2018 DOE Vehicle Technologies Office Annual Merit Review Presentation

Regional Mobility – Chattanooga

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Date: 6/12/2019

Project ID: eems061

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

Milestone Name/Description	Criteria	End Date	Type
1. Data Plan: **Complete data exchange plan between TDOT, City of Chattanooga, and National Labs**	Milestone report documenting the data exchange plan	12/31/2018	Quarterly Progress Measure **Complete**
2. Baseline Energy Usage: **Complete the development of the baseline measure of energy usage**	Milestone report documenting the baseline energy usage in the Chattanooga test bed	3/30/2019	Quarterly Progress Measure **Complete**
3. Digital Twin: **Complete first digital twin representation of the greater Chattanooga area**	Milestone report documenting the capabilities of the digital twin; Stand up software prototype	6/30/2019	Quarterly Progress Measure **In progress**
4. Modeling Approach: **Complete design of the transportation modeling approach for traffic optimization**	Milestone report documenting the approach to traffic optimization	9/30/2019	Annual Milestone

FY20 Milestones

Milestone Name/Description	Criteria	End Date	Type
1. Control Plan: **Develop communication and security protocols for close-looped control of actuated signals in the city**	Milestone report documenting the approach	12/31/2019	Quarterly Progress Measure
2. Modeling and Simulation/AI: **Complete the development of modeling and simulation and AI approaches**	Milestone report documenting the M&S and AI efforts	3/30/2020	Quarterly Progress Measure
3. Control strategy: **Implement initial semi-adaptive signal timing and control approaches**	Milestone report documenting the approaches	6/30/2020	Quarterly Progress Measure
4. Cyber-physical control: **Implement real-time cyber physical control of regional adaptive signals combined with freight**	Demonstration and milestone report documenting the outcomes	9/30/2020	Annual Milestone

