Optimal Energy Management of a PHEV Using Trip Information

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Sponsored by David Anderson

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U.S. Department of Energy

Energy Efficiency and Renewable Energy

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Project Overview

Timeline

- Start: September 2011
- End: September 2012
- Status: **40% complete**

Barriers

- **Cost** of testing advanced technologies through multiple vehicle builds
- **Risk aversion** of OEM to commit to unproven technologies
- **Constant advances** in technologies

Budget

- FY2012 - **$250K**

Partners

- **NAVTEQ** (Map data)
- Argonne's **Transportation Research and Analysis Computing Center** (TRACC) (traffic modeling)

Relevance

The objective is to use destination knowledge, GPS, road profile and current traffic to establish the optimal energy management of a short-range PHEV

- **Predict speed profile** of the trip ahead:
  - to **provide the controller** relevant information about the trip
  - to **benchmark** control strategies using trip information on the predicted speed profiles
- Develop **PHEV control strategies** taking advantage from trip information
- Demonstrate and **quantify** the benefits of trip information on **PHEVs energy efficiency**

Relevant** to the **VT Program goals**: **enable highly efficient** cars and **reduce** both **energy use** and **greenhouse gas emissions

Milestones

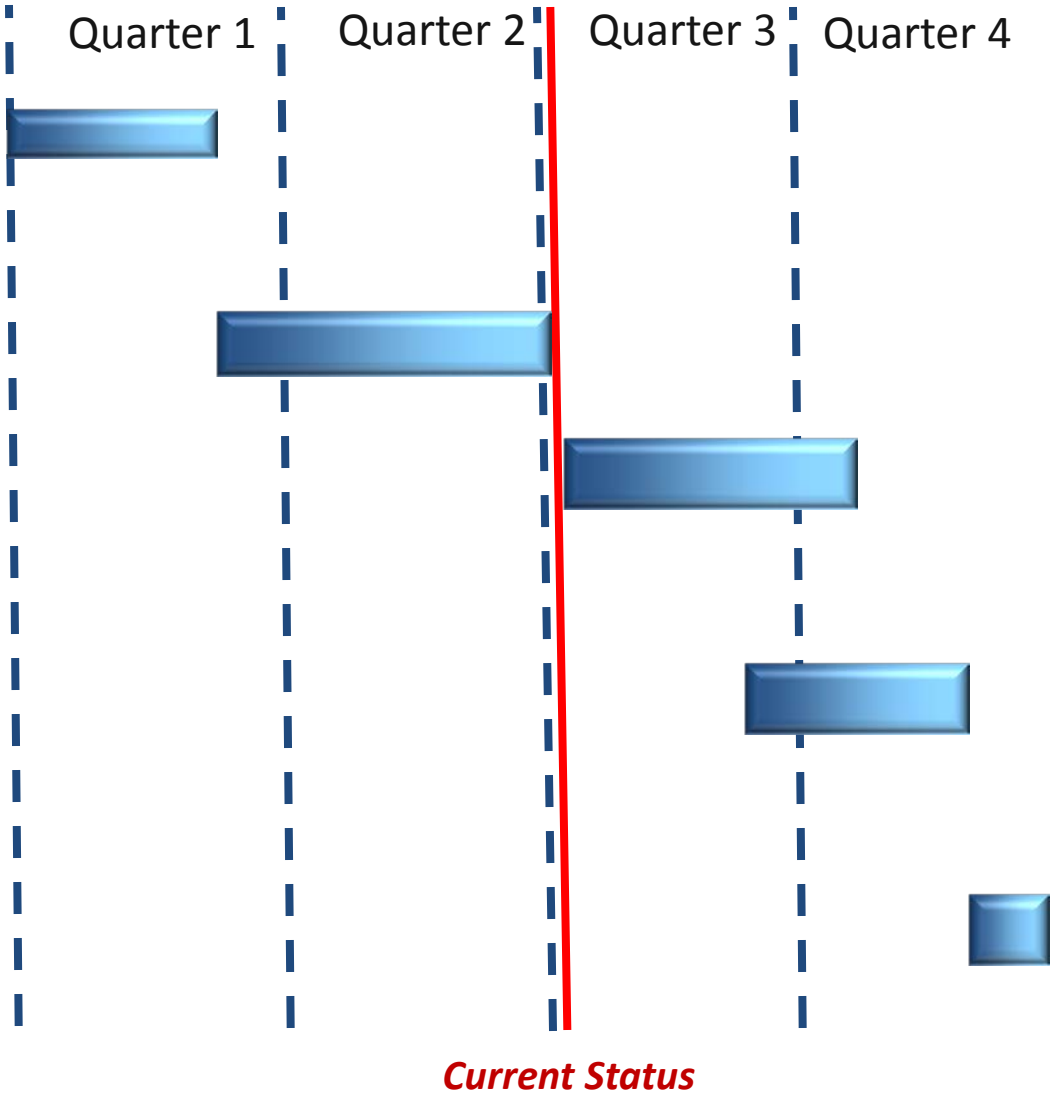
Choose a mapping service with extensive road information

