Modeling & Simulation in Automotive Industry

Prediction of Energy Consumption in Electric Vehicles

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Research and
Advanced Engineering

Outline

- Introduction
- Selected Simulation Applications at Ford
  - Virtual Manufacturing & e-Workcell
  - Virtual Test Track Experiment (VIRTTEX)
- Predication of BEV Energy Consumption
  - BEV Introduction Challenges
  - Vehicle Systems Modeling
  - Traffic Simulation Integration
  - Simulation Results
- Conclusion

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Ford Motor Company

- Global automotive industry leader based in Dearborn, MI.
- Manufactures and distributes automobiles in 200 markets across six continents.

Ford Brands

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Communication & Infotainment Technology

Ford SYNC

MyFord Touch

Ford Hybrid and Electrical Vehicles

FUSION Hybrid

Starting MSRP:	$28,600[1]
Seating for:	5 people
MPG City/Hwy	41/36[2]

ESCAPE Hybrid

Starting MSRP:	$30,570[1]
Seating for:	5 people
Tow up to:	3500 lbs[2]
MPG City/Hwy	34/31[2]

FOCUS Electric

Coming Late 2011

TRANSIT CONNECT EV

Available Now

2013 C-MAX Energi

Coming Fall 2012

2013 C-MAX Hybrid

Coming Fall 2012

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Ford Research & Advanced Engineering

Vehicle & Enterprise Sciences Research Lab

- Information Sciences & Connectivity

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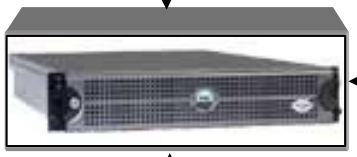
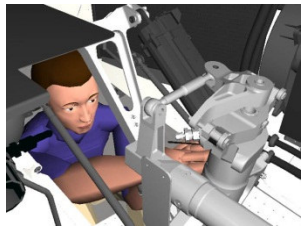
Vehicle Assembly Planning

Vehicle Operations General Office

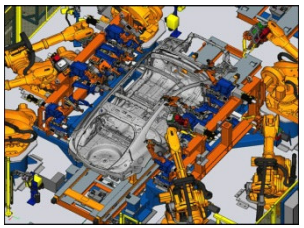
Vehicle Assembly Process Sheet (assembly instructions)



Digital Factory



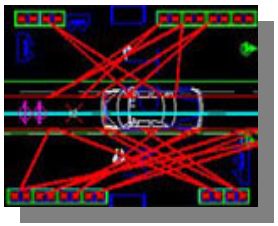
Ergonomics



Simulation

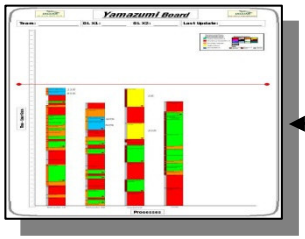
Teamcenter

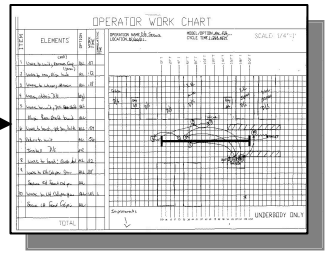
Visualization



Plant Layout

Assembly Plant





Line Balancing ***Workstation Layout***

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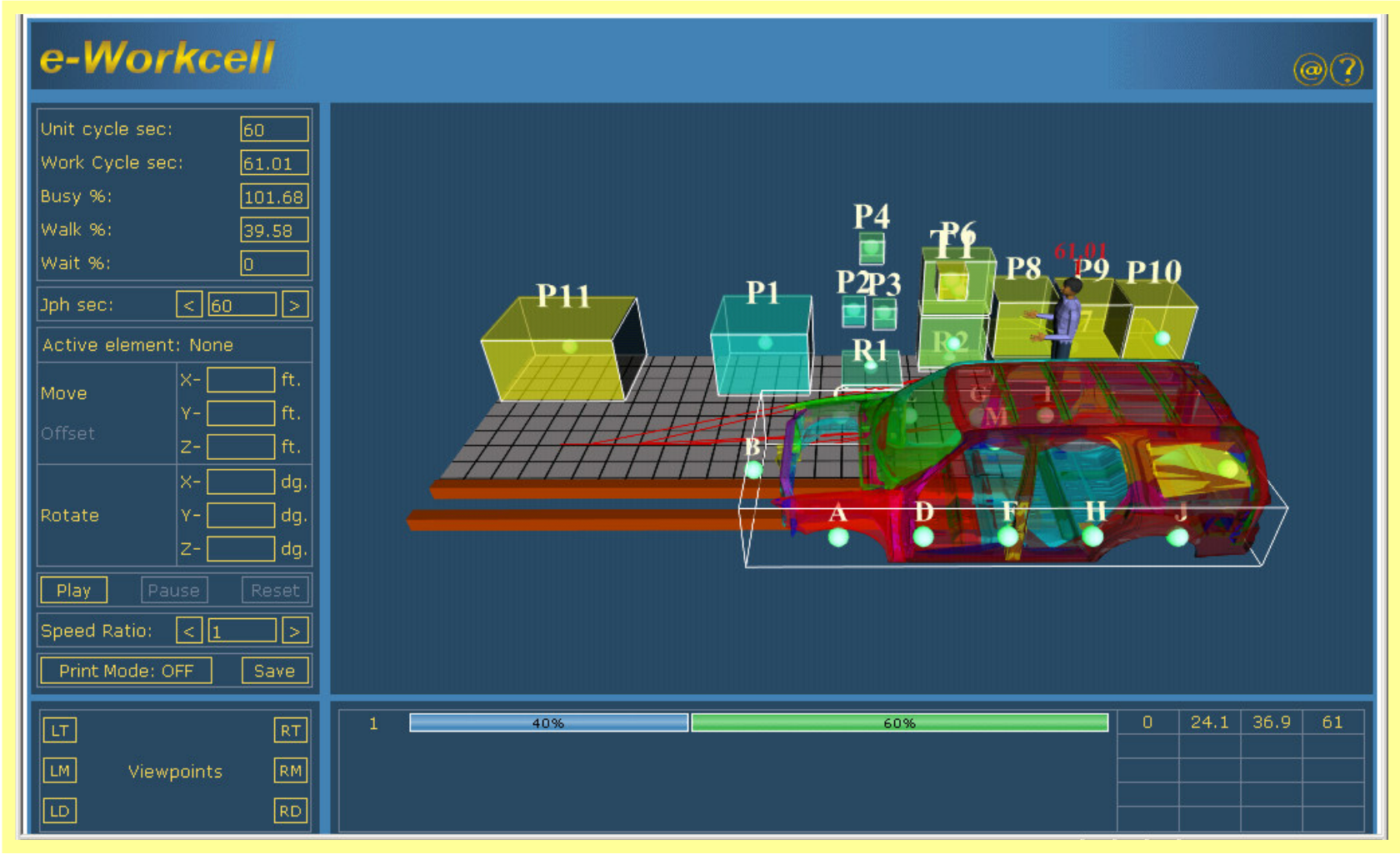
e-WorkCell



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Virtual Test Track Experiment (VIRTTEX)

	Acceleration	Velocity	Displacement
Longitudinal/ Lateral	> 0.6g	> 1.2m/s	± 1.6m
Vertical	1.0g	1.0m/s	± 1.0m
Pitch/ Roll	> 200deg/s^2	> 20deg/s	± 20deg
Yaw	> 200deg/s^2	> 20deg/s	± 40deg

Inside VIRTTEX

- Realistic sound cues
- Steering feedback

Displays

- 180° forward
- 120° rear

Ford Research and Advanced Engineering

Safety-Related Studies in VIRTTEX

- Types of Studies
  - Warning HMI for LDW, FCW, ACC, …
  - Distracted driver
  - Drowsy driver
- Primary Study Results: Driver Performance
  - Quantitative/Objective data
    - Brake/steer reaction times to imminent forward collision event
    - Eyes-off-road time for secondary tasks