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

+

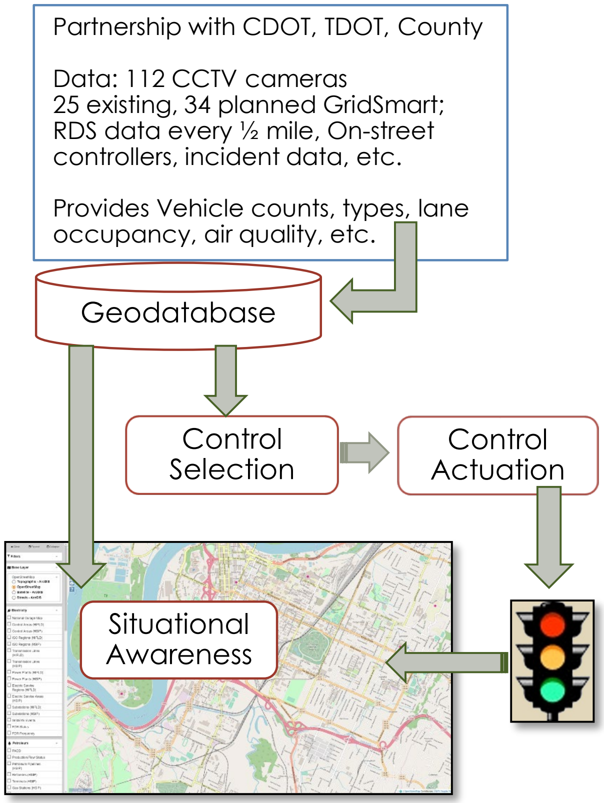
Cyber-Physical control actions

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

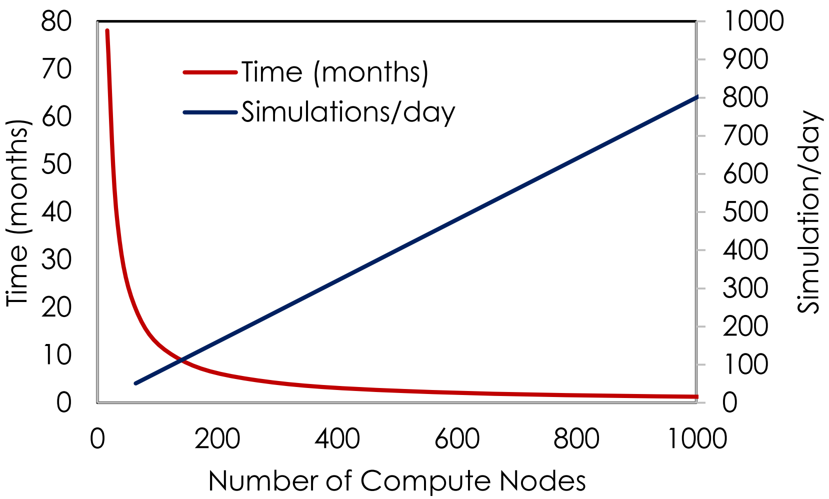
HPC: Simulation and ML: Patterns for Regional Mobility

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

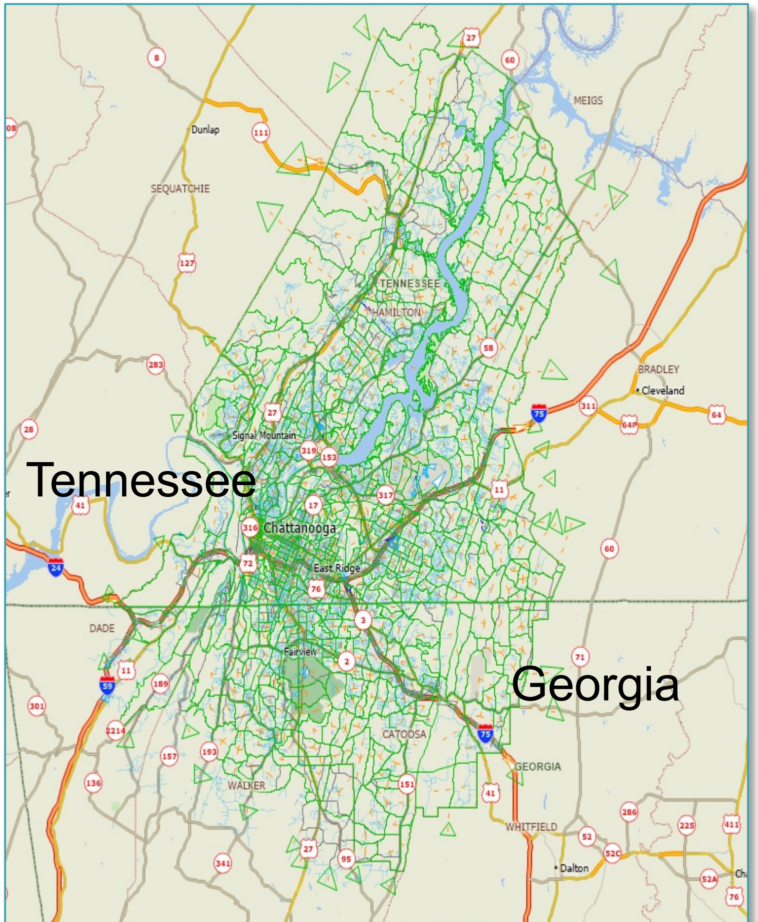
HPC Simulation and Optimization:
- Large scale simulation of regional mobility for Chattanooga
- Faster turn around on ensembles of simulations:
  - Larger simulations
  - Exploration,
  - Calibration and Validation,
  - Optimization
  - Learning
  - Scenarios.

Eagle Supercomputer at NREL



HPC: performance improves with more compute nodes. Can solver larger problem in less time.