Create a cycle generator

Create "alternative" control strategies that takes into account trip information

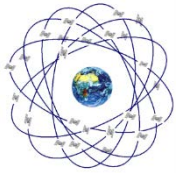
Run study to compare alternative PHEV control to standard PHEV control

Publish Results



Approach

Real-World User Story Modeled in this Study: Driver Selects Destination, Vehicle Runs Optimally



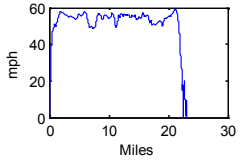
Global Positioning System (GPS)

Current Localization

Final Destination

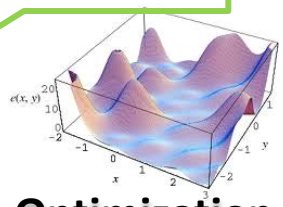
Driver

HMI



Route Estimation

Road schedule



Optimization Unit

Optimal Parameters for Controller

Vehicle Control Unit

Traffic Situation/Forecast

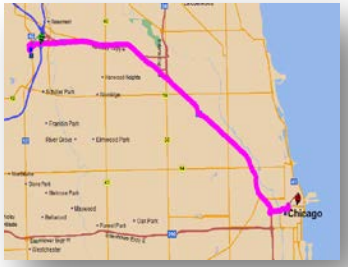
Traffic Management Center

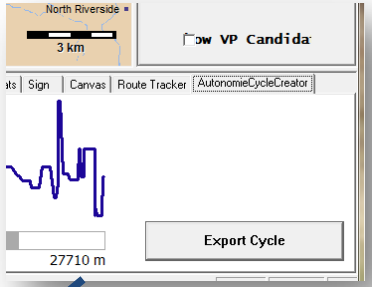
Trip Information
- *Distance*
- *Road profile (grade, lights, etc.)*
- *Trip sections (Urban, Interurban, etc.)*
- *Congestion Level on Each section*
- *Speed limits*

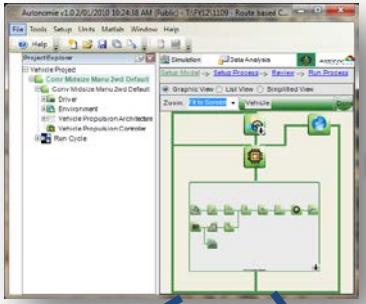
Approach

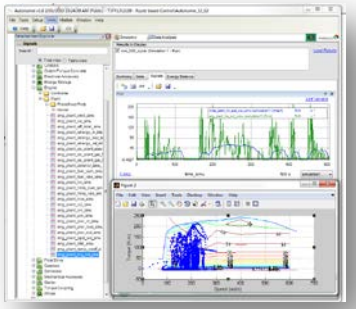
User Workflow Using ADAS RP(1) and Autonomie®

User Action	*Define Trip*	*Export Trip to CSV file*	*Define Vehicle and Select CSV file with Trip Data*	*Run Vehicle Simulation and Analyze Results*
Tool	*ADAS RP*	*ADAS RP plug-in*	*Autonomie®*	*Autonomie®*