VIRTTEX

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2012 FOCUS BEV

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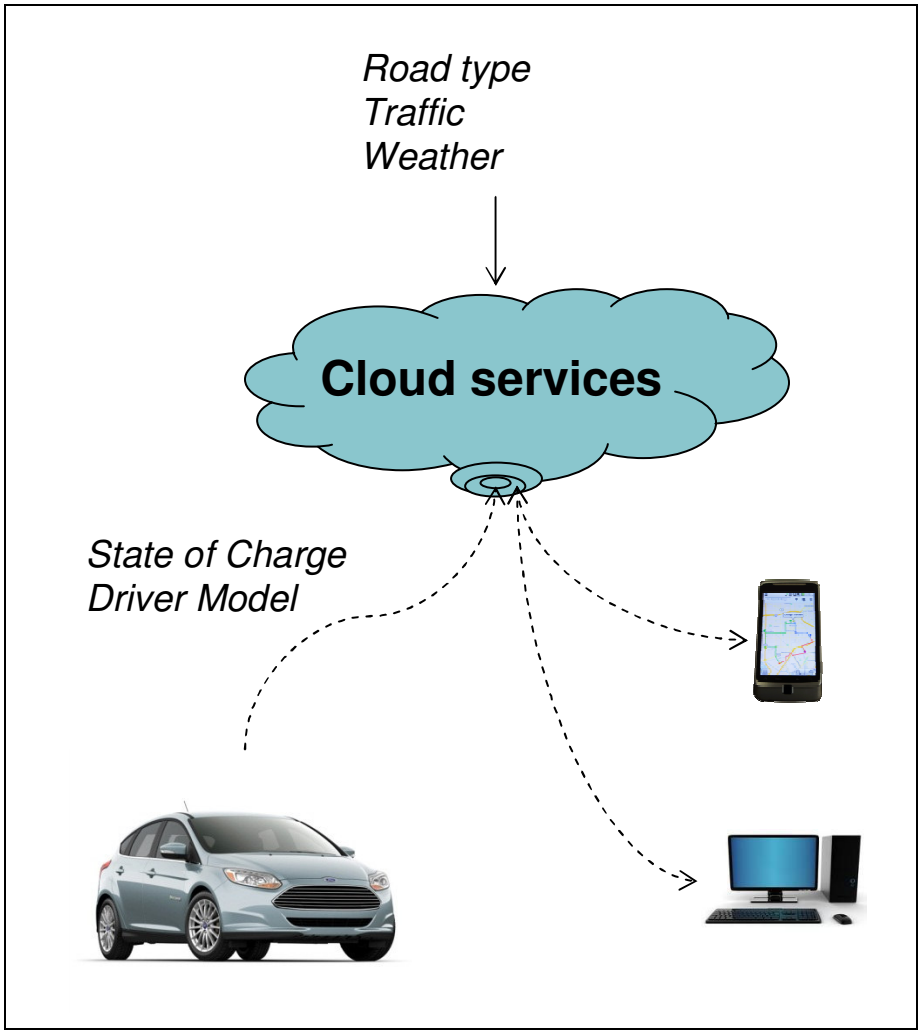
Potential issues with BEV ownership

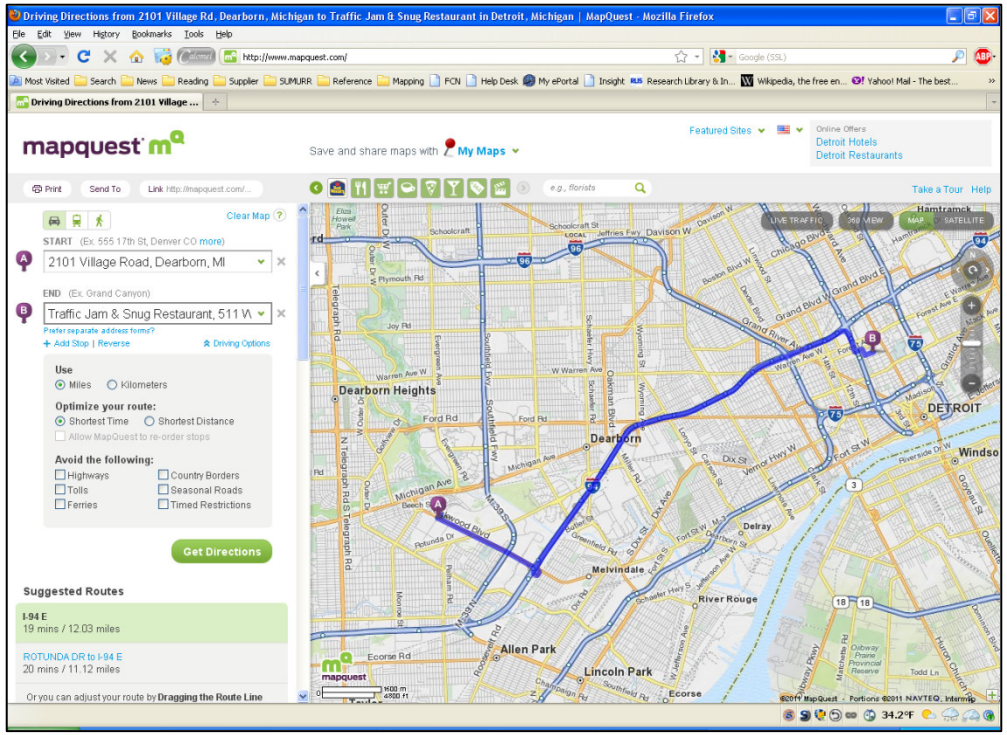
- BEV lack the range of conventional vehicles
- Charging stations are sparse compared to gas stations
- Charging takes a long time compared to a fill up

Telematics and cloud-based services can help BEV owners

- Give the driver a energy efficient route
- Compute and communicate the distance to empty
- Help the driver plan trips that consider driving range, locations of charging stations and charging times
- Lots of others



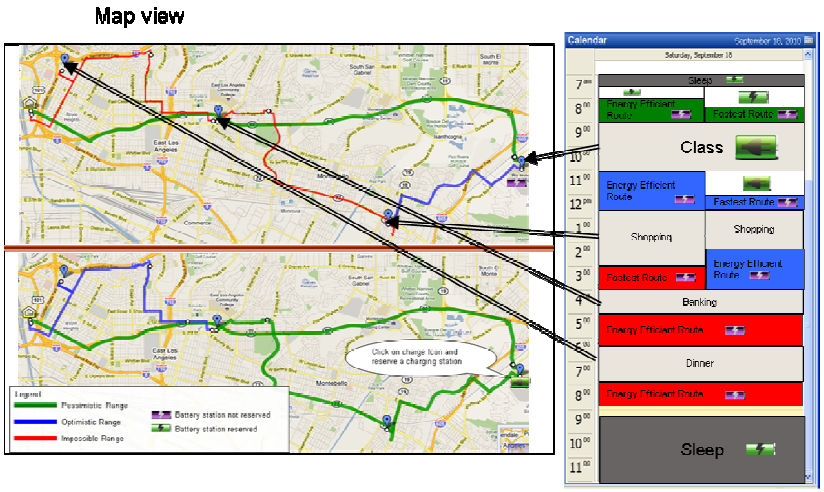
What route will I prefer?



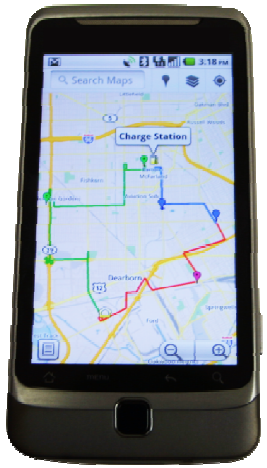
- What is the cheapest route?
- What is the greenest route?
- What is the fastest route?
- What is the shortest route?
- What is the scenic route?
- What is the safest route?

Can I make it through the day?

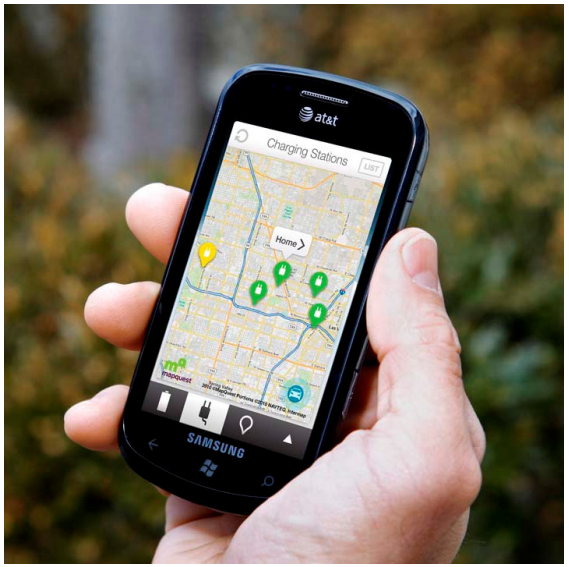
Desktop Applications:



Mobile Applications:



- How do I get to the places I need to go without killing my battery?
- If I need a battery charge, how can I spend my time while it is charging?
- How shall I organize my day around keeping my vehicle charged?