Chattanooga-Hamilton County-North Georgia TPO

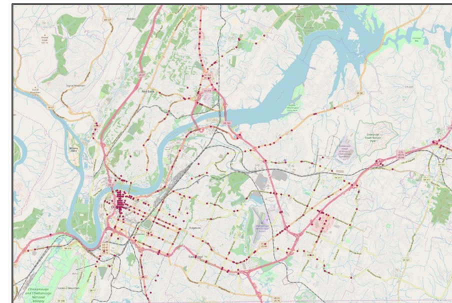


- Study region boundary defined
- 1,037 TAZs for TPO region
- Complete street network with centroid connector notional links to represent within TAZ flows
- Origin-destination TAZ vehicle flow averages (at AM peak, PM peak, and off-peak times) for 2014 and projected for 2045 (passenger, single-unit,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

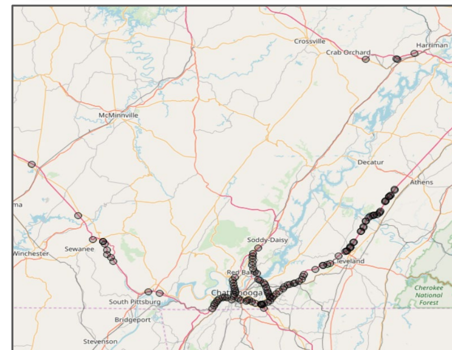
Data	Acquired	Requested	Source
Road network	Yes	No	TPO, Navteq
Historic traffic flows	No	Yes (GDOT)	TDOT, GDOT
Historic radar data	Yes	Yes (GDOT)	TDOT, GDOT
Incident Data	Yes	Yes (GDOT)	TITAN, GDOT
Origin-Destination Data	Yes	No	TPO

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



Map of Chattanooga illustrating the locations of the traffic signals.



RDS locations in the region

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

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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:

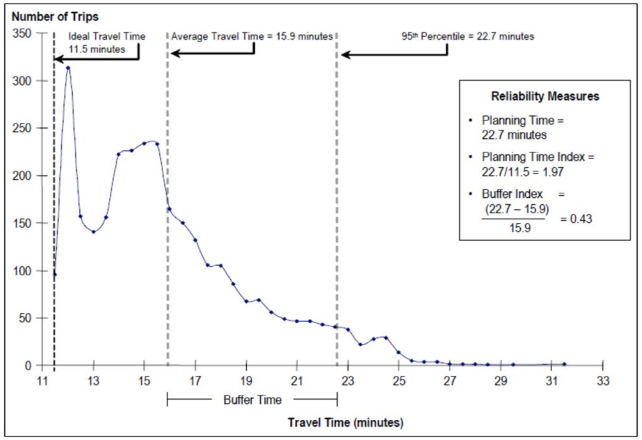
- GridSmart Camera access
  - Live traffic volumes, vehicle class, …
  - (Video feed)
- Sensys, BlueToad
- Origin/Destination Pairs

- 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

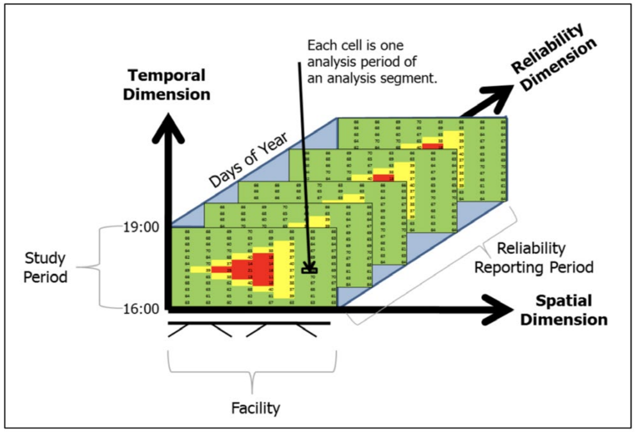
Priority data sources: RDS sensors along highways, GridSmart cameras at intersections, SPaT controllers for signals, Freight data from ATRI, Probe data from WAZE, and incidents

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])



