TRANSPORTATION SYSTEM IMPACT : POLARIS
WORKFLOW DEVELOPMENT, IMPLEMENTATION
AND DEPLOYMENT

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# PROJECT OVERVIEW

## Timeline
- Project start date: Oct. 2020
- Project End date: Sep. 2023
- Percent complete: 20%

## Barriers
- High uncertainty in technology deployment, functionality, usage, impact at system level
- Computational models, design and simulation methodologies
- Quantifying the impact of new mobility trends requires not only a deep understanding of the new technologies but also how these will influence vehicle usage, energy consumption and cost

## Budget
- FY21-FY23 Funding: $14,460,000
- FY21 Funding Received: $5,280,000

## Partners
- Argonne (Lead), ORNL, LBNL, NREL
- Universities of New South Wales, Illinois-Chicago, Washington, George Mason, Texas-Austin, Georgia Tech, California-Irvine, Michigan State, Gustave Eiffel
- Ford, GM, Microsoft, City Tech
Why is Transportation System Simulation Critical?

- Traveler Behavior
- Passenger Movement
- Goods Movement
- Connectivity
- Vehicle Electrification
- Shared Mobility
- Automation
- Electric Grid
- Charging Infrastructure
- E-Commerce
POLARIS-CENTERED WORKFLOW DEVELOPED TO EXPLORE FUTURE MOBILITY TECHNOLOGY IMPACTS ON TRANSPORTATION (SMART1.0)

Key modeling features:
- Full-featured activity-based model
- Includes freight shipments and local deliveries
- High-fidelity vehicle energy consumption
- Integrated demand, multimodal network assignment and traffic flow
- EV charging and grid integration
- Connection to UrbanSIM land use
- Traveler behavior impacts of VOTT across many choices

Computational performance:
- Fully agent-based
- High-performance C++ codebase
- Large-scale models with 100% of agents
- 4-6 hr runtime for up to 10 million agents
- Cross-platform – Linux/Windows HPC clusters

Core of the DOE Smart Mobility Workflow
### RELEVANCE: SIGNIFICANT CHALLENGES REMAIN IN REFINING AND DEPLOYING THE WORKFLOW

#### Process
- Numerous manual steps
- Lack of robust user interfaces
- Ad-hoc, file-based connections
- Computational barriers and inefficiencies
- Lack of common post-processing tools
- Limited validation, calibration of stand-alone tools
- No calibration for joint process
- Deploy workflow to stakeholders

#### Features
- Vehicle-to-anything (V2X) connectivity
- Vehicle automation
- Infrastructure management
- Transit, TNC, micro-transit optimization, and integration
- Parking and curb management
- Eco-approach/departure/routing
- Freight management and optimization under changing demand environment

#### Studies
- Need to quantify the specific impact of individual modes, technologies and management strategies (e.g., connectivity, new modes, freight, electrification, land use...) and how they collectively affect the transportation system.
- Need to quantify the uncertainty impact of numerous technology disruptions and behavioral changes on the transportation energy, mobility, emission and productivity.
OBJECTIVES: IMPROVE WORKFLOW PROCESS, ADD FEATURES, QUANTIFY IMPACTS AND DEPLOY TO STAKEHOLDERS

**Workflow Improvements & Deployment**
- Improve computational performance
- Automate connections
- Deploy on HPC and Cloud
- Enhance post-processing
- End-user deployment

**Studies and Analyses**
- Develop common integrated scenarios
- System control opportunities
- Freight technology and distribution trends
- EV charging and grid impacts
- Field testing and related studies
- Impact of traveler behavior and induced demand
- Transit operations and integration with new modes

**New Features**
- Traffic flow, connectivity and control
- Expanded multi-modal options and integration
- New behaviors, long-term decisions
- Freight and logistics behaviors and strategies
- Expanded EV charging, including fleets
- Land-use & transportation integration

**Stakeholder Engagement**
- Identify stakeholders in transportation and energy forecasting
- Identify research gaps and key questions
- Develop relevant scenarios with stakeholder input
- Communicate results
- Identify opportunities for workflow deployment
PROJECT EXPECTED OUTCOMES

**Process**
- Deployed workflow at a large scale to support a large number of stakeholders (both developers and users)
- Enable the simulation of a very large number of scenarios
- Shorten workflow runtime
- Additional capabilities to support new technology evaluations
- Improved results confidence (e.g., model validation, control calibration)

