CONNECTED VEHICLE POWERTRAIN OPTIMIZATION WITH RANDOM TRAFFIC SIMULATION

Overview Presentation to ARPA-E (NEXTCAR)

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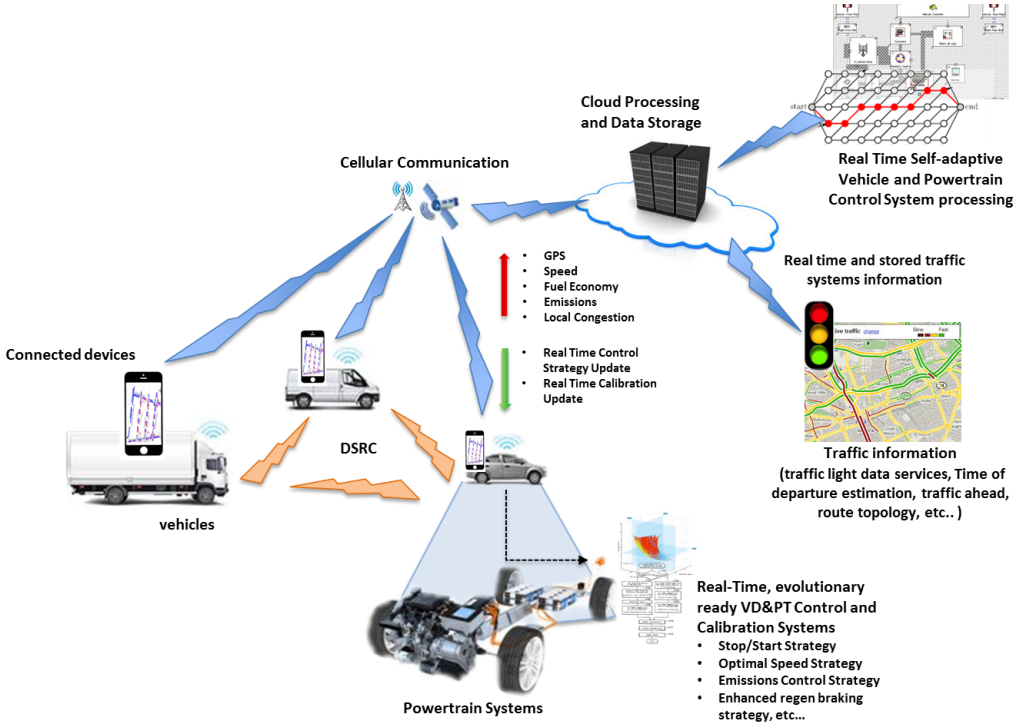
AGENDA

- R&D Project Background
- Objectives
- Technical Approach
  - Scalable System of Systems Approach
  - Traffic Modeling
  - Energy Modeling and Integration
- Results to Date
- Next Steps

BACKGROUND

Rapid growth of connected vehicle technologies and strong interest in autonomous vehicle development raises important questions for AVL and our clients:

- What are future powertrain requirements?
- What additional emissions and energy efficiency improvement can be achieved?
- How can connected technology contribute to these potential improvements at the vehicle level and what large scale synergistic effect can be expected?
- How will autonomous vehicle penetration within the transportation system affect its overall dynamic – what emergent behavior will occur?
- What will be the dominant technologies, and what are the new risks and challenges to overcome?



OBJECTIVES

The primary objectives of the our R&D is to answer these strategic questions and develop a vision that will be applied and tested through simulation and eventually incorporated into a demonstration vehicle.

AVL ADAS capabilities are based on the IODP (Integrated Open Development Platform) process which integrates Vehicle, Powertrain, Sensors, GPS, and other inputs through a combination of simulation and hardware as available. Using HiL and Dyno/Test Bench capabilities this method provides support for all activities across a vehicle development lifecycle – progressing from detailed design analysis to Real-Time control and calibration optimization.