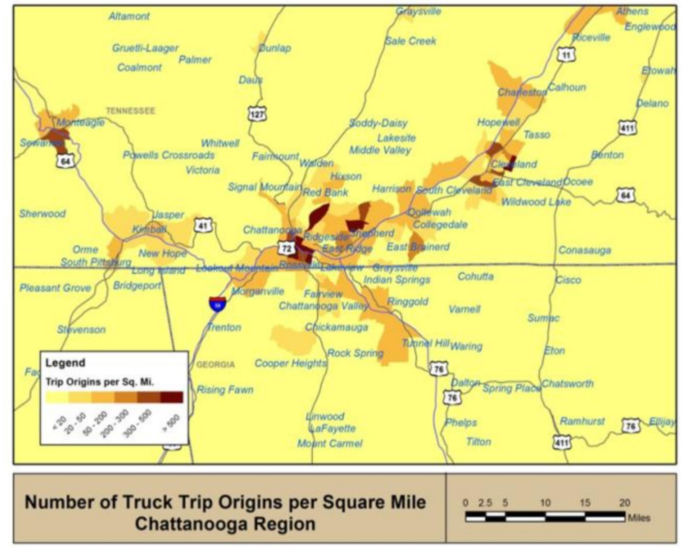
Source: Travel Time Index Measures from Sample Travel Time Frequency Distribution (FHWA 2016)



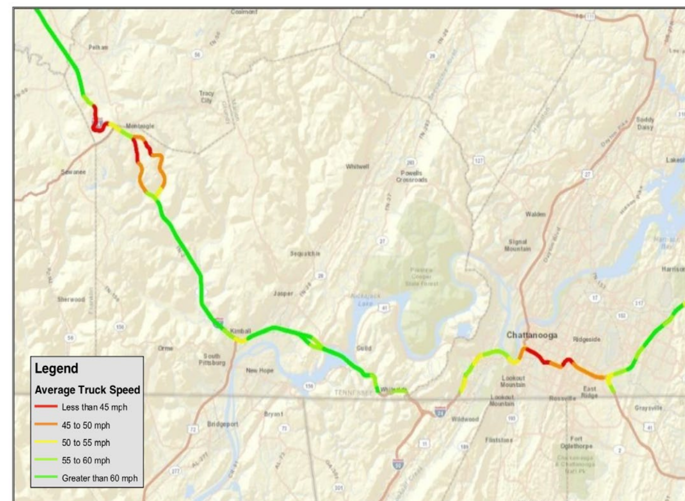
Source: Time-Space Reliability of Travel Time, Highway Capacity Manual 2017