**Features**
- Enhanced workflow capabilities focusing on xIL, connectivity, people and goods movements, PEV charging
- Supports the successful deployment of a significantly improved and expanded SMART workflow at a large scale to support a large number of stakeholders
- Supports internal and external studies

**Studies**
- Provide insights validated through targeted deployment
- Explore individual technologies, management strategies, and other phenomena related to future mobility
- Develop common scenarios and insights with multiple technologies
- Share results and insights with the transportation stakeholder community
SUBSTANTIAL INTERACTION BETWEEN ARGONNE’S WORKFLOW AND OTHER DOE PROJECTS

Clemson FOA (EEMS110)
Analysis-TNC (VAN042)
CERC-LDV

O’Hare Optimization
HPC - Transit (EEMS088)

CERC-Truck
RPI FOA
Cummins FOA (EEMS109)

Drones (EEMS098)

Helics+ (OE project)

Curb Allocation (EEMS100)

RoadRunner (EEMS094)

Micromobility (EEMS097)

Core Tools (EEMS013)

LiveWire (EEMS066)

MEP (EEMS099)

Vehicle Technologies (VAN035)

Collaborator lead
Argonne lead
<table>
<thead>
<tr>
<th>Milestone</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorporate automated calibration routines for limited set of parameters in POLARIS workflow</td>
<td>Stakeholder engagement plan</td>
<td>Deploy POLARIS post-processing routines in workflow and connect to UrbanSim/POLARIS information</td>
<td>Quantify impact of single technology across tools (RoadRunner, AimSum, POLARIS)</td>
<td>Deploy POLARIS workflow in AMBER</td>
</tr>
<tr>
<td>Implement road pricing in traffic model</td>
<td>Complete POLARIS comparison and validation with ground-truth GPRA baseline data for all 4 cities.</td>
<td>Unconstrained micro-mobility operations implemented</td>
<td>Workflow migrated to HPC</td>
<td>Incorporate V2I/connectivity capabilities</td>
</tr>
<tr>
<td>Updated VOTT model for CAV</td>
<td>Active demand control through V2I and V2V connectivity</td>
<td>Autonomie ML vehicle energy consumption models for different vehicle classes including MD/HD</td>
<td>Improve MEP computational efficiency</td>
<td>Implementation of heuristic ride-hailing strategies</td>
</tr>
<tr>
<td>Freight population model implemented</td>
<td>Explore impact of VOTT from connectivity and automation</td>
<td>Stand-alone MDT tour formation model implemented and connected to workflow</td>
<td>Supply chain and freight agent partnership models developed</td>
<td>Improve mode choice model with micro-mobility options</td>
</tr>
<tr>
<td></td>
<td>Urban freight impacts of off-hours delivery</td>
<td>LD EVSE location optimizer in workflow and development of MD/HD and TNC charging</td>
<td>Run scenarios for GPRA cities</td>
<td>UrbanSim-POLARIS population coupling</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Optimization scenarios for transit agencies in Chicago</td>
<td>Supply chain and freight agent partnership models developed</td>
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<td></td>
<td>Study on impact of new modes on mode choice behavior</td>
<td>Run scenarios for GPRA cities</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Initial estimation of regional drone e-commerce delivery</td>
<td>Explore impact of VOTT from connectivity and automation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Impact of new mode choices and VOTT on land use changes</td>
<td>Urban freight impacts of off-hours delivery</td>
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</tbody>
</table>

**Q1:** Stakeholder engagement plan

**Q2:** Complete POLARIS comparison and validation with ground-truth GPRA baseline data for all 4 cities.

**Q3:** Deploy POLARIS post-processing routines in workflow and connect to UrbanSim/POLARIS information.

**Q4:** Quantify impact of single technology across tools (RoadRunner, AimSum, POLARIS).
APPROACH
IMPROVE, AUTOMATE AND DEPLOY THE POLARIS-CENTERED WORKFLOW

**Improve Existing Linkages**
- UrbanSim
- MEP

**Automate Existing Model Linkages**
- POLARIS
- SVTRIP
- AUTONOMIC
- EVI-Pro

**Automate Existing Process**
- New Model Development
- Model Validation
- Post-processing / Visualization

**Deploy to Stakeholders**
- #1 – Desktop
  - ANWIN
  - POLARIS
- #2 – HPC
  - Microsoft Azure
  - POLARIS
- #3 – Surrogate Models
  - EMEWS
  - POLARIS