For the conceptual and strategic phase presented here, our objectives have been to:

- Develop a light and scalable vehicle dynamic and powertrain environment where large scale simulation can be performed quickly with appropriate accuracy.
- Generate vehicle and traffic behavior data within a stochastic but controlled test environment so as to identify the value of connected data *(how effectively can it be used for energy reduction optimization).*
- Generate varied boundary conditions and test connected vehicle dynamic and powertrain control strategies in a safe and repeatable manner
- Develop understanding of local and large scale effect on the use of connected data by integrating infrastructure optimization (traffic control signals for example) and identify conflicts or synergies between different vehicle solutions and the global optimum (overall traffic energy usage).
- Identify future scenarios and technological development focus for AVL.

TECHNICAL APPROACH

A system of systems approach was chosen in order to combine small and large scale effect of Intelligent Traffic Systems / ADAS technologies within a light, scalable test environment.

In order to minimize complexity, the simulation environment was fully developed in MATLAB. The input from different codes (AVL Cruise, Simulink,…) where integrated via Response Surface Modeling as opposed to co-simulation. This provides accurate input source data without impact on CPU time.

As of today, the MATLAB code includes:

- An Intelligent Driver car-following Model for traffic generation.
- A Stochastic driver behavior generator, allowing variability in driver behavior (“real drivers” vs. autonomous vehicle can have different behaviors such as: acceleration rates, minimum gap to lead vehicle, reaction time…)
- An EV powertrain model (Conventional and Hybrid powertrains being developed) within each traffic vehicle
- Traffic Lights (optimized control in the works) and speed limit constraints
- An off-line optimization algorithm for a vehicle to optimize its velocity within traffic and signal constraints (can pick any vehicle in the traffic flow within traffic flow and signal constraints)
- 100-1000s of vehicles can be simulated on an FTP type cycle in seconds (laptop). Data generated includes:
  - Vehicle positon, velocity, acceleration, kW demand and energy consumption (E)
  - Global and local statistics on vehicle density, average speed across the route
  - All variables can be accessible to a vehicle and the optimization routine at any given time step

TRAFFIC MODELING

The traffic simulation uses an Agent Based architecture, where all vehicles behavior can be independently set up.

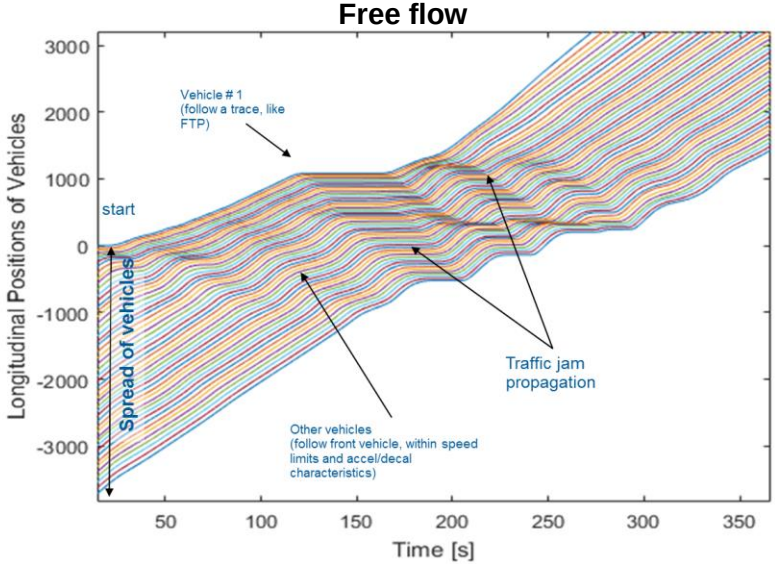
A stochastic approach is used to vary:

- Acceleration and deceleration behaviors
- Time gap and minimum vehicle-to-vehicle distance gap
- City and highway speed limits and compliance delta (driver compliance %)
- Traffic Light Timing