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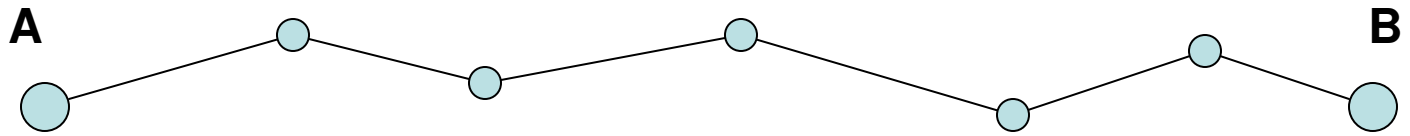
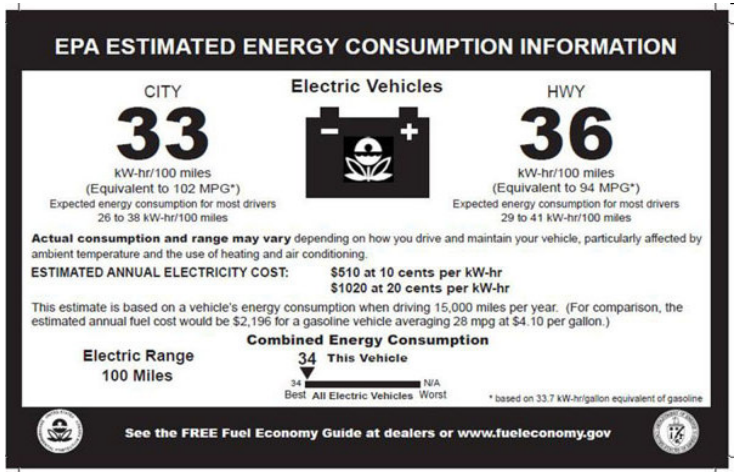
Problem Statement

- Accurate energy consumption estimates are at the heart of many new features needed for BEV drivers
- Digital maps represent road system as a graph where arcs correspond to the road segments with the given characteristics (e.g. road type, grade, speed limit, etc.)

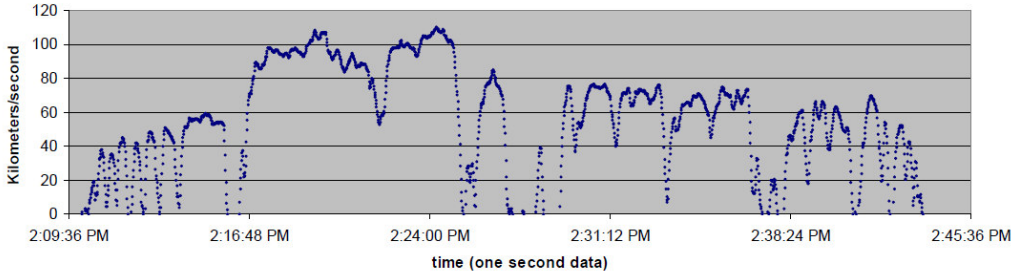


- The energy consumption over the given route is the sum of power consumption estimates for the arcs comprising that route
- We need a method to estimate energy consumption for the given static and dynamic parameters of the road segment

Using the vehicle sticker to determine energy consumption

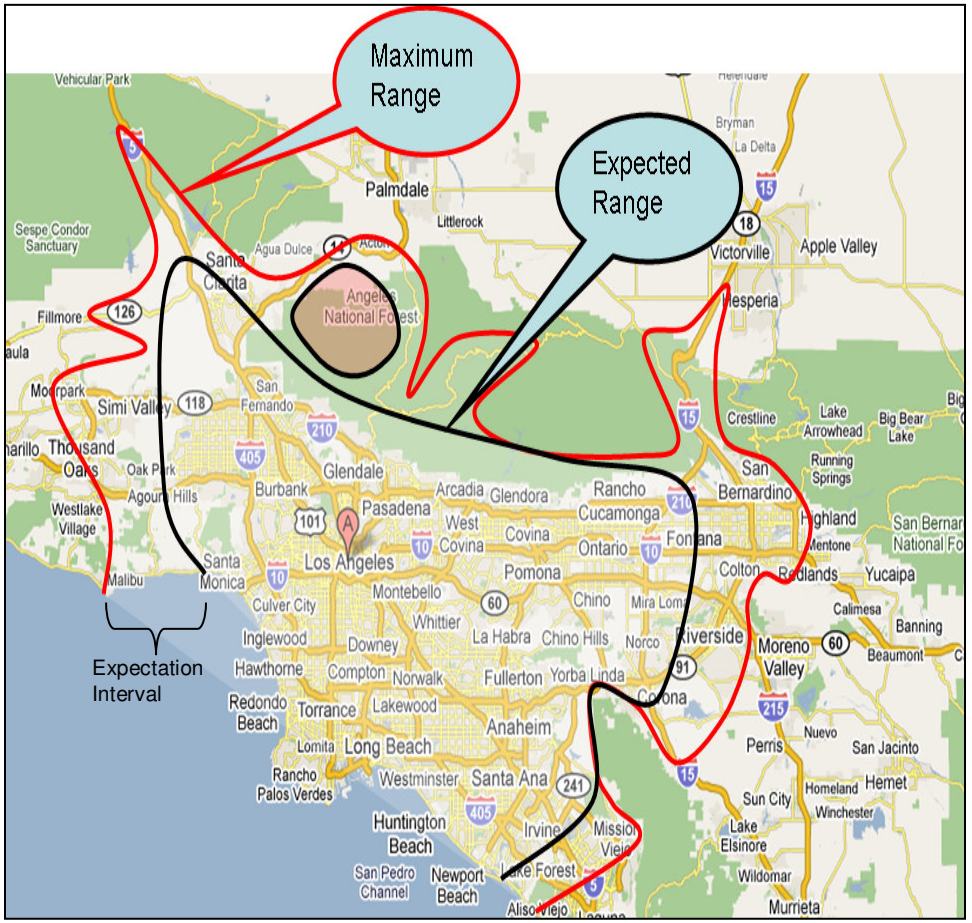


- MPG (for a BEV kWh/mile) are determined using a standard laboratory test using drive cycles as an input
- Sticker mileage is based on laboratory tests designed to compare energy efficiency of vehicles, but not for in-use energy consumption



Factors that influence energy consumption

- **Factors that can be accurately predicted:**
  - the road type
  - topography
  - vehicle parameters
- **Factors that have a lot of noise:**
  - weather
  - traffic control
  - vehicle interactions
  - driver characteristics



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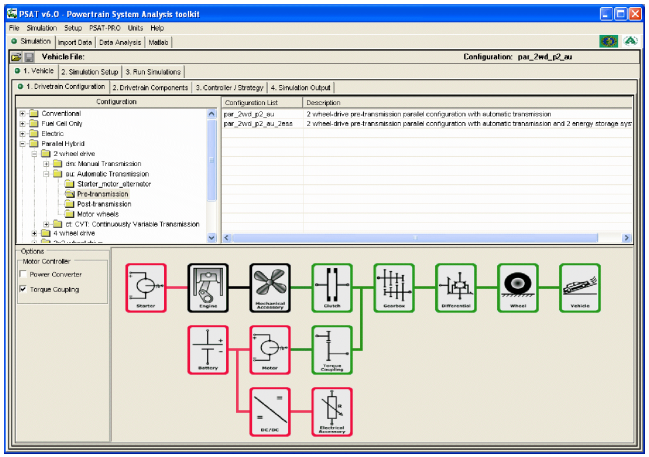
Vehicle Systems Modeling Tools

- **POWERTRAIN SYSTEMS ANALYSIS TOOLKIT (PSAT)**
  Argonne National Laboratory



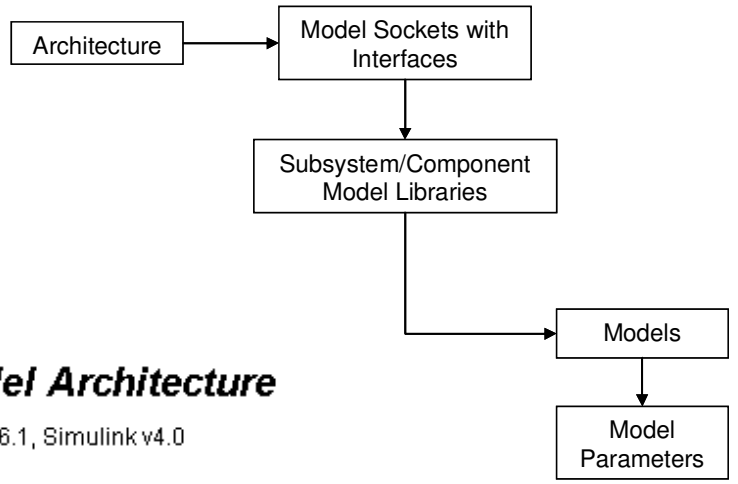
- Ford Simulink-CVSP is Ford's corporate standard tool for vehicle performance and fuel economy modeling and simulation