Results
DEVELOP NEW FEATURES TO SUPPORT STUDIES
Data driven approach in collaboration with partners and stakeholders

<table>
<thead>
<tr>
<th>Behavior</th>
<th>Multimodal</th>
<th>Freight</th>
</tr>
</thead>
</table>
| • Ride hailing and micro mobility choice  
• Ride hailing driver behavior  
• VOTT impacts on choices  
• Parking choice  
• MaaS adoption and vehicle disposal  
• Joint household travel & car pooling | • Transit and ride hailing optimization / coordination  
• Ride hailing and car sharing options (corner-to-corner, commuting..)  
• Micro-mobility operations and transit integration | • Extend supply chain and agents partnerships  
• Asset choice models  
• E-commerce  
• Last-mile delivery (lockers, drones, hubs)  
• ML parcel truck touring model… |

<table>
<thead>
<tr>
<th>EV Charging &amp; Grid</th>
<th>Traffic and Connectivity</th>
<th>Land use</th>
</tr>
</thead>
</table>
| • TNC and MDT/HDT  
• Machine learning (ML) vehicle energy consumption across classes  
• EVSE location using optimization (grid and space constraints) | • Pick up/drop off and curb management impact on traffic flow  
• Multi-class flow meso models  
• Connectivity and information flow; sensing  
• Signal optimization, prioritization & EAD  
• Road/congestion pricing; eco-routing | • Parking supply / pricing / management  
• Curb space operations  
• Tight coupling with POLARIS population  
• Impact of transportation on land use evolution |
ANALYZE TRANSPORTATION TECHNOLOGIES IMPACTS

Quantify individual impacts as well as synergies

Evolving Transportation Supply
- System & Fleet Controls

Evolving Demand & Behavior
- Charging Network
- Sharing
- Land Use

System Interactions
- Vehicles in Motion & at the Curb
- Electric Grid
- UrbanSim
- ALEAF

Validation
- Scenario Runs
- Mobility, Energy, Productivity, GHG and Economic Impacts

SVTRIP
- AUTONOMIE
- GREET
- MEP

ALEAF
- Example of Technology Application
- Analysis of Impacts

TECHNICAL ACCOMPLISHMENTS AND PROGRESS
POLARIS WORKFLOW DEPLOYED ON HPC WITH AUTOMATED CONNECTIONS ENABLES LARGE-SCALE STUDIES

- Workflow was implemented as **manual** connections between a series of different codes; launched at each lab as needed
- **Automating** the connections required substantial changes to each code-base
- Built **job-manager** using Swift-T HPC scripting tool
- **Azure deployment** architecture design being developed

**UrbanSim**
- Triggered by POLARIS completion
- Ingests POLARIS transp. LOS
- Generates new land use, population, employment files

**POLARIS**
- Linux deployment
- Triggered by UrbanSim completion

**aws**
- Triggered by Polaris completion
- Generates MEP measures – send back to Job manager for analysis

**docker**
- Job manager for parallel computing
- Set up initial scenario configuration
- Trigger model calls
Deep Learning

Surrogate Models

Model Exploration

Deep Learning Network

EMEWS Results

https://emews.github.io/

Vector field

• Active Learning
• Design of Experiments
• Response Surface Methodology
• Asynchronous two-step methodologies
• Dynamic Programming

Bayesian Calibration

Z_i = \xi(x_i) + e_i = \rho \eta(x_i, \theta) + \delta(x_i) + e_i \sim N(\phi, \lambda)

MATHEMATICAL FRAMEWORK DEPLOYED FOR LARGE-SCALE MODEL EXPLORATION FOR FAST CALIBRATION AND SIMULATION-BASED OPTIMIZATION
NEW POLARIS POST-PROCESSING ENABLES STREAMLINED ANALYSIS OF LARGE STUDIES

- Deployed Jupyter Notebooks based post-processing tool to analyze POLARIS workflow runs
- Supports multiple study runs comparison – compatible with HPC workflow deployment
- KeplerGL based mapping function for spatial data
- Distributable web-based analysis and reporting for stakeholder access
Prior meso-model limitation: tracked vehicles only as they enter/leave links

Converting meso-scale model to Lagrangian coordinates enables:
- Individual vehicle tracking
- Allows Heterogeneous vehicles on traffic
- Natural method to capture curb impacts, connectivity