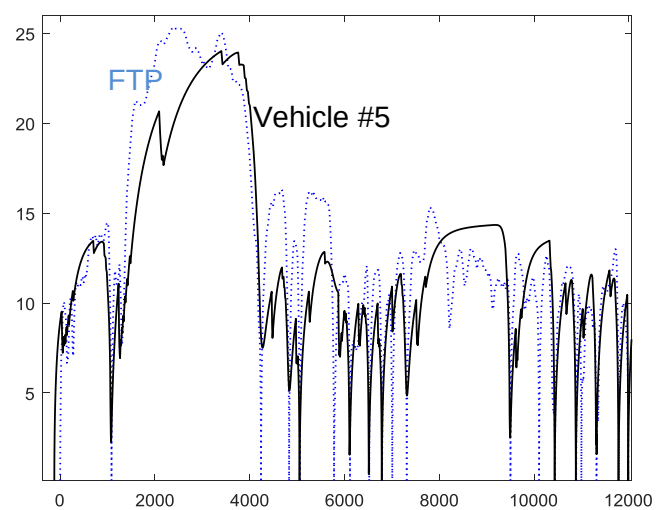
Using Design of Experiments – the test environment parameters can be varied to generate virtually the entire spectrum of real world driving conditions.

Traffic Lights can be inserted to the free flow simulation to mimic city cycle. Here comparing one vehicle behavior to EPA FTP cycle.

Free flow



With Traffic Signal Infrastructure



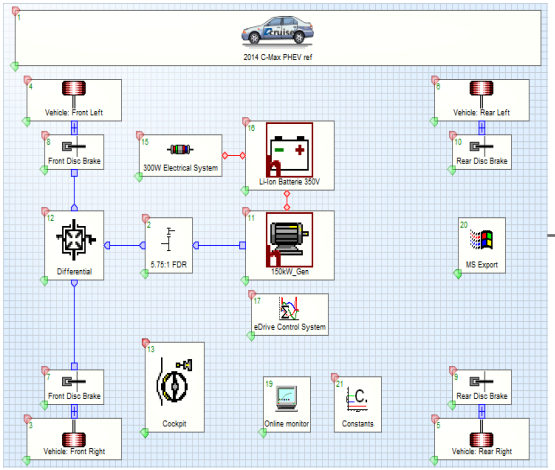
ENERGY MODEL

The objective of the energy model is to provide:

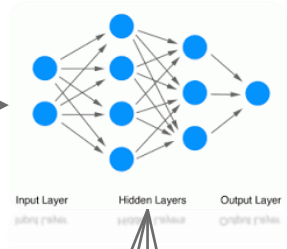
- All the possible states for the optimization to make an optimal choice in the vehicle speed
- And/Or any control related optimization (for example - mode switching for hybrids).

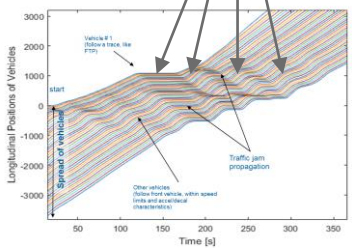
For fast run time, the AVL EV Cruise model was transformed into a Neural Network (quasi-steady simulation). Only energy consumption was fitted but future model will include emissions from AVL MoBEO models.

