Modeling & Simulation in Automotive Industry
Prediction of Energy Consumption in Electric Vehicles

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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
Communication & Infotainment Technology

Ford SYNC  

MyFord Touch
Ford Hybrid and Electrical Vehicles

**FUSION Hybrid**
- Starting MSRP: $28,600
- Seating for: 5 people
- MPG City/hwy: 41/36

**ESCAPE Hybrid**
- Starting MSRP: $30,570
- Seating for: 5 people
- Tow up to: 3500 lbs
- MPG City/hwy: 34/31

**FOCUS Electric**
- Coming Late 2011

**TRANSIT CONNECT EV**
- Available Now

**2013 C-MAX Energi**
- Coming Fall 2012

**2013 C-MAX Hybrid**
- Coming Fall 2012
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)

Assembly Plant

Digital Factory
Ergonomics
Simulation
Teamcenter
Visualization
Plant Layout

Line Balancing
Workstation Layout

Research and Advanced Engineering
e-WorkCell
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Virtual Test Track Experiment (VIRTTEX)

**Displays**
- 180° forward
- 120° rear

**Inside VIRTTEX**
- Realistic sound cues
- Steering feedback

<table>
<thead>
<tr>
<th></th>
<th>Acceleration</th>
<th>Velocity</th>
<th>Displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Longitudinal/Lateral</strong></td>
<td>&gt; 0.6g</td>
<td>&gt; 1.2m/s</td>
<td>± 1.6m</td>
</tr>
<tr>
<td><strong>Vertical</strong></td>
<td>1.0g</td>
<td>1.0m/s</td>
<td>± 1.0m</td>
</tr>
<tr>
<td><strong>Pitch/ Roll</strong></td>
<td>&gt; 200deg/s²</td>
<td>&gt; 20deg/s</td>
<td>± 20deg</td>
</tr>
<tr>
<td><strong>Yaw</strong></td>
<td>&gt; 200deg/s²</td>
<td>&gt; 20deg/s</td>
<td>± 40deg</td>
</tr>
</tbody>
</table>
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
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 an 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:**

- 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?

**Mobile Applications:**
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.

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**EPA ESTIMATED ENERGY CONSUMPTION INFORMATION**

- **CITY**
  - Electric Vehicles: 33 kWh/100 miles
  - Combined Energy Consumption: 33 kWh/100 miles
- **HIGHWAY**
  - Electric Vehicles: 36 kWh/100 miles
  - Combined Energy Consumption: 36 kWh/100 miles

*Actual consumption and range may vary depending on how you drive and maintain your vehicle, particularly affected by ambient temperature and the use of heating and air conditioning.*

**ESTIMATED ANNUAL ELECTRICITY COST:**

- $510 at 10 cents per kWh
- $120 at 20 cents per kWh

This estimate is based on a vehicle's energy consumption when driving 15,000 miles per year. For comparison, the estimated annual fuel cost would be $1,156 for a gasoline vehicle averaging 28 mpg at $4.10 per gallon.

- **Electric Range:** 160 miles

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**Graph:**

- **Kilometers/second**
- **Time (one second data):**
  - From 2:05:36 PM to 2:45:36 PM

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**Research and Advanced Engineering**

**United States Environmental Protection Agency**

**National Vehicle and Fuel Emissions Laboratory**
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 reuse and sharing and reduces model development time and cost
- Subsystem connections specified through well-defined interfaces
- Structure & interfaces are fixed, model content is not

```
Vehicle Model Architecture
for MATLAB v6.1, Simulink v4.0
```

```
Architecture → Model Sockets with Interfaces

Subsystem/Component Model Libraries

Models

Model Parameters

```

```
Driver Bus

Environment Bus

Plant Bus

Control Bus

Main Bus

Electrical

Auxiliaries

Powerplant

Transmission

Driveline

Chassis

Brakes

Steering

VehSysCt

```

```
Controller

Local Control Signal Bus

Main Control Signal Bus

Main Plant

Main Plant Signal Bus

```

```
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```
Predicting energy consumption for continuous values

Vehicle Speed - Acceleration

Drivetrain Simulation Computer Application (Simulink - CVSP)

Vehicle Parameters

1 Passenger

2 Passenger

3 Passenger

4 Passenger

Vehicle Speed

Grade [%]

Vehicle Speed

Grade [%]

Vehicle Speed

Grade [%]
Sample Energy Consumption Maps

Acc Load = 800 [W]
Computing kWh/mile for a drive cycle
Multiple drive cycle energy ranges

Many drive cycles under fixed conditions with simulated noisy conditions

kWh/mile for a drive cycle

Statistical Analysis

Energy consumption expectation interval

Minimum Energy

Maximum Energy

Energy Consumed

1 Passenger

2 Passenger

3 Passenger

4 Passenger
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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

Energy (W-hrs) vs Flow (vehicles per hour) for 0% Grade:

- Blue line: No regeneration
- Pink line: Regeneration

Energy decreases with increasing flow, showing a significant difference in energy consumption between the two conditions.
Effect of Adaptive Cruise Control

No cruise

Cruise
Effects of Road Type, Energy Consumption and Travel Time

![Bar chart showing energy consumption and travel time across different road types and energy levels.](image)

The chart illustrates the relationship between road type, energy consumption, and travel time. It shows that as energy consumption increases, travel time also increases for all road types: Freeway, Urban, and Residential. The data points indicate a linear trend, with each road type displaying similar patterns in energy per mile and travel time per mile.
Power Consumption Estimates

Effects of road type and accessory loads

Effects of road type and gradient

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

A = accessory load [watts]
B = F(Road Type, gradient°)
C = F(Vehicle Speed)

Data Analysis

Digital Maps Routing
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