SYSTEMS-LEVEL TRANSPORTATION SIMULATION: CREATING THE SMART MOBILITY MODELING WORKFLOW

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MOBILITY: CONNECTING PEOPLE TO OPPORTUNITY

The solutions we are developing will power the next transportation revolution, ushering in a new era of SMART Mobility.
TRANSPORTATION IS FUNDAMENTAL TO OUR WAY OF LIFE

Population density is increasing — 75% of the population lives in urban mega-regions.

More congestion leads to increased greenhouse gases and pollution.

Transportation costs are high — second only to housing expenses.
The SMART Mobility Consortium is a multi-year, multi-laboratory collaborative dedicated to further understanding the energy implications and opportunities of advanced mobility solutions.
Mobility

The quality of a network or system to connect people to goods, services, and employment that define a high quality of life.
VTO SYSTEMS-LEVEL R&D
FIVE RESEARCH FOCUS AREAS

CONNECTED AND AUTOMATED VEHICLES
Identifying the energy, technology, and usage implications of connectivity and automation and identifying efficient CAV solutions.

MOBILITY DECISION SCIENCE
Understanding the human role in the mobility system including travel decision-making and technology adoption in the context of future mobility.

MULTI-MODAL FREIGHT
Evaluating the evolution of freight movement and understanding the impacts of new modes for long-distance goods transport and last-mile package delivery.

URBAN SCIENCE
Understanding the linkages between transportation networks and the built environment and identifying the potential to enhance access to economic opportunity.

ADVANCED FUELING INFRASTRUCTURE
Understanding the costs, benefits, and requirements for fueling/charging infrastructure to support energy efficient future mobility systems.
TRANSPORTATION IS A SYSTEM OF SYSTEMS

- CONNECTED VEHICLES
- GOODS MOVEMENT
- SHARED MOBILITY
- BUILT ENVIRONMENT
- PASSENGER MOVEMENT
- TRAVELER BEHAVIOR
- VEHICLE TECHNOLOGIES
- E-COMMERCE
- TRANSIT
- AUTOMATED VEHICLES
SMART MOBILITY MODELING WORKFLOW

By creating a multi-fidelity end-to-end modeling workflow, SMART Mobility researchers advanced the state-of-the-art in transportation system modeling and simulation.

LAND USE EV CHARGING PASSENGER MOVEMENT GOODS MOVEMENT TRAVELER BEHAVIOR CONTROL

AGENT BASED TRANSPORTATION SYSTEM MODEL

VEHICLE MILES TRAVELED (VMT) CONGESTION VEHICLE HOURS TRAVELLED (VHT) ENERGY COST GREENHOUSE GASES (GHG)
SYSTEMS-LEVEL TRANSPORTATION SIMULATION: CREATING THE SMART MOBILITY MODELING WORKFLOW

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Group Manager
Vehicle and Mobility Systems
Argonne National Laboratory
RESEARCH QUESTIONS ARE NUMEROUS AND DIVERSE

- Will new technologies and services promote or inhibit shift of travelers to lower energy travel modes? What is the impact on VMT, energy…?
- Will these technologies encourage development further from urban areas, and thus decrease urban density?
- What changes in charging and fueling infrastructure are needed to support these technologies and services in various scenarios?
- How can traffic control infrastructure leverage the new technologies for better management of traffic and thus less energy?
- What is the energy impact and sensitivities on freight delivery vehicles?
- Will these technologies and services promote a shift from private ownership?
- What will be the impact on powertrain, vehicle design, and attribute mix? …
END-TO-END MODELING WORKFLOW

AGENT-BASED TRANSPORTATION SYSTEM MODELING

TRIP PROFILES

VEHICLE ENERGY

MESOSCOPIC SIMULATION

MICROSCOPIC TRAFFIC FLOW

MULTI-VEHICLE CONTROL

EV Charging

Land Use

Vehicle Markets

Traveler Behavior

System Control

Goods Movement

METRICS (MEP...)

