2018 DOE Vehicle Technologies Office Annual Merit Review Presentation

Regional Mobility – Chattanooga

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Oak Ridge National Laboratory

Date: 6/12/2019

Project ID: eems061

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Overview

Timeline

• Project start: Oct 2018
• Project end: Sep 2020
• Percent complete: 25%

Budget

• Total: $4M
• FY19: $2M, ORNL: $1.2M NREL: $800K
• FY20: $2M, ORNL: $1.2M NREL: $800K

Barriers

• Freight and passenger: lack of observability and controllability of the system to reduce energy footprint
• Disparity, lack of openness, and heterogeneity of transportation data from sensors, controls, and probes
• Significant computational complexity for the application of advanced data science and simulation to large systems and data sets.

Partners

• Tennessee Department of Transportation (TDOT)
• City of Chattanooga
Relevance – Project Objectives

• **Key target:** Achieve 20% energy savings at the regional level.
  – Highways, linked arterials and freight present an opportunity at the systems level.
  – Framework to be transferable and applicable to other regions.

• **Near real-time situational awareness:** Create a ‘Digital Twin’ of an entire metropolitan region providing real-time situational awareness for analysis of the entire region
  – Requires data processing at scale across a variety of data sources
  – Demands large scalable computing approaches

• **Near real-time control of traffic infrastructure and vehicles:**
  Digital Twin forms the basis of a cyber physical control system for control of the highway/road infrastructure and connected vehicles in the ecosystem
  – Fast simulation and algorithmic decisions
  – Orchestration of computational resources on High-Performance Computing resources
  – Data science and artificial intelligence/ machine learning approaches
## FY19 Milestones

<table>
<thead>
<tr>
<th>Milestone Name/Description</th>
<th>Criteria</th>
<th>End Date</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Data Plan:</td>
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<tr>
<td>Complete data exchange plan between TDOT, City of Chattanooga, and National Labs</td>
<td>Milestone report documenting the data exchange plan</td>
<td>12/31/2018</td>
<td>Quarterly Progress Measure Complete</td>
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<tr>
<td>2. Baseline Energy Usage:</td>
<td></td>
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<tr>
<td>Complete the development of the baseline measure of energy usage</td>
<td>Milestone report documenting the baseline energy usage in the Chattanooga test bed</td>
<td>3/30/2019</td>
<td>Quarterly Progress Measure Complete</td>
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<tr>
<td>3. Digital Twin:</td>
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<tr>
<td>Complete first digital twin representation of the greater Chattanooga area</td>
<td>Milestone report documenting the capabilities of the digital twin; Stand up software prototype</td>
<td>6/30/2019</td>
<td>Quarterly Progress Measure In progress</td>
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<tr>
<td>4. Modeling Approach:</td>
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<tr>
<td>Complete design of the transportation modeling approach for traffic optimization</td>
<td>Milestone report documenting the approach to traffic optimization</td>
<td>9/30/2019</td>
<td>Annual Milestone</td>
</tr>
<tr>
<td>Milestone Name/Description</td>
<td>Criteria</td>
<td>End Date</td>
<td>Type</td>
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<td>------------------------------------------------------------------------------------------</td>
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<tr>
<td>1. Control Plan:  Develop communication and security protocols for close-looped control of actuated signals in the city</td>
<td>Milestone report documenting the approach</td>
<td>12/31/2019</td>
<td>Quarterly Progress Measure</td>
</tr>
<tr>
<td>2. Modeling and Simulation/AI:  Complete the development of modeling and simulation and AI approaches</td>
<td>Milestone report documenting the M&amp;S and AI efforts</td>
<td>3/30/2020</td>
<td>Quarterly Progress Measure</td>
</tr>
<tr>
<td>3. Control strategy:  Implement initial semi-adaptive signal timing and control approaches</td>
<td>Milestone report documenting the approaches</td>
<td>6/30/2020</td>
<td>Quarterly Progress Measure</td>
</tr>
<tr>
<td>4. Cyber-physical control:  Implement real-time cyber physical control of regional adaptive signals combined with freight</td>
<td>Demonstration and milestone report documenting the outcomes</td>
<td>9/30/2020</td>
<td>Annual Milestone</td>
</tr>
</tbody>
</table>
Technical Approach

- Create multi-institutional collaboration of Transportation Science, Data Science and Simulation Science Researchers to work on ‘digital twin’, enabled by high-performance computing.
- Engage the broader high-performance computing to work on common problems.