Developing communication layer (including vehicle position, sensor models, message passing)

Road pricing model operational in POLARIS including demand and supply aspects

**IMPROVED TRAFFIC FLOW MODEL ENABLES DETAILED V2V AND V2I STUDIES**

Higher fidelity traffic flow with semi-microscopic vehicle following
IMPLEMENTED MICRO-MOBILITY AND FIRST/LAST MILE OPTIONS

Network specification, router and operational models updated

- Implemented two micromobility options
  - **Docked**: A bicycle/scooter, i.e., a micromobility vehicle can only be picked up from a station, and dropped off at a station
  - **Undocked**: A micromobility vehicle can be picked up anywhere if exists, and dropped off anywhere

- Network specification updated to include **micromobility nodes** (docking stations) and micromobility links

- **Routing algorithm** enforces dropping off docked vehicle before boarding transit vehicle or before arriving at ultimate destination

- Each traveler move along an assigned route. Actions include:
  - Walking, biking, driving, waiting, boarding, traveling in a transit vehicle (seated or standing), alighting, being rejected to board, re-routing, picking a micromobility vehicle, dropping a micromobility vehicle
BEHAVIORAL DEMAND MODELS
SUBSTANTIALLY UPDATED

Unique survey data from partners underlies models

Long term mobility choices
• AV adoption, vehicle disposal driven by daily travel outcomes
• Micro-mobility adoption

New modes & mode choice
• Solo vs pooled rideshare
• Impact of AV on pooled adoption
• Incorporation into mode choice module in POLARIS
• E-scooter and bike choice

Impact of CAV on Value of Time
• Analysis of VOTT derived from discrete choice stated-preference survey
• Identify key factors driving VOTT change
• Impact of journey satisfaction, time use and latent characteristics on VOT
PREDICTIVE, AGENT-BASED FREIGHT MODEL FRAMEWORK CAPTURES TRADE AND TRANSPORTATION DECISIONS

High-fidelity representation of fleet decisions, fleet operations, and end-to-end shipment and vehicle movements

1. Supply chain formation (global+US+region)

2. Firm population & asset decisions (US+region)
   - Facility locations
   - Distribution center control
   - Private fleet ownership
   - Diesel
   - Electric
   - H2

3. Transport chain formation (global+US+region)

4. Operational decisions (US+region)
   - Delivery stops
   - Vehicle tours
   - Charging stop
   - Depot
   - 300 mi
FROM GLOBAL SUPPLY CHAINS AND MULTIMODAL US FLOWS TO 24-HOUR SIMULATION OF ALL PASSENGER & COMMERCIAL TRIPS

End-to-end tracking of shipments through omni-channel distribution paths, from production to consumption

UNIQUE FEATURES:

- Multimodal (truck, rail, air, water..)
- Data-driven baseline
- Predictive models for future scenario analysis
- Fleet choice & truck touring models to evaluate future fleet mix and operational patterns
- Integrated freight & passenger activities:
  - Traffic
  - E-commerce
  - (upcoming) Charging/Grid
FIRM SYNTHESIS IMPROVES FREIGHT REPRESENTATION IN AGENT-BASED FREIGHT MODEL

Data-driven simulation of businesses and their locations

The new detailed firm population allows us to study:

- **Baseline and future** business population (future growth from Urbansim)
- **Fleet decisions** and **distribution asset decisions** by firms (predictive models under development)
- **Trade demand (shipments)** between firms (predictive models under development)
- **Shipment & truck movements** both **between firms** and **within firm** (e.g., distribution center → store)
NEW MACHINE LEARNING MODEL ESTIMATES VEHICLE SOC FOR CHARGING DECISIONS

Model estimates BEV energy consumption at the link level

- Machine learning (ML) model developed to predict link-level electricity consumption across all vehicle classes:
  - Light-duty (LD), medium-duty, heavy-duty
- ML model utilizes 46 parameters categorized into:
  - Vehicle specific data (class, eight, rolling resistance...)
  - Traffic specific data (speed, stopped time, length...)
- RMSE of 81 Wh, mean absolute error of 2.3%, at trip level.
- Integration with POLARIS using TensorFlow Lite
- Future work will focus on computational performance improvement and expansion to plug-in HEVs.
NEW API DESIGN ENABLES THIRD PARTY CODE EVALUATION/EXECUTION IN POLARIS