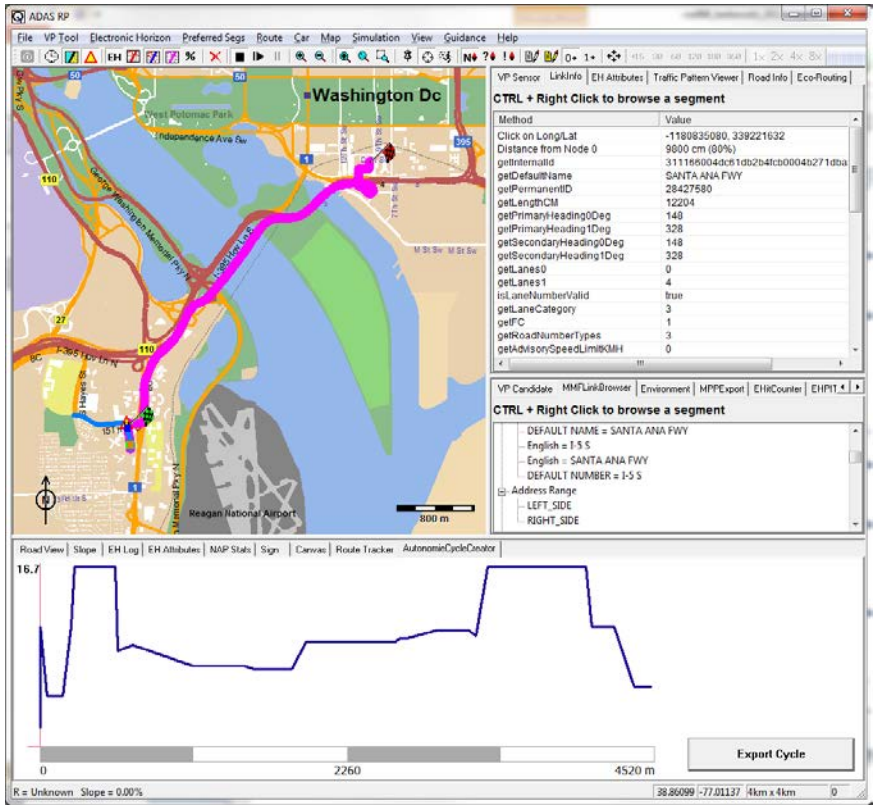


Product	**ADAS RP plug-in to export trip information**
	Drive Cycle Generator (Process): - Trip data processing - Target speed generation
	Vehicle Controller with Geographical Information Processor (Vehicle)

(1) *ADAS RP - Advanced Driver Assistance Systems Research Platform*

Technical Accomplishments

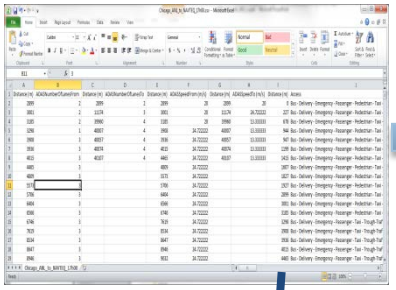
ADAS RP Plug-in Allows Exporting Road Data



- ADAS = Advanced Driver Assistance Systems
- ADAS RP (RP= Research Platform) is a software framework to develop prototypes of applications that use positioning and maps.
- Includes NAVTEQ maps and traffic patterns
- The user can define a route by selecting the start and the end of the route
- A **plug-in was developed** for Autonomie® in C#:
  - Selects useful information for all links along the route
  - Formats the information
  - User can export the data in Autonomie (CSV format using the “Export cycle” button)

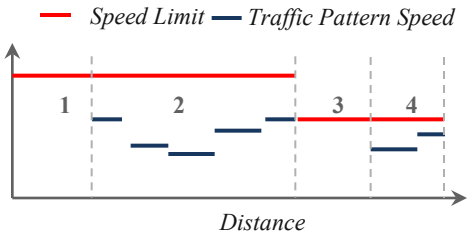
Technical Accomplishments

Raw Trip Data Is Processed

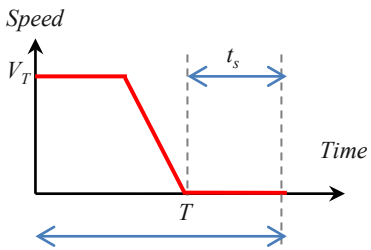


Raw data
- Expected speed
- Speed limit
- Traffic pattern speed
- Traffic lights and stop sign position
- Slope