‘Digital Twin’ for Regional Mobility, Chattanooga

Situational Awareness from real-time data feeds

Simulation and Modeling, and Machine Learning

Cyber-Physical control actions

- Allows observability at a regional scale
- Identifies and evaluates improvements
  Demonstrates feasibility/anticipated outcomes
- Algorithmically actuates hardware
Technical Approach

Phase 1
Situational Awareness

- Obtain real-time data
- Visualize real-time data
- Quantify baseline energy consumption
- Estimate energy savings for identified corridors
- Develop freight plan

With TDOT and CDOT partners
- Identify how to bridge to operations
- Run the paperwork
- Identify/address security risks

Phase 2
Simulation-based Optimization

- Optimization of Infrastructure for control (e.g. Signals, Freight)
- Simulation/AI driven control.

Demonstrate feasibility

Demonstrate on city infrastructure
- Understand infrastructure needs
- Understand control logic
- Be able to degrade gracefully

Out years

Phase 3
Scale-up to other areas
Operationalize
Connected freight

Phase 4
Light duty commercial;
Partnership;
Transport “App”

Phase 5
Autonomous Vehicles;
Advanced powertrain

Partnership with CDOT, TDOT, County

Data: 112 CCTV cameras
25 existing, 34 planned GridSmart; RDS data every ½ mile, On-street controllers, incident data, etc.

Provides Vehicle counts, types, lane occupancy, air quality, etc.

Geodatabase

Control Selection

Control Actuation

Situational Awareness
HPC: Simulation and ML: Patterns for Regional Mobility

HPC unlocks the power of Simulation and Machine Learning through parallel processing, distributed computing and accelerators.

**Data Science:**
- Faster interactions with larger datasets.
- Greater application of complex analysis pipelines.
- Advanced algorithms that learn quantities of interest from integrating ground truth data and sparse but extensive data.
- Historical and Real-Time

**HPC Simulation and Optimization:**
- Large scale simulation of regional mobility for Chattanooga
- Faster turn around on ensembles of simulations:
  - Larger simulations
  - Exploration,
  - Calibration and Validation,
  - Optimization
  - Learning
  - Scenarios.

HPC: performance improves with more compute nodes. Can solve larger problem in less time.
Chattanooga-Hamilton County-North Georgia TPO

- Study region boundary defined
- 1,037 TAZs for TPO region
- Complete street network with centroid connector notional links to represent within TAZ flows
- Origin-destination TAZ vehicle flow averages (at AM peak, PM peak, and off-peak times) for 2014 and projected for 2045 (passenger, single-unit, and multi-unit trucks)

<table>
<thead>
<tr>
<th>Data</th>
<th>Acquired</th>
<th>Requested</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road network</td>
<td>Yes</td>
<td>No</td>
<td>TPO, Navteq</td>
</tr>
<tr>
<td>Historic traffic flows</td>
<td>No</td>
<td>Yes (GDOT)</td>
<td>TDOT, GDOT</td>
</tr>
<tr>
<td>Historic radar data</td>
<td>Yes</td>
<td>Yes (GDOT)</td>
<td>TDOT, GDOT</td>
</tr>
<tr>
<td>Incident Data</td>
<td>Yes</td>
<td>Yes (GDOT)</td>
<td>TITAN, GDOT</td>
</tr>
<tr>
<td>Origin-Destination Data</td>
<td>Yes</td>
<td>No</td>
<td>TPO</td>
</tr>
</tbody>
</table>
Technical accomplishments/progress

• **Data from partner stakeholders is key**

• **Data partners:** City of Chattanooga, Tennessee Department of Transportation, Multiple other agencies: MPO, GA-DOT, Titan, INRIX, TomTom, HERE, ATRI, etc.

• **Reference/dynamic data:** characteristics of infrastructure/ data collected by sensors

• **Significant complexity in variety and nuances of the data, and in the systems that serve the data**

City of Chattanooga
- NDA executed; VPN setup
- Reference data, signal info received
- Real-time access to GridSmart cameras working (28 + 100 planned)
- Working on real-time access to SPaT

TDOT
- **Radar Detector Sensors**
  - Located every ½ mile on average
  - Receiving daily 2GB file once a day
  - 30s data from RDS sensors
  - Lane occupancy, speed, classification
- **Weather sensors – offline**
- **TDOT development effort for real-time**
Regional Data from Hamilton County, and other sources

From Hamilton County
- Road network (multiple versions)
  - TAZ/NavTeq
  - Augmented with data from other versions
- Traffic light locations and schedule
- Historic traffic counts

