for Sustainable Intelligent Transportation Systems** – traffic micro simulation and optimal control
- **Western Michigan University Energy Efficient and Autonomous Vehicles Lab** – vehicle optimal energy management and control
- **NREL** – Mobility Energy Productivity metric evaluation and refinement

Collaboration between Stakeholders

- NREL and Universities (CSU and WMU)
  - Summer internships (2019)
- Universities and Local Stakeholders
  - Data sharing and presentations to:

  Colorado DOT, Fort Collins Traffic, TransFort, Clean Cities Coalitions, Michigan DOT, Colorado Energy Office, Denver Regional Council of Govts

Proposed Future Research

FY 2021

- We now know the individual benefits, we must quantify the synergistic benefits of system-level data sharing, infrastructure management and CAV controls optimization
- Application to the situated 3 transportation problem sets (congestion, BRT prioritization, Class 8 preemption), tested for replicability in Denver
- Quantifying changes to Mobility Energy Productivity synthetically and spatially

Any proposed future work is subject to change based on funding levels

Summary

- Gathered and synthesized a synchronized, real-world dataset including infrastructure, vehicle, on-vehicle camera, radar, SPaT, and traffic cameras.
- Validated second-by-second FE and emissions simulations of multiple vehicle types and scales
- Developed new algorithms and integration to enable optimization of traffic system-level, and vehicle level control
- Evaluated using novel & holistic transportation system metrics

Thank you

Colorado State University