- External code directly interacts with POLARIS seamlessly
- Interface through .DLL so POLARIS is agnostic to any new code (i.e., POLARIS is not “aware” of the code itself in the DLL)
- Facilitates algorithm evaluation, especially for external users
- Currently developing and testing the following modules:
  - Ride hailing strategies for assignment, EV charging, station placement, repositioning
  - Traffic signal control
  - Connected vehicles
  - Road pricing
- Partners feedback for improving API interface ongoing with:
  - Georgia Tech, UCI, UT
- Initial deployment with Ford in Corktown area model for signal controllers
NEW CAPABILITIES SUMMARY

Workflow Process
- Deployed to ANL HPC resources
- Initial testing of automated connections between components
- Implemented and tested large-scale calibration and simulation-based optimization capabilities
- Jupyter Notebooks based post-processing tools for large scale study analysis

Behavior
- Ride-hailing and micro mobility mode choice
- VOTT impacts on choices

Multimodal
- Ride hailing
- Micro-mobility operations and transit integration

Traffic and Connectivity
- Multi-class flow meso models
- Connectivity and information flow
- Road/congestion pricing; eco-routing

Freight
- Extend supply chain and agents partnerships
- E-commerce

EV Charging & Grid
- Ride-hailing and MDT/HDT
- ML vehicle energy consumption across classes

Land use
- Tight coupling with POLARIS population
**STAKEHOLDER ENGAGEMENT GUIDED STUDY DESIGN AND IMPLEMENTATION**

Initial stakeholder engagement focused on existing models

<table>
<thead>
<tr>
<th>City</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicago</td>
<td>CACC &amp; VMT, Off-hours delivery, Transit optimization, COVID impact</td>
</tr>
<tr>
<td>Atlanta</td>
<td>Long-haul freight, On-demand shuttles, Rideshare optimization</td>
</tr>
<tr>
<td>Detroit</td>
<td>Traffic signal optimization, Land-use impact, Rideshare optimization, V2I</td>
</tr>
<tr>
<td>Austin</td>
<td>Automated vehicles, Rideshare optimization, Road pricing and tolling, EV charging</td>
</tr>
</tbody>
</table>
QUANTIFIED IMPACT OF VARIOUS ROAD PRICING STRATEGIES

- Road pricing is an important policy lever to control regional congestion
- Pricing scheme and strategy may vary based on regional need
- Austin’s CAMPO region chosen to test toll strategy efficacy
- Toll estimation can be a function of Speed, Travel Time, etc.

Four strategies considered:
- **Baseline**: time-varying toll on existing expressway
- **Fixed** tolls levied as $0.13/km
- **Area-based** tolls – i.e. cordon charge of $8 for entry
- **Congestion pricing** based on speed or delay
## DELAY-BASED ROAD PRICING INCREASES SPEEDS BY 11%, REDUCES ENERGY USE

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Vehicle Miles Traveled (in millions)</th>
<th>Vehicle Hours Traveled (in millions)</th>
<th>Speed (in mph)</th>
<th>Greenhouse Gases (in tons)</th>
<th>Energy Use (in MWhr)</th>
<th>Revenue (in $)</th>
<th>#Auto Trips (in millions)</th>
<th>#Total Trips (in millions)</th>
<th>%SOV Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>42.6</td>
<td>1.63</td>
<td>26.1</td>
<td>372.8</td>
<td>1129.4</td>
<td>$19.91k</td>
<td>4.96</td>
<td>7.01</td>
<td>70.8%</td>
</tr>
<tr>
<td>Congestion pricing</td>
<td>42.9</td>
<td>1.48</td>
<td>29.1</td>
<td>359.1</td>
<td>1087.9</td>
<td>$1.44M</td>
<td>4.88</td>
<td>6.98</td>
<td>69.9%</td>
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<tr>
<td>Flat price</td>
<td>42.2</td>
<td>1.60</td>
<td>26.0</td>
<td>369.9</td>
<td>1120.5</td>
<td>$1.44M</td>
<td>4.89</td>
<td>6.98</td>
<td>70.0%</td>
</tr>
<tr>
<td>Cordon pricing</td>
<td>41.7</td>
<td>1.61</td>
<td>26.2</td>
<td>370.0</td>
<td>1120.7</td>
<td>$348.74k</td>
<td>4.65</td>
<td>6.99</td>
<td>66.5%</td>
</tr>
</tbody>
</table>
MOBILITY METRICS IMPROVE MARGINALLY WITH CACC, BUT REVERSED WHEN VOTT ADDED

- Moderate improvement in vehicle and trip speeds in Chicago area when considering only traffic flow impacts of CACC, but not much change between 40% (high) and 65% (very high) penetration.
- Adding in VOT impact¹ on highways increases travel greatly -> 4.9% to 6.5% miles.
- Causes drastic increase in congestion with 24% increase in travel times.
  - Improved capacity alleviates some of this impact (same VHT for high and v. high).