Requested:
- GridSmart Camera access
  - Live traffic volumes, vehicle class, ...
  - (Video feed)
- Sensys, BlueToad
- Origin/Destination Pairs
- Probe data – WAZE access granted
- Discussions with Tom-Tom and INRICS
- Freight data
  - Data issues observed in automated classification from TDOT sensors
  - ATRI data being obtained
- Incident data
  - Lag in availability
  - Multiple systems – TITAN, GEARS, DPS, WAZE – duplication and consistency issues
- NPMRDS data access available
  - Not real-time; only bulk downloads possible

Priority data sources: RDS sensors along highways, GridSmart cameras at intersections, SPaT controllers for signals, Freight data from ATRI, Probe data from WAZE, and incidents
Metrics – Establishing a baseline

- Metrics are measures of performance of the transportation system
  - Mobility – macroscopic and microscopic traffic flow dynamics
    - Demand flow – vehicle miles traveled by passenger and freight
    - Congestion – level of service (volume/capacity ratio), vehicle hours of delay, average speed
    - Variation & Reliability – average travel time, planning time index, buffer index and travel time reliability index
    - Vehicle queues - 95th Percentile queue length is the typical measure
    - Controlled delays from signalized intersections
  - Safety – damages and fatalities form traffic incidents
    - Segment level - Fatalities per VMT, Serious injuries per VMT
    - Intersection level – crashes per 100,000 vehicles
  - Energy – system and vehicular level energy usage and consumption patterns
    - RouteE – Route Energy estimation over a particular link or series of links
    - On-road vehicle fuel consumption = VMT*1/MPG
  - Mobility & Energy Productivity (MEP) – holistic measure of quality of mobility and energy
    - MEP Metric = F (mobility weighted by [energy, cost, trip purpose])

Source: Travel Time Index Measures from Sample Travel Time Frequency Distribution (FHWA 2016)
Source: Time-Space Reliability of Travel Time, Highway Capacity Manual 2017
Freight Mobility : Current State

• Major Bottleneck Locations
  – SR-317 from 0 to 4.8 mile post in TDOT Region-2
  – I-24 between US-27 & I-75
  – SR-153 between SR-319 (Dupont Pkwy) and SR-319 (Amnicola Hwy)

• Criterion
  – LOS-F and segment truck volume > 5,000 per day
  – Daily average truck speed of < 45mph
  – Hamilton County ranked 4th in state in truck crashes

• Data Sources
  – American Transportation Research Institute
    • GPS data of truck routes along with speed, data/time stamp and truck number.
  – SmartWay, RDS, TITAN
    • Identify truck volumes at major corridors and traffic incidents
  – NPMRDS
    • Freight Performance Metrics, E.g. Truck Travel Time Reliability

Average Truck Speeds, ATRI 2013
Freight Mobility: Data Science Application

- Historic freight truck GPS data
  - Understand routing behavior under normal and congested conditions
  - Aggregate the GPS data to derive OD matrices

- Real-time truck flows
  - Data from sensors e.g. RDS, SmartWay cameras, and GridSmart
  - Use machine learning workflows to derive near real-time truck flows from cameras

- Control Strategies Evaluation in Simulation
  - Dynamic route diversions under traffic incidents
  - Dynamic pricing, e.g. peak-hour congestion, roadway pricing by facility type
RDS Highway Data: Shallowford Road Corridor

- RDS sensors  (November 2018 to March 2019)
- Gridsmart cameras
- Interstate on/off ramps
- TDOT SmartWay Traffic cameras

Using the You-Only-Look-Once (YOLO) deep image processing network to identify cars and trucks from low-resolution traffic cameras

Analyze long-term RDS data to identify patterns in the traffic flow near Shallowford Road and the shopping center.

Northbound:
Noticeable speed-up and reduction of congestion north of Shallowford Road (detector 1419)

Southbound:
Significant influence of vehicles entering the interstate from shopping mall during evening peak
- Increases congestion and slows traffic

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RDS sensors
Gridsmart cameras
Interstate on/off ramps
TDOT SmartWay Traffic cameras
Simulation: Looking at Signal Impact on Energy, Freight

Passenger Vehicles  Freight: Trucks

Actuated Signals showed decrease in energy consumption vs Static Phase Signals
Candidate Corridor for Cyber-Physical Control

**Shallowford Road Arterial with ramps to Interstate** identified for analysis and optimization based on data availability and priority discussion with City of Chattanooga, TN

- Opportunity to study impact of control measures
- GridSmart Cameras
- Signalized Intersections with timing information
- Radar Detection Systems from highways
- Traffic Incidents for year 2018