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy
WORKFLOW DEVELOPMENT PROCESS

- **Model Workshop**
- **SMART Gantt Chart developed across consortium developed scenarios**
- **Quantify energy, mobility and MEP impact of new transportation technologies**
- **SMART Workflow Proof-of Concept**
- **Develop & Implement processes for model I/O**
- **Seamless workflow leveraging expertise across multiple national research organizations**
LEARNING FROM DETAILED MODELS TO SCALE TO LARGER ONES

Microsimulation

Freeway corridor with different level market penetration of CAVs

Driver model, control

Urban corridor

Mesosimulation

Fundamental Diagram POLARIS Input

Model & calibration improvement

Parameters

Current

Future

Note: Any proposed future work is subject to change based on funding levels.
SAME MODELS USED ACROSS MULTIPLE PROJECTS

Microscopic & Mesoscopic Simulations -> Autonomie for Energy
=> Provides consistent and comparable results

Vehicle Models

Vehicle energy consumption, cost...

Individual vehicles speed

CAVs Coordination

Travel Behavior

ACC / CACC Control

Real Vehicle System

CACC Feedback Control

Microscopic & Mesoscopic Simulations

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Travel Behavior
MULTIPLE TOOLS REQUIRE ITERATIVE PROCESS

Land Use / Transportation System Coupling Example

- Employment by industry and population for each building
- Link performance by time
- OD Skims by mode and time
- Polaris Zone table
- Simulate every 5 years
- UrbanSim
- Simulate every year from $t_0$ to $t_{\text{end}}$
- Population synthesizer
- Demographics by block
- Output to Polaris at $t_5, 10, 15...$
PEV CHARGING LOCATION AND BEHAVIOR
IMPROVED SCENARIOS – FREIGHT EXAMPLE

Base year:
Traffic Analysis Zone - Level: Total Parcel
Deliveries
Stop-Level: Random Delivery Locations
Medium Duty Delivery Tours

WholeTraveler

Survey Data

Network Routing

SVTRIP

E-commerce Behavioral Model

POLARIS

WholeTraveler

Survey Data
HPC ENABLES OPTIMIZATION & CONTROL

Implemented processes to efficiently link to external optimization tools

Example: Platoon Formation Decision

Example: Personally Owned AVs

Original schedule
Updated schedule

Person 1
Vehicle 1

Person 2
Vehicle 2

CAV, pick-up

work
shop

H
errand

H
errand

H

H

69:00  70:00  71:00  72:00  73:00  74:00  75:00  76:00  77:00  78:00  79:00  80:00  81:00  82:00  83:00  84:00  85:00  86:00  87:00  88:00  89:00
MAIN WORKFLOW OUTPUTS

- Vehicle miles traveled (VMT)
  The total amount of miles traveled by all vehicles in the system for each scenario, representing a measure of the load on the system from the transportation network perspective.

- Productive miles traveled (PMT)
  The total amount of person-miles traveled by all travelers in any mode (i.e., cars, ride-hailing/taxi vehicles, transit vehicles, walking, and biking), plus all freight delivery miles, unloaded miles (e.g., taxi, ride-hailing vehicles, or fully automated vehicles without a passenger, freight delivery vehicles without a load).
  - PMT represents a measure of the load on the system from a user perspective (i.e. how much mobility is the system providing). A higher ratio of PMT to VMT indicates better system performance.

- Vehicle hours traveled (VHT)
  The total travel time for all vehicles in the system, representing another measure of the transportation system load. VHT increasing faster than VMT indicates growing congestion and delay in the system.

- Productive hours traveled (PHT)
  The total travel time for all users in the system, with users defined the same as for PMT.

- Average vehicle travel/network speed
  The ratio of VMT / VHT.

- Average trip/travel speed
  The ratio of PMT / PHT.