Cruise Model

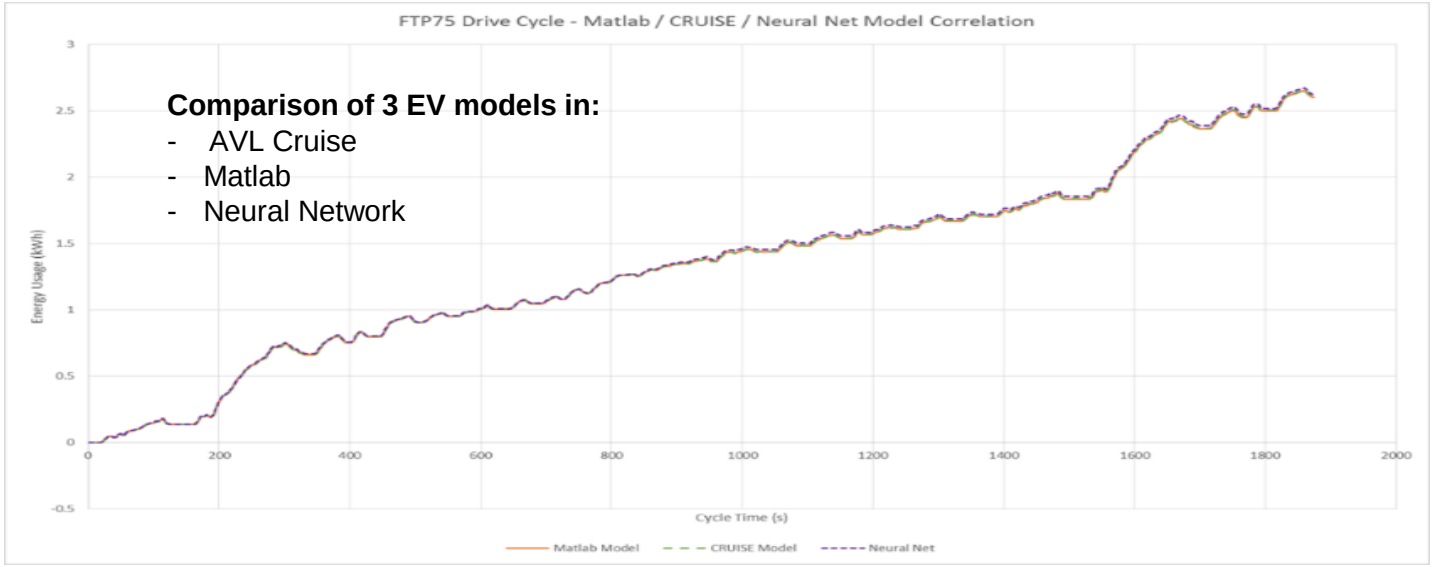


Neural Net



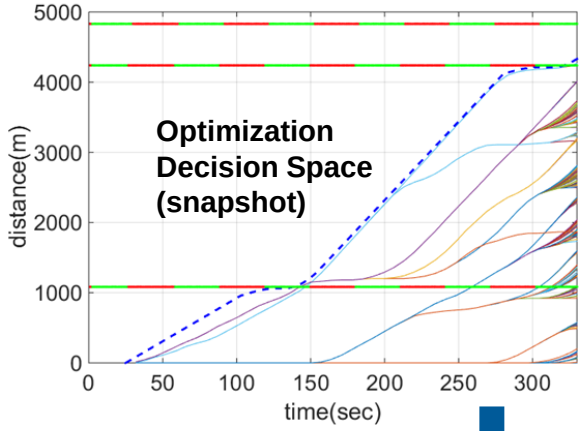


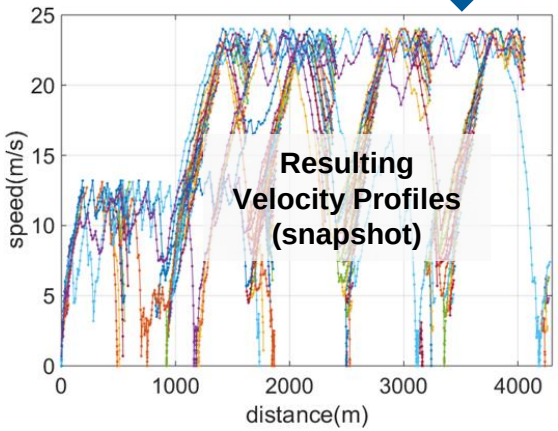
Inline integration
To traffic simulation