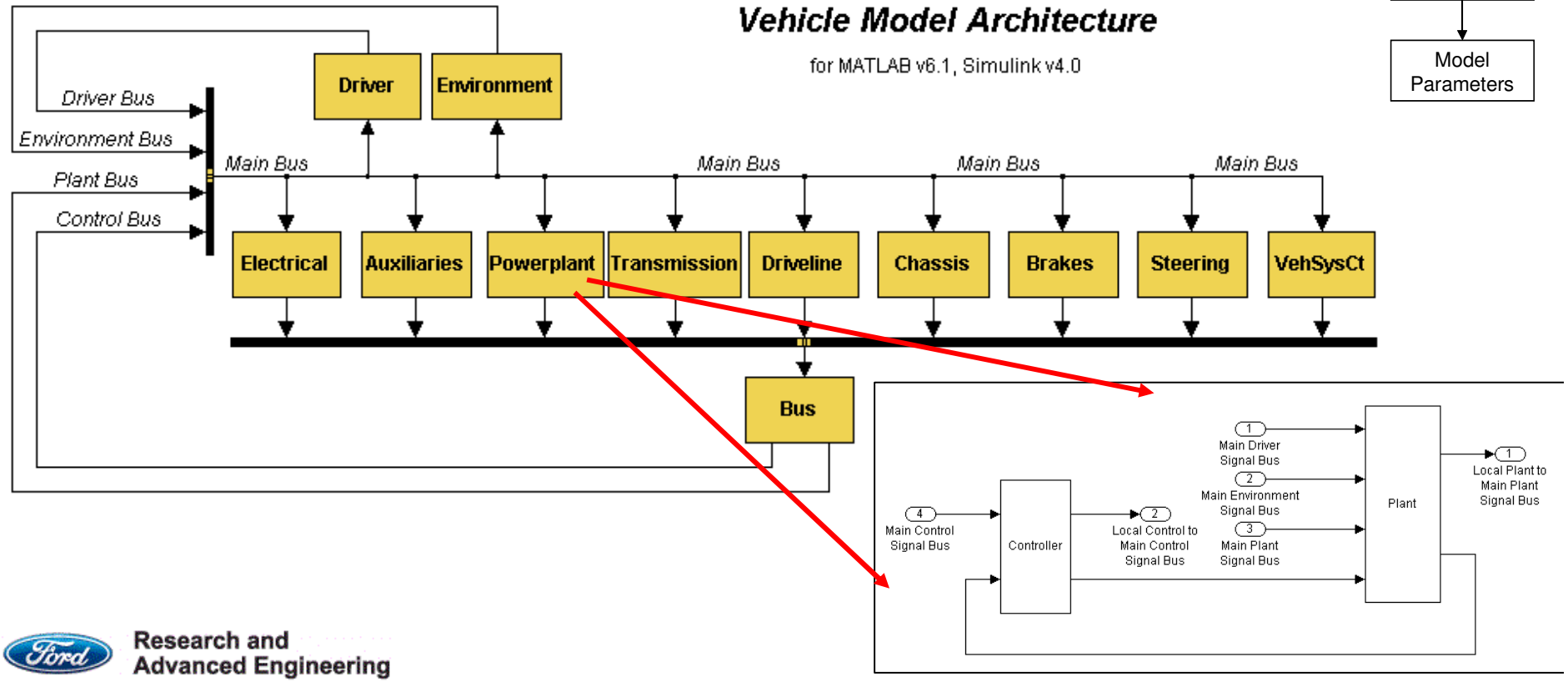
Simulink-CVSP

- Used on vehicle programs to set Performance & Fuel Economy targets
- Model architecture and subsystem interfaces follow Vehicle Model Architecture
- Includes extensive set of component models and vehicle / component parameter database
- Supported by company-wide processes to generate vehicle and component parameter data for new programs
- Includes standard test management and report generating scripts
- Capabilities can be extended by users
  - New models can be added to existing libraries (e.g. Hi-fi engine model into engine library)
  - New libraries with new models can be added

Vehicle Model Architecture

- Well defined model structure that facilitates model re-use and sharing and reduces model development time and cost
- Subsystem connections specified through well-defined interfaces
- Structure & interfaces are fixed, model content is not





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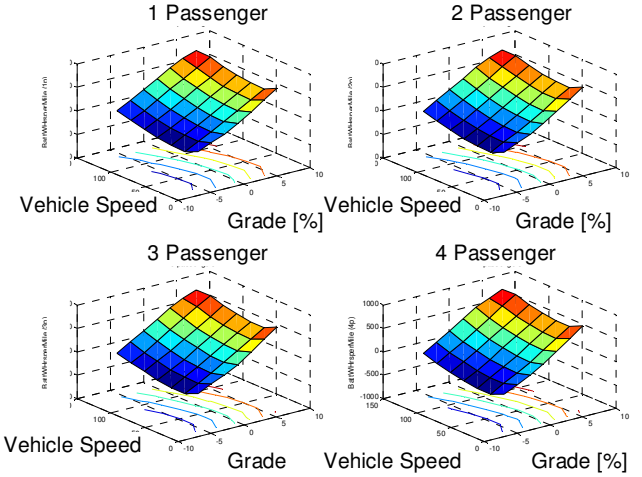
Predicting energy consumption for continuous values

Vehicle Speed - Acceleration

Vehicle Parameters

Drivetrain Simulation Computer Application (Simulink - CVSP)



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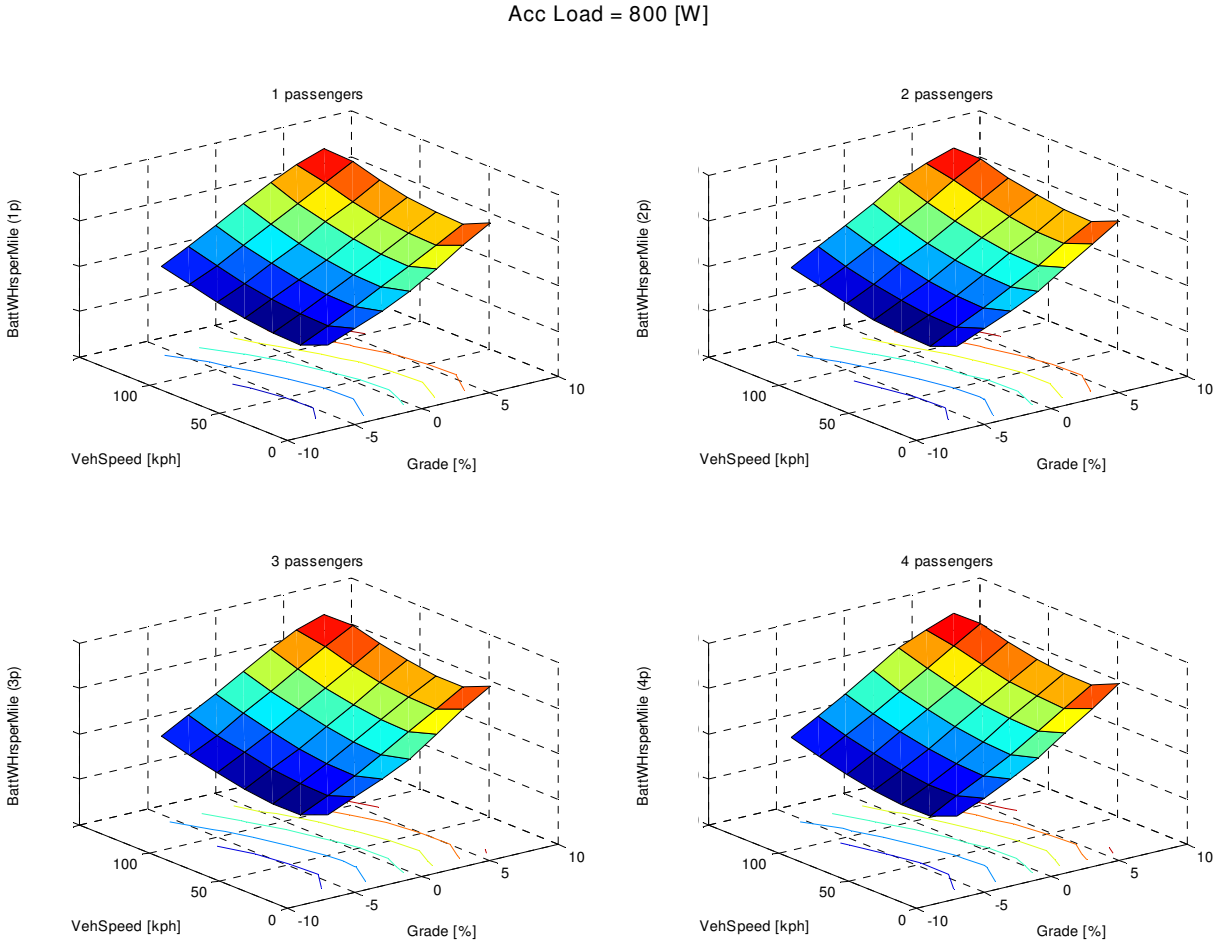
Sample Energy Consumption Maps