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



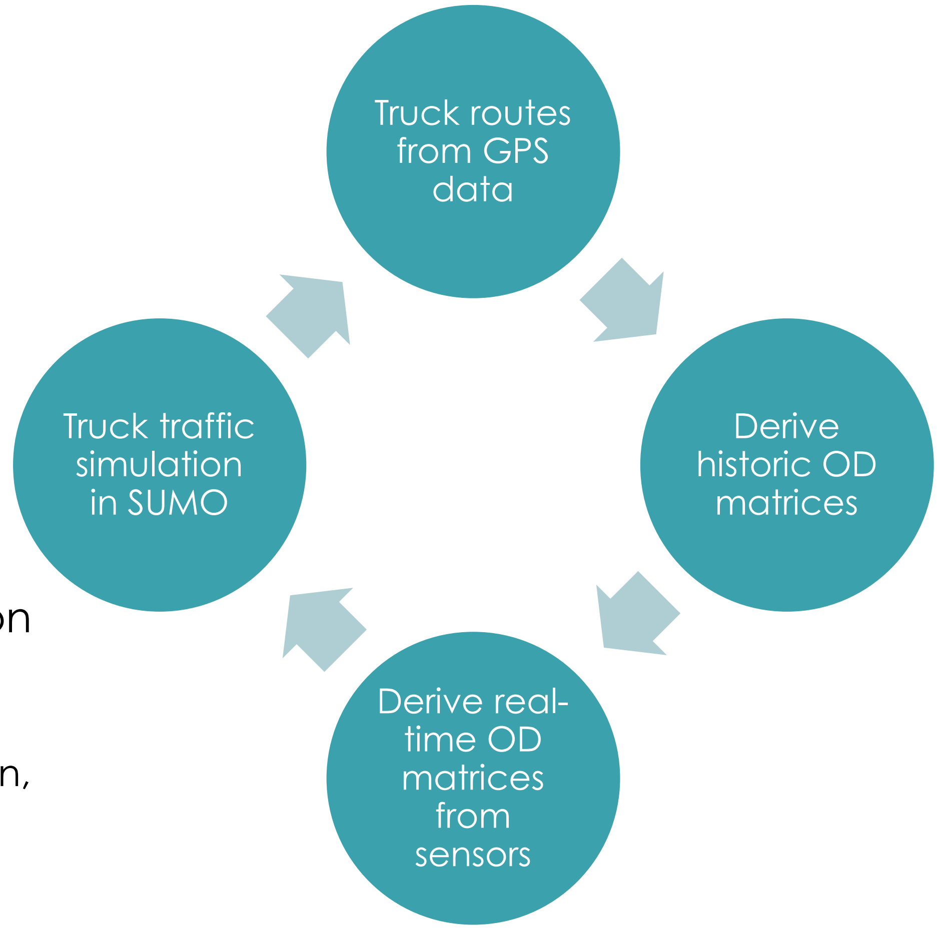
Number of Truck Trip Origins per Square Mile
Chattanooga Region



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



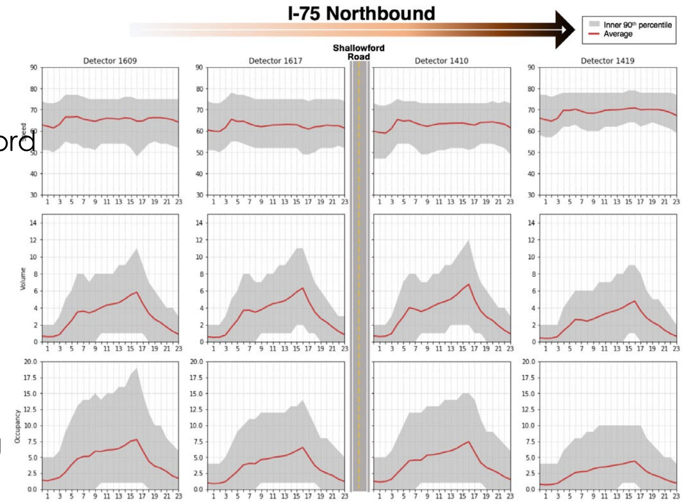
RDS Highway Data: Shallowford Road Corridor

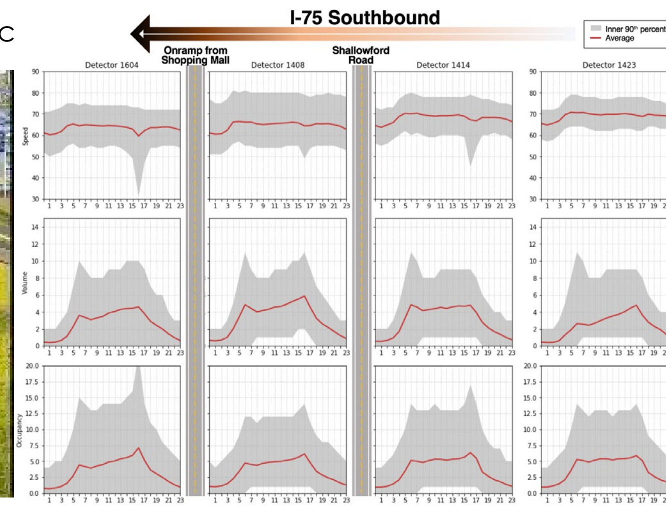
RDS sensors (November 2018 to March 2019)
Gridsmart cameras
Interstate on/off ramps
TDOT SmartWay Traffic cameras