1. Stop scheduling
- Estimate wait time at traffic light
- Estimate wait time at stop sign

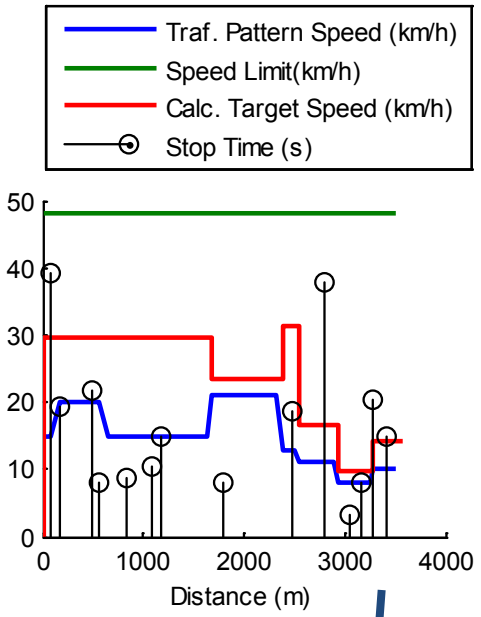


2. Division in Segments
- w/ or w/o traffic speed
- If w/ pattern speed, in constant speed segments



3. Target Speed
- No traffic speed: target speed = speed limit
- w/ traffic speed = factor in stop time

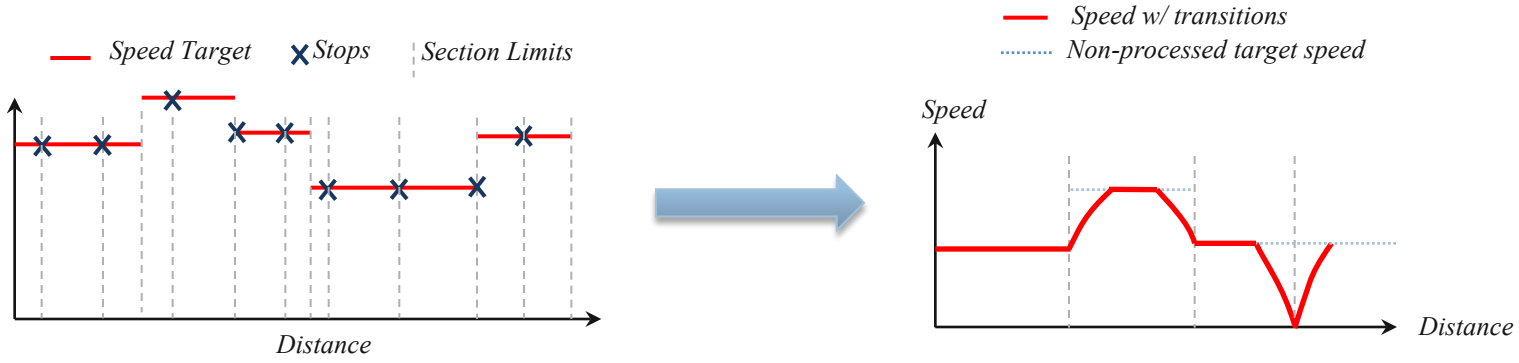
$$\frac{v_T^2}{2d} - (T - t_s)v_T + L = 0$$



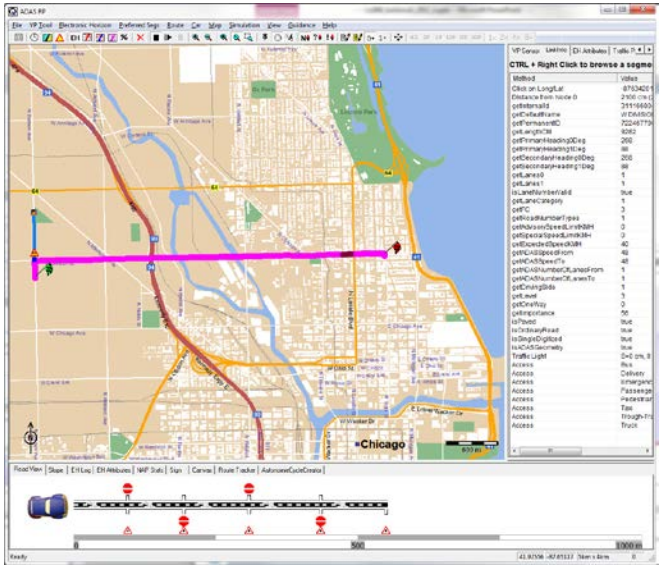
Processed data
- Target speed for each segment
- Stop position and duration
- Grade