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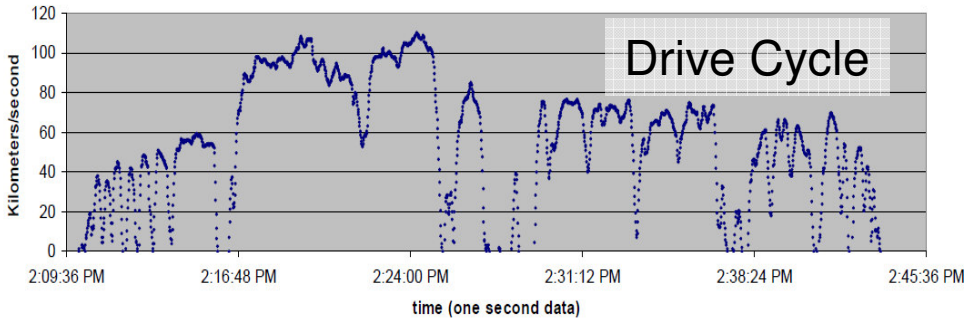
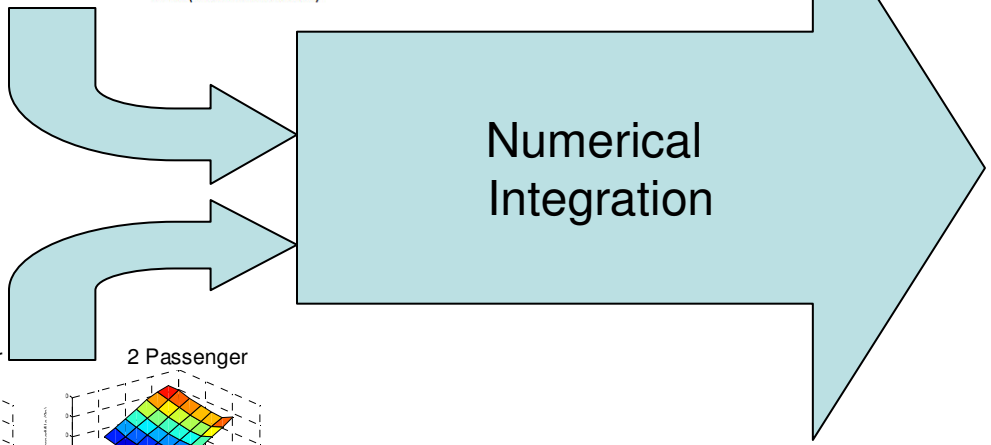
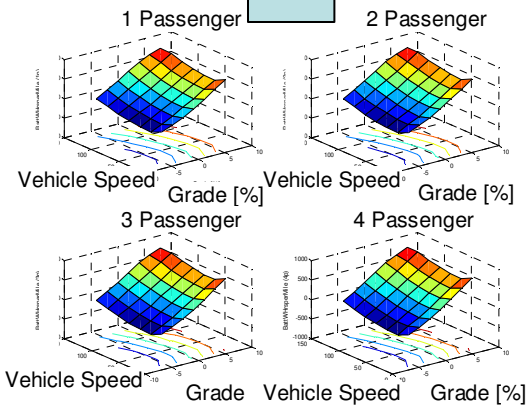
Computing kWh/mile for a drive cycle



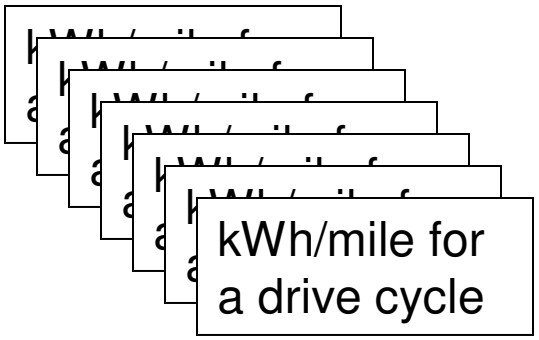


kWh/mile for a drive cycle



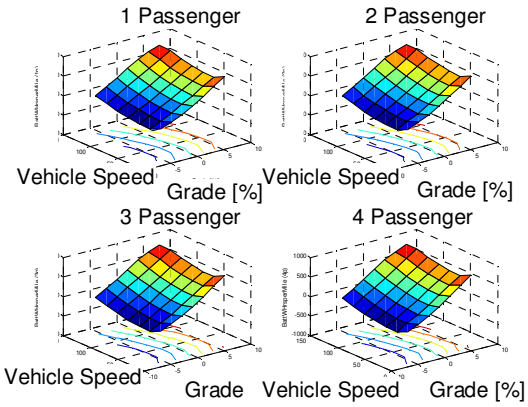
Multiple drive cycle energy ranges

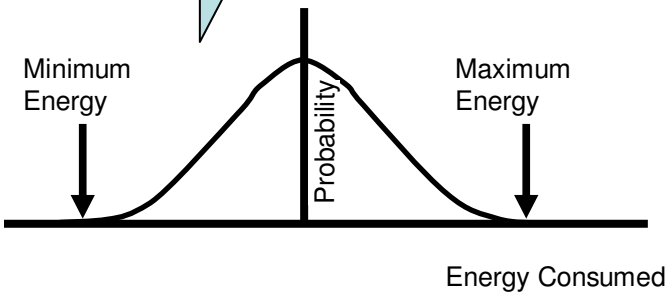
Many drive cycles under fixed conditions with simulated noisy conditions