1. Assumed VOT reduction of 10% for non-mandatory and 55% for mandatory trips based on preliminary survey data.
SHIFTING TO OFF-HOURS DELIVERY (OHD) HAS POTENTIAL TO IMPROVE MOBILITY

OHD Concept: shift delivery times from daytime to overnight *(7 PM-6 AM in this study)*

Motivation: Alleviate congestion, fleet energy and delivery cost (lower travel time of drivers)

Problems:

- Businesses may not have overnight staff to accept OHD
- Noise and emissions from internal combustion (IC) engines -> municipalities often constrain OHD for quality-of-life reasons

Opportunity: Battery electric vehicles (BEV) are quiet and zero-emission (plus trusted vendor programs and/or high-tech secure entry devices are becoming available) -> overcome the problem
### OFF-HOUR DELIVERY RESULTS: LOWER VMT, HIGHER SPEED AND LOWER ENERGY

<table>
<thead>
<tr>
<th>Mode</th>
<th>Scenario</th>
<th>VMT</th>
<th>Speed* (mph)</th>
<th>Fuel (kg)</th>
<th>%Diff (vs. Baseline)</th>
<th>VMT</th>
<th>Speed (mph)</th>
<th>Fuel (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>2,667,914</td>
<td>33.4</td>
<td>870,808</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MDT</td>
<td>Scen. 1</td>
<td>2,612,143</td>
<td>36.3</td>
<td>857,313</td>
<td>-2.1%</td>
<td></td>
<td>8.6%</td>
<td>-3.2%</td>
</tr>
<tr>
<td></td>
<td>Scen. 2</td>
<td>2,620,381</td>
<td>36.0</td>
<td>882,699</td>
<td>-1.8%</td>
<td></td>
<td>7.6%</td>
<td>-2.4%</td>
</tr>
<tr>
<td></td>
<td>Baseline</td>
<td>20,960,043</td>
<td>51.2</td>
<td>10,515,073</td>
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<tr>
<td>HDT</td>
<td>Scen. 1</td>
<td>20,313,124</td>
<td>52.7</td>
<td>10,470,413</td>
<td>-3.1%</td>
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<td>2.8%</td>
<td>-3.8%</td>
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<tr>
<td></td>
<td>Scen. 2</td>
<td>20,356,307</td>
<td>52.5</td>
<td>10,391,911</td>
<td>-2.9%</td>
<td></td>
<td>2.4%</td>
<td>-3.6%</td>
</tr>
</tbody>
</table>

LDT experienced modest improvement in system-wide speed (0.4%) in each scenario.

*System speed computed as \( v = \frac{\text{total miles traveled}}{\text{total hours traveled}} \) by each mode
One major concern is about the **computational efficiency** of using the commercial optimization solvers (e.g., CPLEX, GUROBI).

Expanding the workflow to **leverage HPC** and cloud resources was undertaken to address this concern. Considerable effort was involved in ensuring external optimization code runs in an efficient manner.

...the reviewer **would like to have seen end-users of the workflow** (e.g., MPOs from Chicago, Austin, Detroit) as part of the project team. End-users would be able to better articulate the challenges of deploying some of the modeling contributions of the workflow into the real world.

**Stakeholder engagement plan** has been developed and is being implemented. Scenarios, assumptions and results are regularly discussed with stakeholders. Workflow deployment efforts focused on **providing tools directly to stakeholders**.

The presenter did not mention the performance indicators for the workflow development and results. It would be interesting to know how the team internally assessed performance.