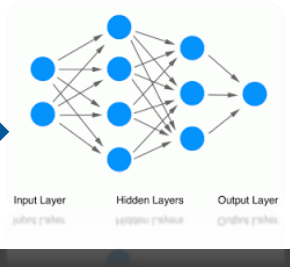
OPTIMIZATION

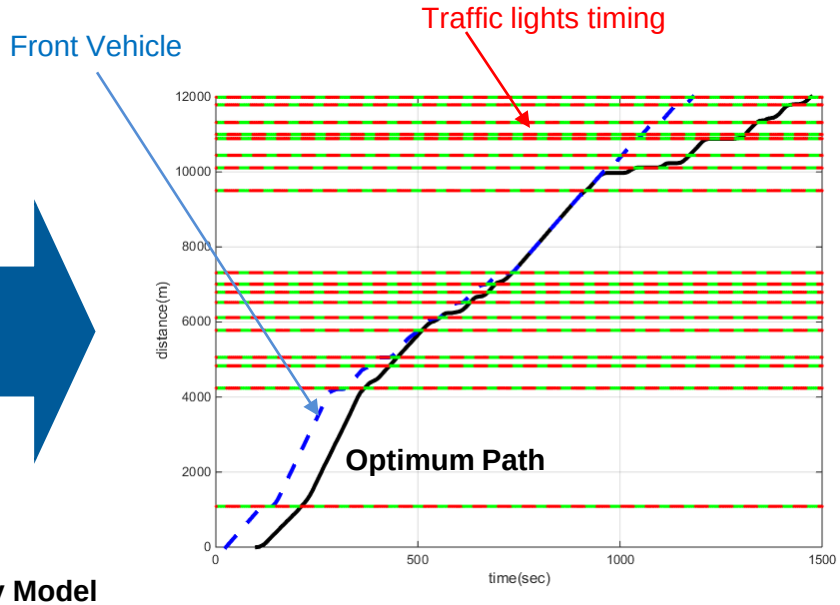
AVL developed an optimization (offline) that takes into account surrounding traffic (position, speed, acceleration data) and traffic light information as the “connected data” stream. It develops various speed profiles and uses the energy model to select the appropriate path (for minimization of energy and trip time).
A real time embedded algorithm using reinforcement learning methodology will be developed based on the optimal strategies developed using results from the offline optimizations.