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

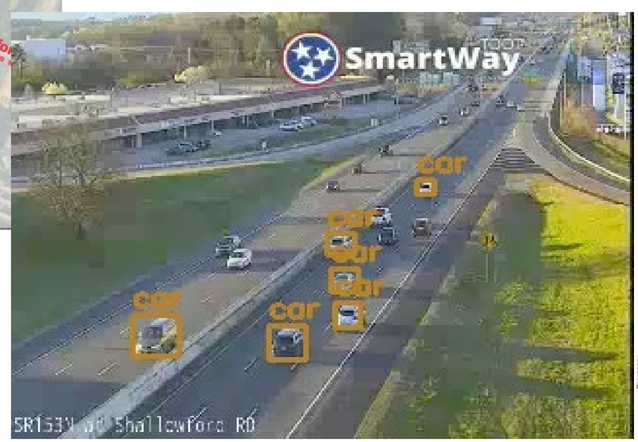
Northbound:
Noticeable speed-up and reduction of congestion north of Shallowford Road (detector 1419)

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

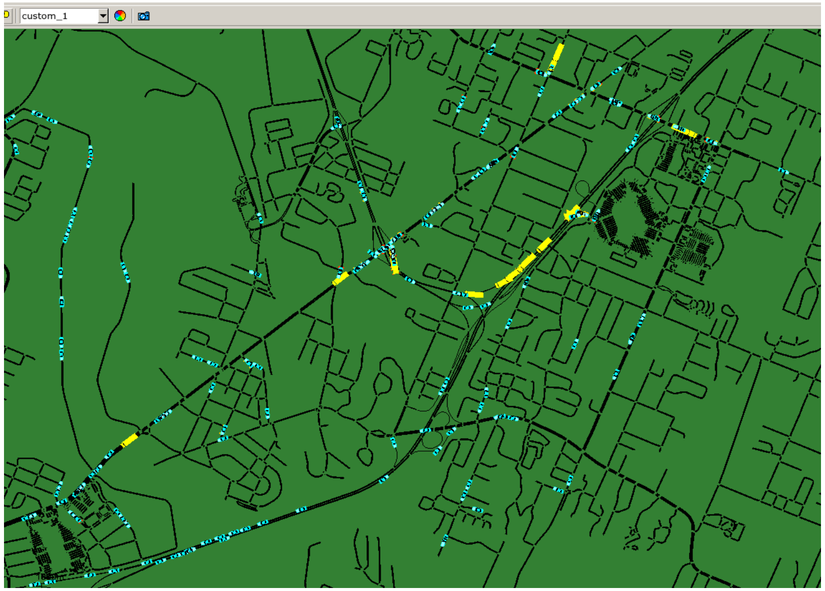




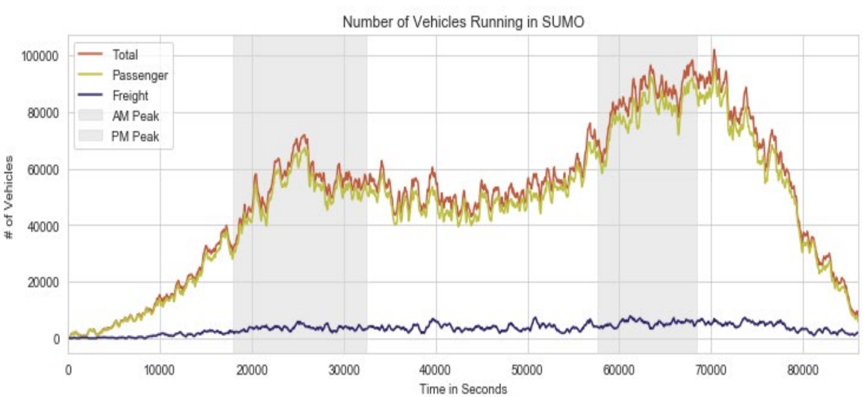
Using the You-Only-Look-Once (YOLO) deep image processing network to identify cars and trucks from low-resolution traffic cameras