Digital Twin

- Sends signals to CDOT systems via VPN tunnel

Coordinated set of signals change along a corridor

Data is collected and compared against baseline metrics

<table>
<thead>
<tr>
<th>Temporal scope: frequency of adjusting signal settings</th>
<th>Signal settings optimization - standard techniques</th>
<th>Performance-based optimization</th>
<th>Near real-time optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-15 minutes</td>
<td>Yes</td>
<td>No</td>
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</tr>
<tr>
<td>Hourly</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>Time-of-day</td>
<td>Yes</td>
<td>Flexible</td>
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<tr>
<td>Daily</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Weekly</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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Collaboration and Coordination

• Coordinating with Lawrence Berkeley National Laboratory, Pacific Northwest National Laboratory, Argonne National Laboratory

• Planning on HPC for Transportation Science meeting in June at National Renewable Energy Laboratory

• Continued close engagement with partners:
  – City of Chattanooga
  – Tennessee Department of Transportation
  – Expanding to other agencies as needed
Remaining Challenges and Barriers

- **Data access and ingestion continues to be challenging**
  - Primarily because of proprietary systems
  - Data partners extremely forthcoming
- **Freight data availability is an issue**
  - Data science techniques employed
- **For cyber-physical control:**
  - Manual control of signals is understood
  - Software control isn’t well understood yet
  - Graceful degradation on faults must to be understood and implemented
Future Work

- Data Science, simulation, and control for freight
- Regional scale mobility optimization – passenger and freight
- Completion of the situational awareness piece
- Engagement with connected fleets and freight companies
  - Leverage FedEx, Amazon, and other connections
- Develop communication and security protocols for close-looped control of actuated signals in the city
- Implement real-time cyber physical control of regional adaptive signals combined with freight and measure impact

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

• **Key target:** Achieve 20% energy savings at the regional level.
  – Highways, linked arterials and freight present an opportunity at the systems level.
  – Framework to be transferable and applicable to other regions.

• **Near real-time situational awareness:** Create a ‘Digital Twin’ of an entire metropolitan region providing real-time situational awareness
  – Massive variety of data sources
  – Data science approach to optimize freight and regional mobility

• **Near real-time control of traffic infrastructure and vehicles:** Digital Twin forms the basis of a cyber physical control system for control of the highway/road infrastructure and connected vehicles in the ecosystem
  – Fast simulation and algorithmic decisions
  – High-Performance Computing for simulation and modeling
  – Data science and artificial intelligence/machine learning approaches
Backup slides
Calibrated Volume Estimates

Volume estimates are essential for informing high-quality metric measurements, including energy.

Disparate data characteristics: spatial resolution and extent, frequency and extent in time, lessor or fuller sampling of reality at a specific location and times.

Using machine learning to fuse probe data with local infrastructure give a powerful tool for creating volume estimates.

The techniques go beyond validating estimates against ground truth but utilize the fuller sampling techniques from infrastructure along with anonymized probe data to make estimates of volume.

1. Gather 24-hour short-term count traffic volume data from TDOT.
2. Gather TomTom network, speed, and probe count data using TomTom API.
3. Gather hourly weather information from The Weather Company.
4. Matched the TomTom network segment locations with the TDOT traffic volume count station locations and fused the TomTom data and weather information with the TDOT traffic volume data.
5. Conduct analysis for feature selection. AADT, probe count, road class, hour of the day, and temperature are the most relevant features that impact the traffic volume.
Focused HPC Simulation of Chattanooga

Simulation Challenges:
- Data Availability
- Network Construction
- Signal configuration
- Demand Construction
- Calibration and Validation

HPC Computational Challenges:
- Lee HWY: 2 hours for a 24 hour Simulation
- Regional area: predict 24 hour to simulate 24 hour traffic
- Need thousands simulations for optimization – can take months
- 10’s of GB of data for high fidelity data: 30 GB for Emissions.
- Hours to process output data
- Approx. 16.5 TB per scenario
Presentations and Publications

- Invited presentation at Smoky Mountains Mobility Conference, 4 Oct, 2018, Chattanooga, TN
- Invited presentation at TennSMART Meeting, 9 April, 2019, Nashville, TN
- Computational Transportation Workshop accepted at ACM SIGSPATIAL

Publications:
- Title: Transportation Systems Analysis and Visualization: A Multi-Scale and Multi-Variate Approach to Shopping Districts
  Conference: Visualization in Transportation (TRB), November 5-6 Washington DC
  Authors: Anne Berres, Srinath Ravulaparthy, Wesley Jones, Jibonananda Sanyal
  Status: Submitted
- Title: Multi-Scale and Multi-Variate Transportation Systems Analysis and Visualization at Regional Scale
  Journal: Transportation Research Record (TRR)
  Authors: Anne Berres, Srinath Ravulaparthy, Juliette Ugitumurera, Sarah Tenille, Wesley Jones, Jibonananda Sanyal
  Status: In planning