Energy Model

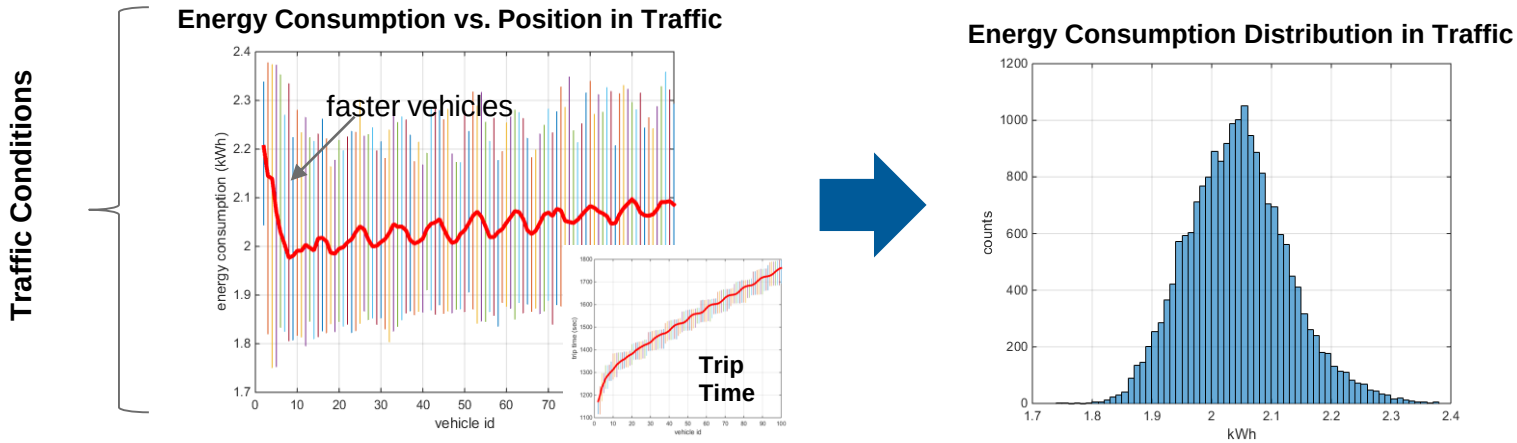


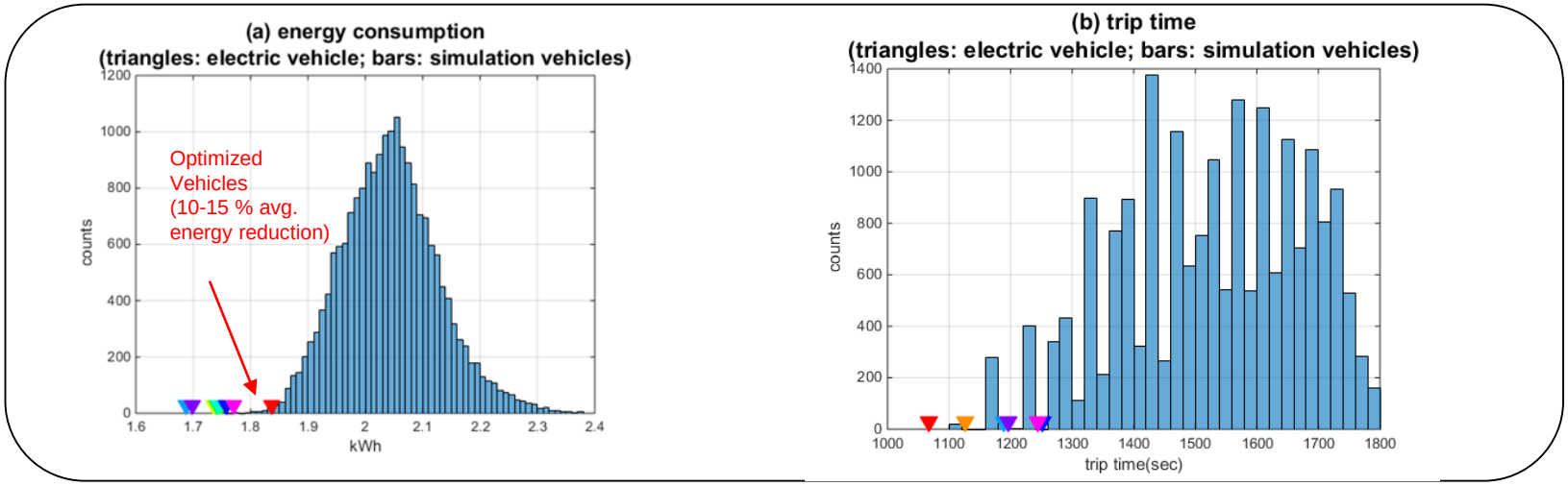


Optimum Path for a route

EXAMPLE RESULTS [1]

A large number of scenarios can be generated quickly thanks to the stochastic nature of the simulation (at the vehicle, driver and infrastructure level). The amount of experience that the optimization will encounter will cover a large range of real driving conditions – creating the foundation for reinforcement learning and integration into the control architecture.



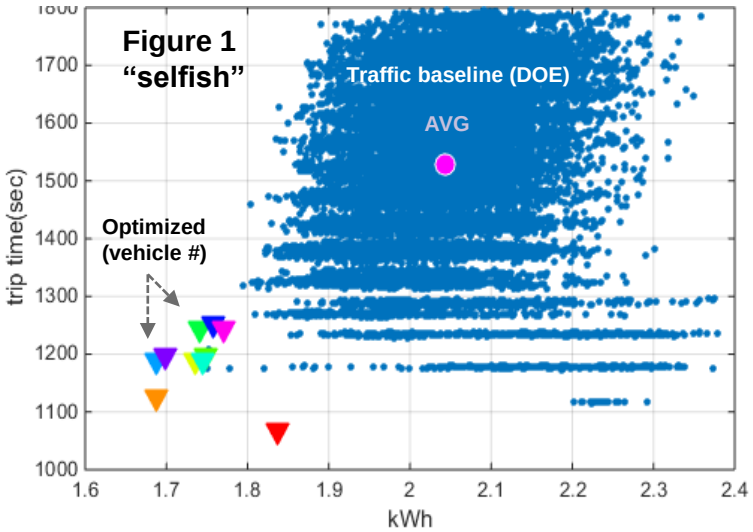


EXAMPLE RESULTS [2]

Optimizing across traffic conditions and vehicle position within provide a range of expected benefit.