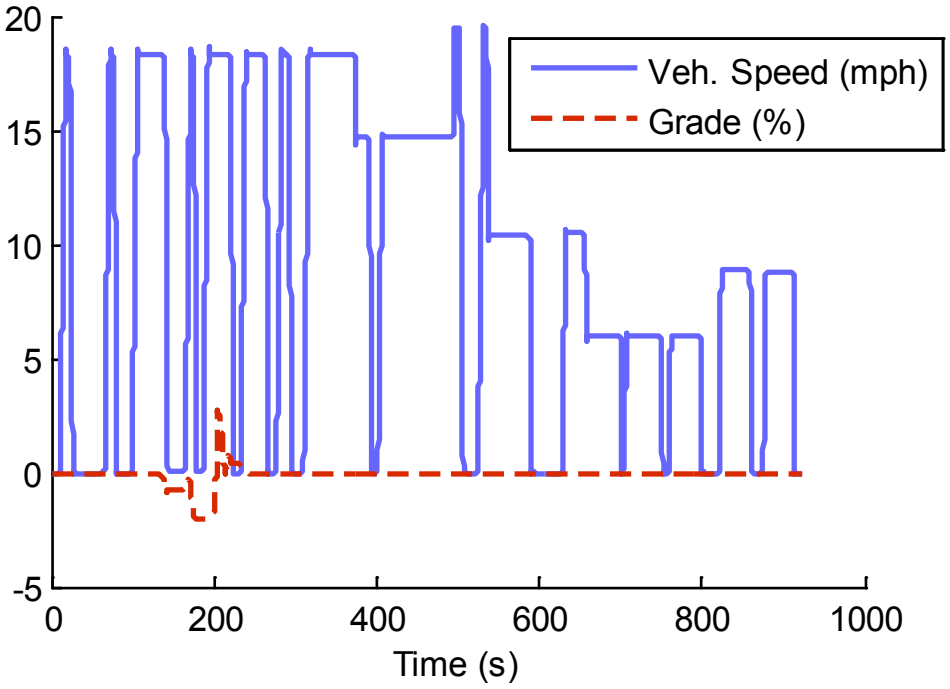
Technical Accomplishments
Vehicle Speed Target Is Generated

- The trip is divided in segments with continuous positive speed:
  - No discontinuities within the segment
  - No stops within the segment
- For each segment, transitional speed target is computed, assuming constant acceleration and constant deceleration
- Output can be directly fed into a distance-based driver for whole vehicle simulation



Technical Accomplishments
Example of a Trip Simulation





***Chicago**:*
Division Ave., between Ashland Ave. and State St. (2.2 mi, 16 min.)

Collaboration and Coordination with Other Institutions

- **NAVTEQ**:
  - Provided a free demo license of ADAS RP, including detailed road information for the whole United-States
  - Provided support to process their data
  - Future collaboration to use their web-based map tool (Nokia Maps)
- Argonne's **Transportation Research and Analysis Computing Center** (TRACC)
  - Provided support on microscopic traffic simulation
- **OEMs**: discussions with R&D engineers

Proposed Future Work

- Drive cycle generation methods will be **tested** and **improved**:
  - Add speed fluctuations on longer sections, and congested highway driving
  - Compare generated drive cycle to **real-world** cycles (from GPS loggers, or database [e.g. Chicago drive cycles])
- Define **baseline PHEV** for study
- Define **control strategies** and test on simple examples using:
  - **Heuristic** optimization (e.g. use EV mode in low speed sections, rather than on highway)
  - **Optimization theory** (e.g. Pontryagin Minimization Principle)
- Implement **algorithms** in Matlab®/Simulink®
- **Compare** trip-based control to standard control (EV + CS)

Summary

- A **process** was created to generate a **speed schedule** (incl. grade and stops) anywhere in the USA
- A **PHEV control** using trip information will be designed.
- That control will be **compared** to standard PHEV control, and the benefits of trip-based control will be **quantified**
- This study will demonstrate that **trip information** can be successfully used to **improve PHEV energy efficiency**, and thus make PHEVs more successful
- The map-based speed target generation will have **numerous side applications**:
  - **Green routing**
  - **Fleet fuel consumption estimation**
  - **Selection of optimal powertrains for specific routes**
  - Etc.