Workflow development and results will be judged through the availability of the workflow on various platforms, deployment to end users and number of studies run using the workflow.
COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS
Active partners through subcontract/consortium/licensing

Workflow Process Improvements

Studies and Analyses

New Features

Studies

Features

Stakeholders

Workflow

Stakeholder Engagement

Microsoft

NREL

Oak Ridge National Laboratory

GEORGE MASON UNIVERSITY

Université Gustave Eiffel

University of California, Irvine

Georgia Tech

Ford

GM

CityTech Collaborativo
Stakeholder engagement

COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS

Workflow Process Improvements

Studies and Analyses

New Features
COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS

Data Providers

- UNSW
- UIC
- TAMU
- SEMCOG
- CMAP
- ArcGIS
- CTA
- Ford
- Moovit
- CDOT
- Divvy
- Asylon
- PepsiCo
- NACFE
- Navistar
- CoStar Group
- Strategic Vision
- Polk
- INRIX
- curbFlow

Agent-Based Transportation System Modeling

Mesoscopic Simulation

Microscopic Traffic Flow

Vehicle Energy Consumption

Multi-Vehicle Control

Metrics (e.g., VMT)

Transfer Behavior

System Control

Goods Movement

EV Charging

Land Use

Vehicle Markets
REMAINING CHALLENGES AND BARRIERS

**Expand Workflow Capabilities**

- Represent vehicle-to-anything (V2X) connectivity
- Vehicle automation impacts
- Infrastructure management (e.g. ITS, traffic signal coordination)
- Transit route/schedule optimization, on-demand and micro-transit, TNC-transit integration
- Parking and curb space management
- Eco-approach/departure/routing and other control strategies
- Freight management and optimization under connectivity, automation
- Deployment and validation of SMART Mobility technologies…

**Expand Workflow Applications**

- What impact will shared mobility, micro-mobility, and multi-modal travel have on transit operations and overall transportation system efficiency?
- How will passenger travel behavior (incl. VOTT), change in response to new technologies?
- How will the ongoing reorganization of consumer goods distribution and new technologies in freight delivery impact regional mobility and productivity?
- How will electrification be implemented and what will be the impact regionally and on building and the grid?...
### PROPOSED FUTURE RESEARCH

#### Workflow Process
- Deploy workflow in AMBER desktop
- Shift workflow from HPC to Azure cloud
- Improve computational performance of key components
- Extend simulation-based model exploration
- Deploy automated calibration for specific cities

#### Behavior
- TNC driver behavior
- Parking choice
- MaaS adoption and vehicle disposal
- Joint household travel & car pooling

#### EV Charging & Grid
- TNC and MDT/HDT
- EVSE location using optimization (grid and space constraints)

#### Multimodal
- Ride hailing and car sharing options (corner-to-corner, commuting..)
- Micro-mobility operations and transit integration

#### Traffic and Connectivity
- Pick up/drop off and curb management impact on traffic flow
- Multi-class flow meso models
- Signal optimization, prioritization & EAD

#### Studies
- Non-recurrent congestion, traffic signal optimization
- Parking and curb management
- Transit optimization and new modes impact
- Drone delivery and e-commerce
- Joint common scenarios for GPRA cities

#### Freight
- Asset choice models
- E-commerce
- Last-mile delivery (lockers, drones, hubs)

#### Land use
- Parking supply / pricing / management
- Curb space operations
- Impact of transportation on land use evolution

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Any proposed future work is subject to change based on funding levels

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SUMMARY

Improved workflow with new features used in stakeholder-led studies

Workflow Improvements & Deployment

• Deployed on HPC at Argonne
• Automated connections between components
• Working with Microsoft on AZURE deployment
• Initial workflow implemented in AMBER
• Expanded post-processing capabilities

Studies and Analyses

• Developed list of key/critical technologies of interest based on lab and stakeholder input
• CACC deployment impacts shows moderate increase in system performance unless changes in VOTT are accounted for
• Small shifts in freight off-hours delivery (5-6%) can improve speeds up to 8% and reduce fuel use by 3%
• Delay-based congestion pricing is optimal road-pricing strategy and can increase system travel speeds up to 10% in Austin study

New Features

• Traffic flow supports V2V, V2I
• Connectivity / communications layer
• Micro-mobility routing and operations
• Long-term mobility choices and impact of VOTT
• Firm synthesis and off-hours delivery
• ML-based vehicle energy consumption model
• API developed for incorporating external optimization and control codes from partners

Stakeholder Engagement

• Identified stakeholders in transportation and energy forecasting
• Identified research gaps and key questions
• Working with multiple MPOs, transportation departments and transit agencies
• Developed initial scenarios (e.g., USDrive)
MOBILITY FOR OPPORTUNITY

FOR MORE INFORMATION
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Argonne National Laboratory
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TECHNICAL BACK-UP SLIDES
KEY POLARIS REFERENCES