- Travel efficiency
  The average energy required to move a person or a good one mile (PMT / total energy).
MOBILITY ENERGY PRODUCTIVITY (MEP)
A comprehensive mobility metric

WHAT

Mobility Energy Productivity (MEP) methodology quantifies the energy, cost, and time-weighted opportunity space within a reachable area.
WORKFLOW IMPLEMENTATION CENTERED AROUND POLARIS

AGENT-BASED TRANSPORTATION SYSTEM MODELING

- Traveler Behavior
- System Control
- Goods Movement

EVI-PRO
UrbanSim
Vehicle Markets

POLARIS

Aimsun
ROAD RUNNER

SVTRIP

METRICS (MEP...)

UrbanSim
EVI-PRO
Vehicle Markets
WORKFLOW IMPLEMENTATION CENTERED AROUND BEAM
RESULTS
EXAMPLES
VEHICLE AND POWERTRAIN CONTROL OFFER SIZABLE BENEFITS

Adaptation to conditions, other vehicles, traffic lights

UP TO 20% INDIVIDUAL VEHICLE FUEL CONSUMPTION REDUCTION

<table>
<thead>
<tr>
<th>Energy savings (%)</th>
<th>suburban</th>
<th>urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>EV</td>
<td>9</td>
<td>5.1</td>
</tr>
<tr>
<td>Conv</td>
<td>13.3</td>
<td>14.1</td>
</tr>
<tr>
<td>+V2I</td>
<td>10</td>
<td>21.8</td>
</tr>
</tbody>
</table>

suburban urban
HIGH ACC PENETRATION MAY NEGATIVELY IMPACT TRAFFIC

Lack of communication leads to traffic instabilities, congestion

FUEL CONSUMPTION INCREASES AS MUCH AS 60%
CACC HELPS TRAFFIC FLOW, LOWERS ENERGY USE
Vehicle communication + automation improves traffic flow

UP TO 20% FUEL SAVINGS
**MOBILITY SCENARIOS CONSIDERED**

A world of

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>HIGH SHARING, PARTIAL AUTOMATION (A)</strong></td>
<td>New technology enables people to significantly increase the use of transit, ride-hailing and multi-modal travel. Partial automation is introduced and is primarily used on the highway.</td>
</tr>
<tr>
<td><strong>HIGH SHARING, HIGH AUTOMATION (B)</strong></td>
<td>Technology has taken over our lives, enabling high usage of fully automated driverless vehicles, ride-hailing and multi-modal trips, which are convenient and inexpensive. As a result, private ownership has decreased and e-commerce has increased.</td>
</tr>
<tr>
<td><strong>LOW SHARING, HIGH AUTOMATION (C)</strong></td>
<td>Fully automated privately owned driverless vehicles dominate the market. The ability to own AVs leads to low ride-sharing and an expansion of urban/sub-urban boundaries, while e-commerce has increased.</td>
</tr>
</tbody>
</table>
SHARED CAVS ENABLE HIGH SYSTEM EFFICIENCY
Compared to personally owned CAVs

CHICAGO

High Sharing / Low Automation

Low Sharing / High Automation

23% Energy
18% VMT
0% PMT

17% Speed

22% Energy
25% VMT
7% PMT

18% Speed
INCREASE IN E-COMMERCE LOWERS OVERALL SYSTEM VMT AND ENERGY

Fewer shopping trips, more deliveries make the difference

**CHICAGO**

**SHOPPING TRIP** = 7 to 8 miles, each way

**DELIVERY TRIP**

1 ADDED STOP = 0.4 mile

![Bar chart showing energy consumption](chart)

- **55%** MDT (Delivery)
- **30%** LDV (Shopping)

1 delivery/HH/Week (Baseline)
5 deliveries/HH/Week (High Sharing / High Automation)
5 deliveries/HH/Week (Low Sharing / High Automation)
8% REDUCTION IN TRAVEL TIME AND ENERGY

15–25% FUEL SAVINGS

18% VMT DECREASE

7–13% FUEL SAVINGS

20% FUEL CONSUMPTION REDUCTION