- Figure 1: shows the expected benefit for a vehicle which is only bounded by upstream traffic.
- Figure 2: shows the benefit deterioration of if the optimum vehicle does not affect downstream flow of vehicles (minimum disturbance to vehicle behind).
- Figure 3: shows the impact of creating a Platoon of vehicle. While efficiency is improved, the longer the platoon, the longer the trip time.

These demonstrate the need for a global optimization feature across traffic in order to harmonize benefits (time, energy) especially with the diversity of vehicles and their powertrain.



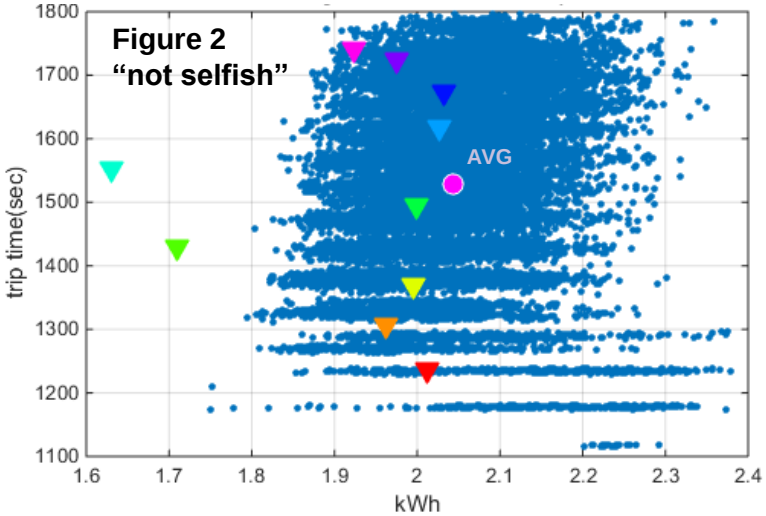
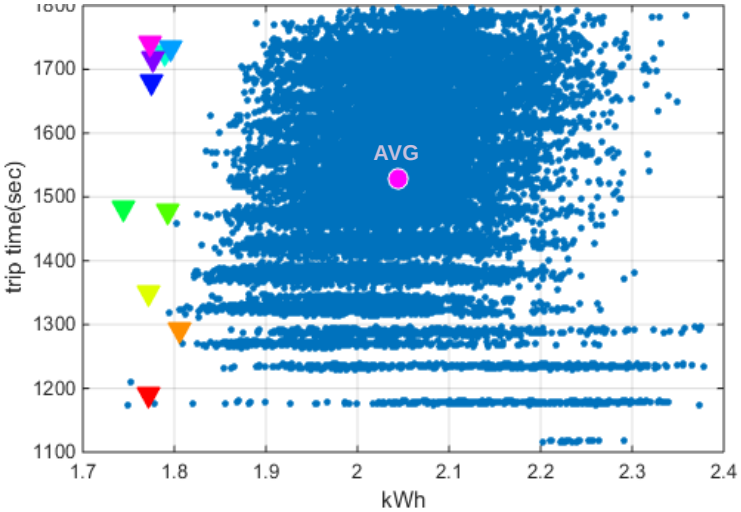


Figure 3: "platooning and size"



NEXT STEPS

- Extend Traffic Simulation to multi-lanes, multi-routes + optimized traffic light impact
- Include Conventional and PHEV powertrain models within the traffic and optimization feature.
- Powertrain control and adaptive calibration will be additional dimensions in optimizing for energy reduction and inclusion into the reinforcement learning based controller:
  - PHEV will focus on optimizing engine/e-motor power blending
  - PHEV and Conventional vehicle will include some level of self adaptive engine calibration mapping.
- Integration into 3D vehicle dynamics / sensors (LIDAR, Radar,…) with ADAS capability in preparing for the prototyping phase.
- Demo vehicle development (2018 +).

Optimized Platooning?