- **Integrated modeling and agent-based modeling techniques:**

- **Activity-based modeling and traveler behavior:**

- **Network and traffic flow modeling:**

- **Freight Modeling**

- **TNC / SAV Modeling**
## DESIGNED SCENARIOS TO EXPLORE IMPACT OF CACC AND CONNECTIVITY WITH AND WITHOUT VOTT IMPACT

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scenario Names</th>
<th>2035 Baseline</th>
<th>2035 High Penetration</th>
<th>2035 Very High Penetration</th>
<th>2035 High Penetration - VOTT</th>
<th>2035 Very High Penetration - VOTT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component Technology</td>
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<td>3</td>
<td>4</td>
<td>3</td>
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<td>Land Use</td>
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<td>1</td>
<td>1</td>
<td>0.45 (mandatory) / 0.9 (non-mandatory) - highway travel only</td>
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</tr>
<tr>
<td>Market Penetration</td>
<td></td>
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<tr>
<td>Classes</td>
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<tr>
<td>Passenger</td>
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<tr>
<td>Powertrains</td>
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<td>CACC (%)</td>
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<tr>
<td>Full Automation (%)</td>
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</table>

- CACC: Connected and Adaptive Cruise Control
- VOTT: Vehicle Operating Technology

Additional Information:
- Are we simulating vehicles sales (new) or stock (mix of old and new)? **Stock**
- Is this highway only, or is it for all streets? **Highway only**
- Assume 1.2 second following distance (about ~100 feet @ 55 mph). Same for all manufacturers; all can communicate. Max chain of 12 vehicles.
- Do we want to consider that people with CACC may drive more? **Yes - use UNSW VOTT model**
- Are we including aero reduction? **No aero reduction**

Baseline and Market Penetration:
- Market Penetration: 14%
- Long term baseline: 0.45 (mandatory) / 0.9 (non-mandatory) - highway travel only
# ROAD PRICING STUDY SCENARIO DESIGN

Deployed in Austin, TX region (CAMPO)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
<th>Flat Per Mile Toll</th>
<th>Cordon Pricing (marked by major roads or physical boundaries or CBD)</th>
<th>Congestion Pricing (Simoni et al. [Austin] or Bagheri et al. [NYC])</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
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</tr>
<tr>
<td>Land Use</td>
<td>Baseline</td>
<td>Baseline</td>
<td>Baseline</td>
<td></td>
</tr>
<tr>
<td>Component Technology</td>
<td>Baseline</td>
<td>Baseline</td>
<td>Baseline</td>
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<tr>
<td>Additional accessory load</td>
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<td>Full Automation (V)</td>
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<tr>
<td><strong>VOTF Factor</strong></td>
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<tr>
<td>Classes</td>
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<tr>
<td>Passenger</td>
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<tr>
<td>Market Penetration</td>
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<tr>
<td>Powertrains</td>
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<tr>
<td>CACC</td>
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<td>Full Automation</td>
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<tr>
<td>Tolls</td>
<td>MCPAC only</td>
<td>Per Mile Toll</td>
<td>Area Type - based Cordon Tolls</td>
<td>Congestion Pricing</td>
</tr>
</tbody>
</table>
Based on (1) a behavioral model from the literature (led by Rensselaer Polytechnic Institute), (2) example deployments from other areas, and (3) the research team’s judgment, the following NAICS codes are identified as candidates for OHD (3-digit NAICS codes were used in the willingness-to-accept behavioral model):

- Manufacturing (NAICS 31-33)
- Wholesale trade (NAICS 42)
- Retail trade (NAICS 44-45)
- Hospitals (NAICS 62)
- Arts, entertainment, & recreation (NAICS 71)
- Accommodations & food services (NAICS 72)
- Other services (NAICS 81)
Start times are distributed throughout the day according to the Federal Highway Administration (FHWA) Traffic Data Computation Method: Pocket Guide (2018; Publ. No. FHWA-PL-18-027).

In scenario 1, candidate MDT/HDT OHD trips (based on RWTA) are selected and their start times are shifted from daytime to a random overnight time.

In scenario 2, candidate MDT/HDT OHD trips (based on RWTA) are examined; if the trip’s destination permits OHD, or there is no residence in a 50 meter radius, the trip is shifted to a random overnight time.

Note: this spike occurs because new OHD trips are added to existing overnight trips.