Statistical Analysis

Energy consumption expectation interval





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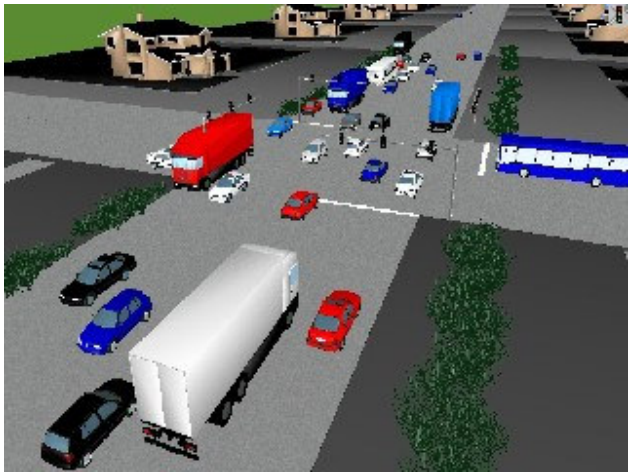
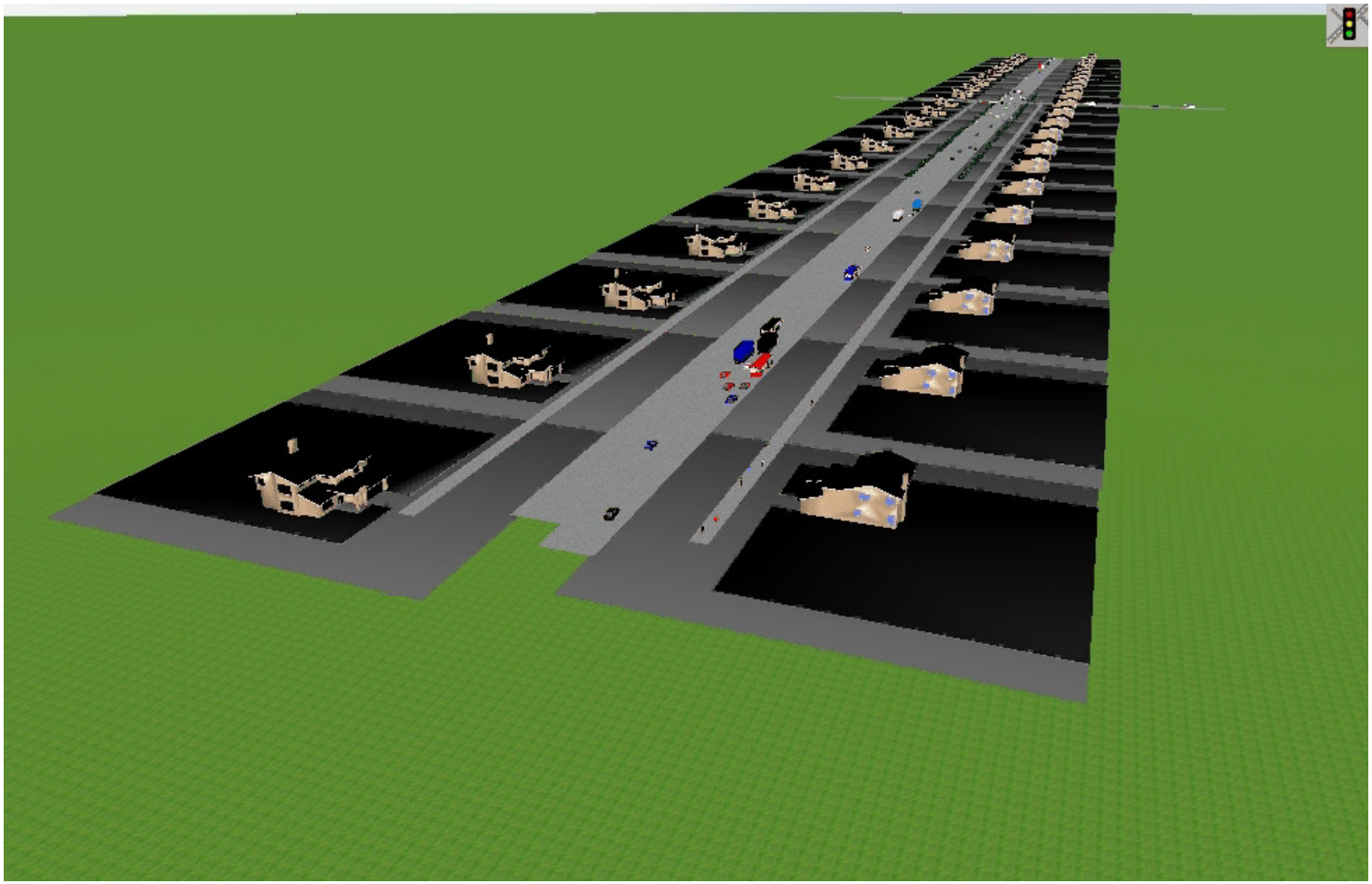
Traffic Simulation VISSIM

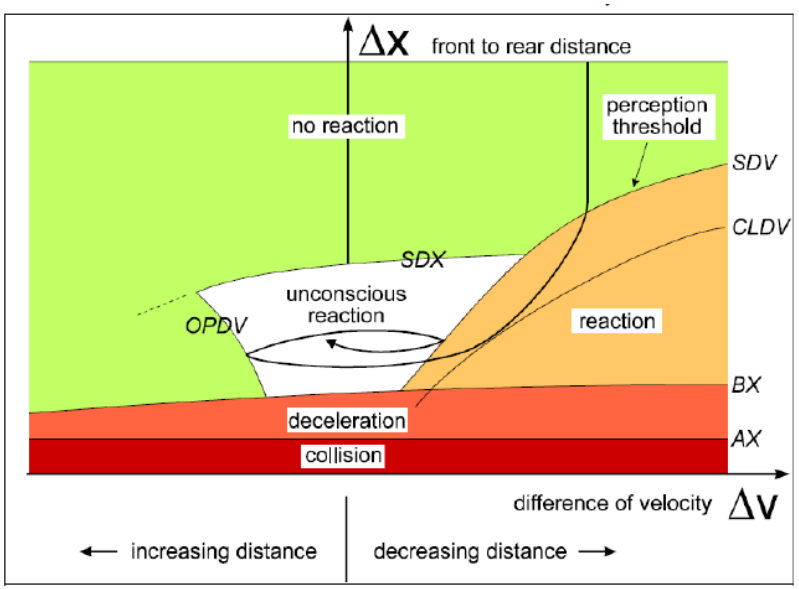
- Transportation system design, analysis and optimization applications:
  - Analysis of urban traffic and public transportation operations
  - Optimization and fine-tuning of signal priority logic
  - Comparison of transportation design alternatives



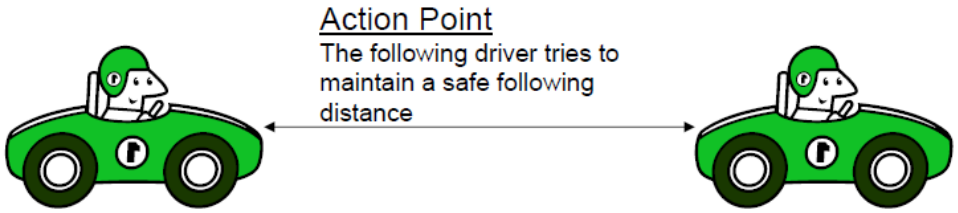
Traffic Simulation Example



Wiedemann's Psycho-physical model



Car following logic (Wiedemann 1974)



Action Point
The following driver tries to maintain a safe following distance

Weber's Law
The variation the driver can perceive is the distance times the Weber fraction (typically 10%)

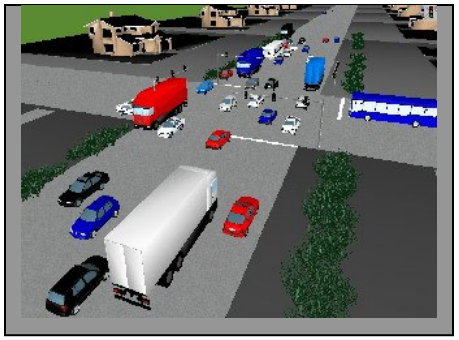
Conservative Driver

Aggressive Driver

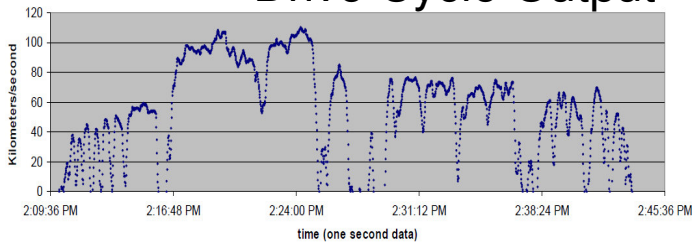
Simulation Framework

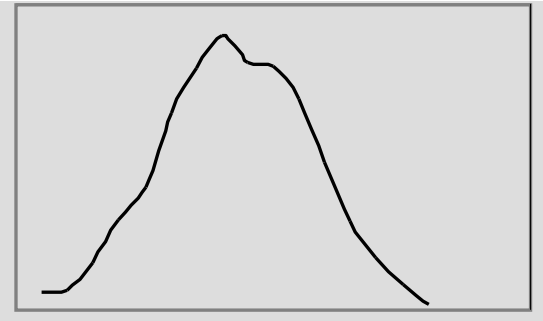
Road Model
Traffic Conditions
Driver Model

Traffic Simulation



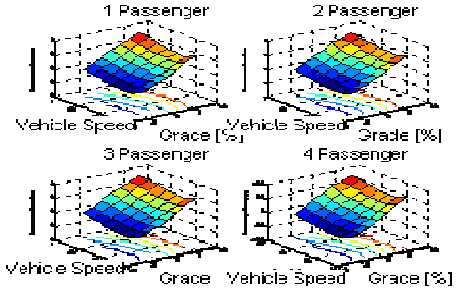
Drive Cycle Output





Accessory loads
Vehicle Weight

Energy Consumption



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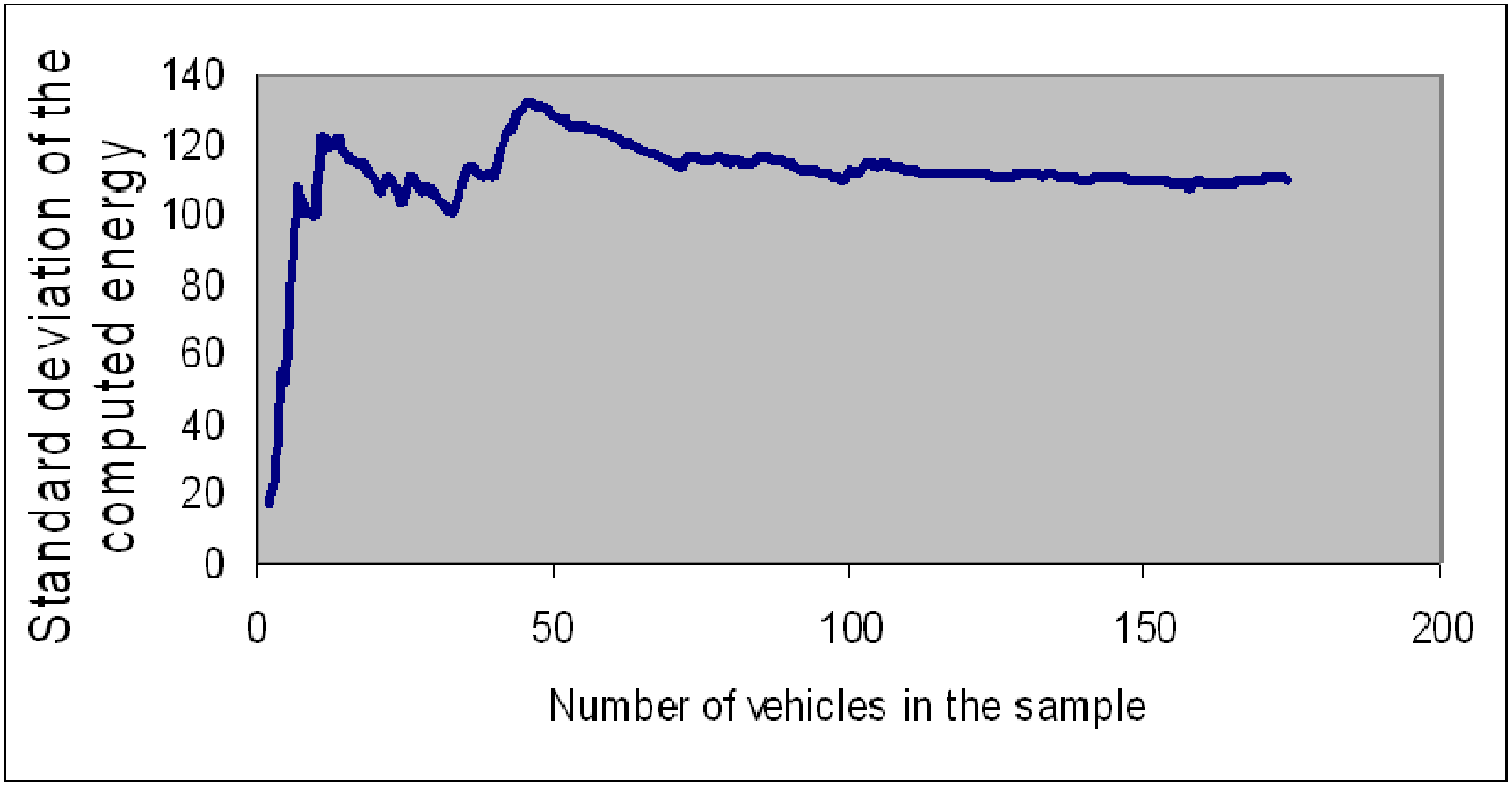
Standard Deviation vs. Sample Size



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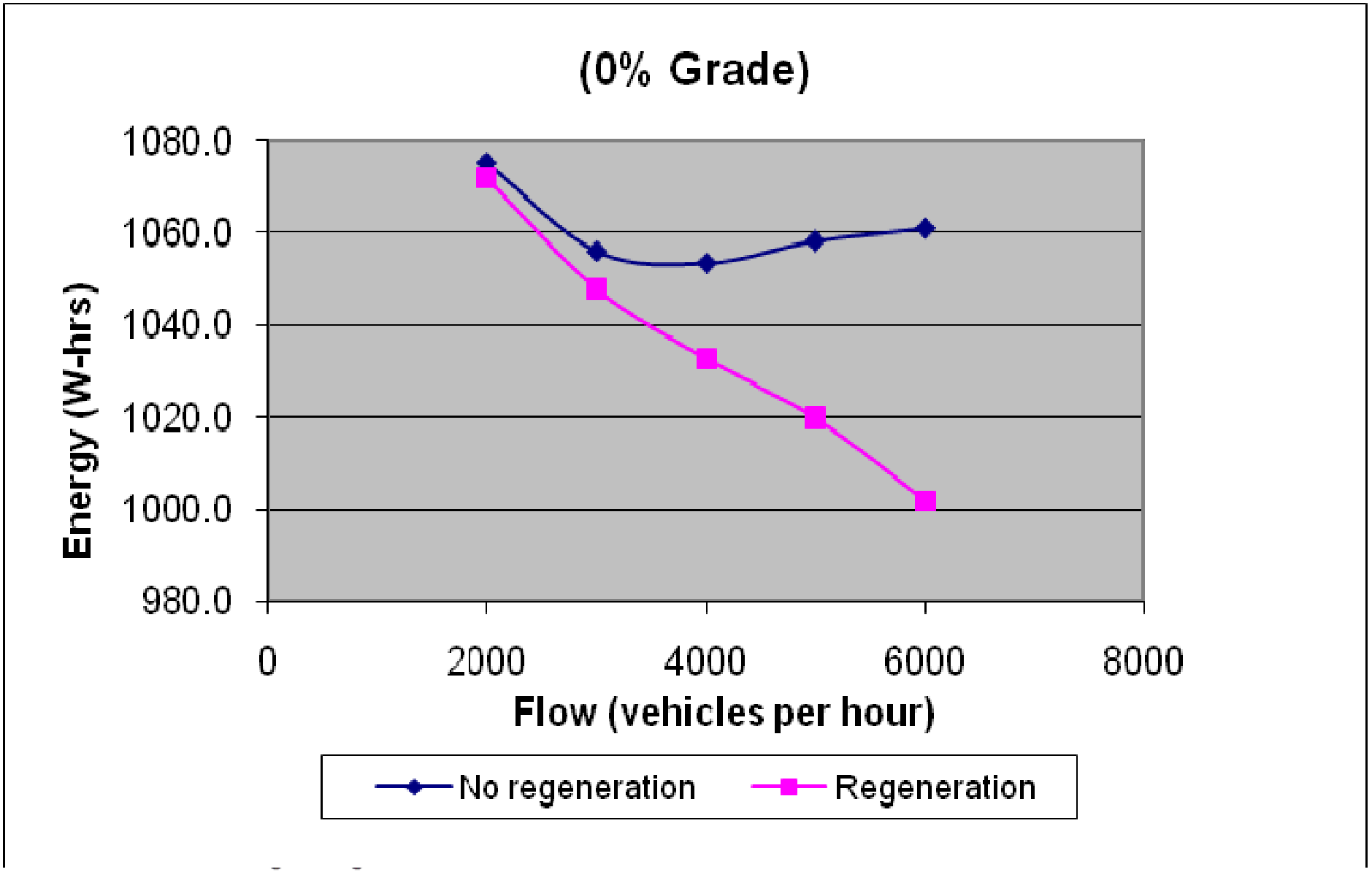
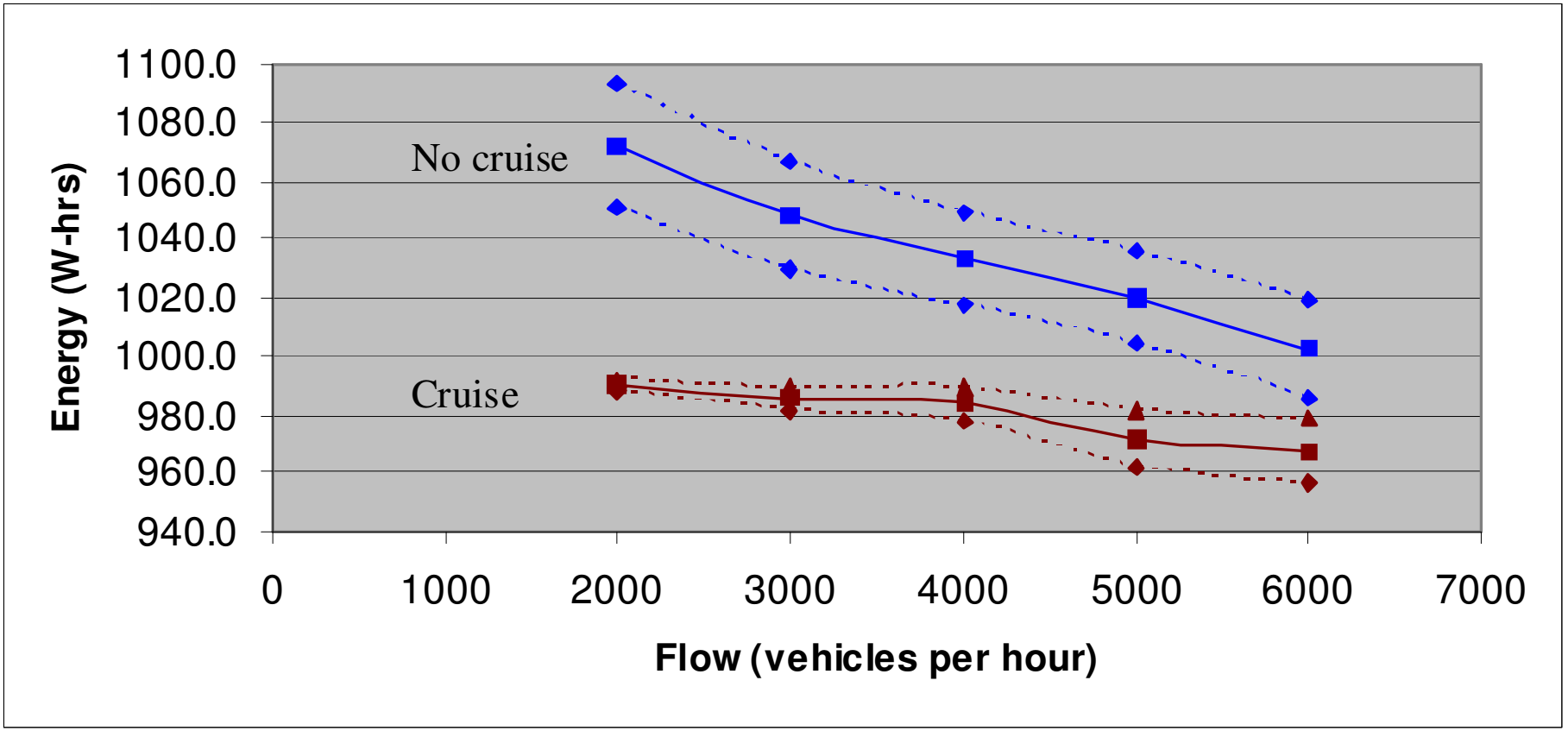
The effect of regeneration



Effect of Adaptive Cruise Control



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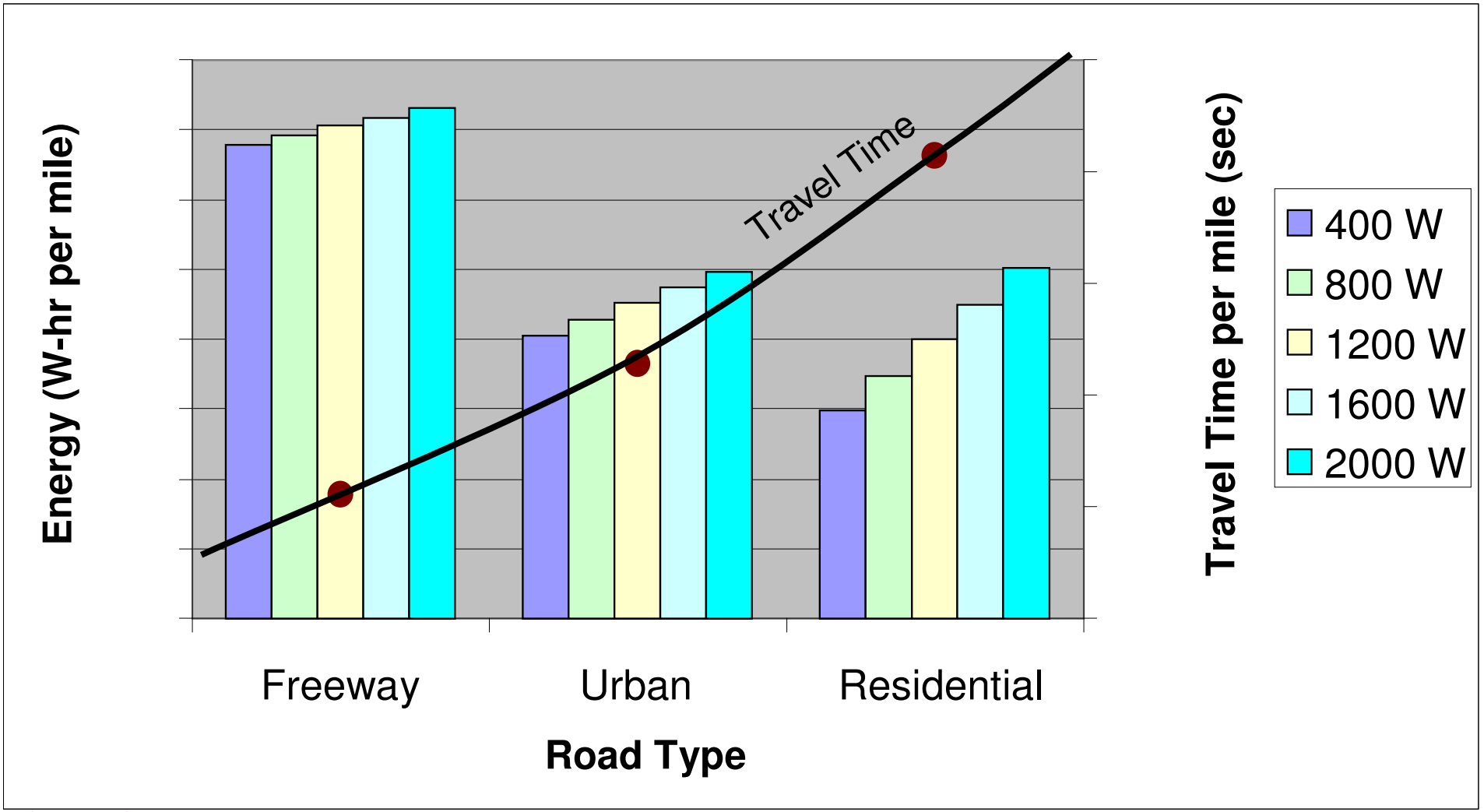
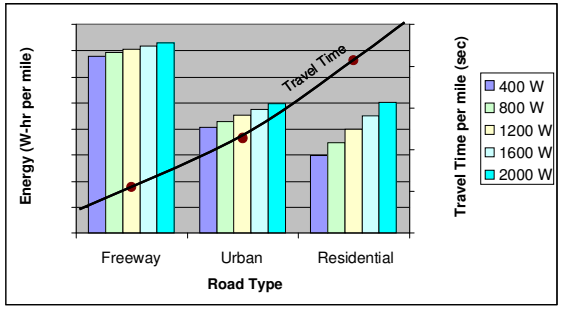
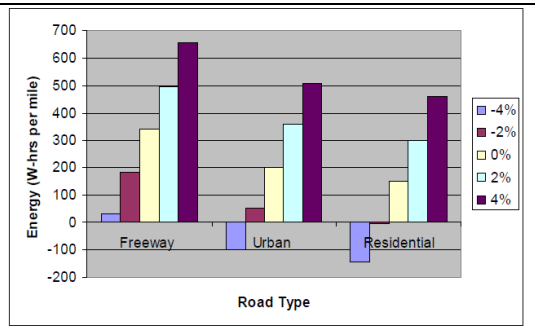
Effects of Road Type, Energy Consumption and Travel Time



Power Consumption Estimates



Effects of road type and accessory loads



Effects of road type and gradient

Data Analysis

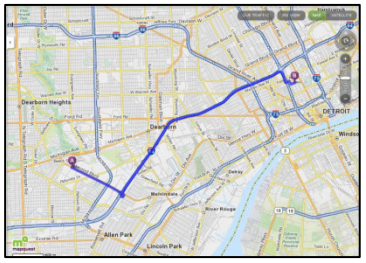
<u>Energy Consumption Estimate (Mean, St.Dev.)</u> = A * (travel_time) + (B + C) * distance

A = accessory load [watts]

B=F(Road Type, gradient°)

C=F(Vehicle Speed)

Digital Maps Routing



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Conclusion

- **Integration of Vehicle Systems Modeling and Traffic Simulation**
  - **enables meaningful energy management features for new vehicles**
  - **provides an efficient and effective approach for vehicle design optimization and calibration**
  - **allows to combine road infrastructure design with vehicle design for energy efficient transportation**

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Q & A

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