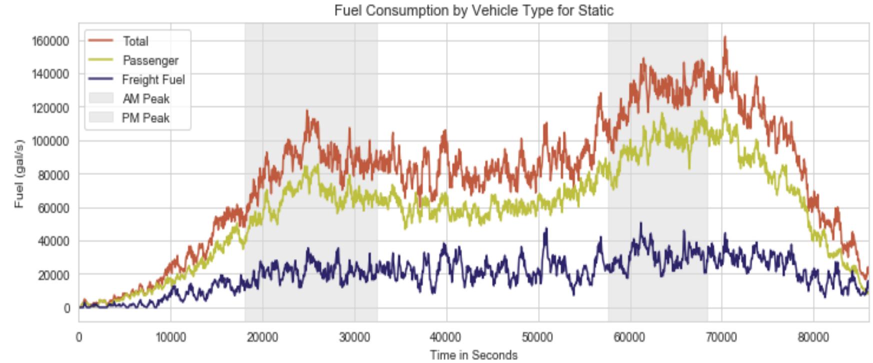


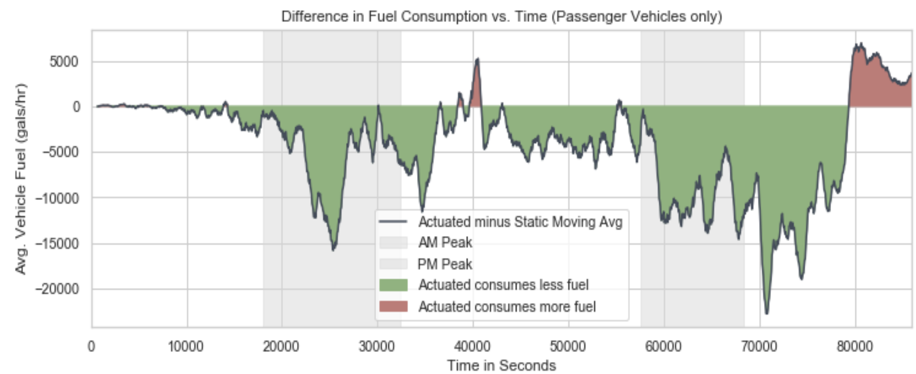
Simulation: Looking at Signal Impact on Energy, Freight

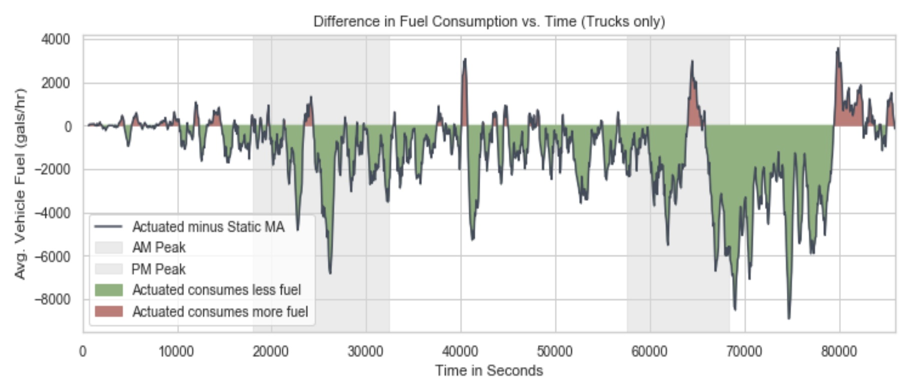


Passenger Vehicles   Freight: Trucks









Actuated Signals showed decrease in energy consumption vs Static Phase Signals

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Candidate Corridor for Cyber-Physical Control

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

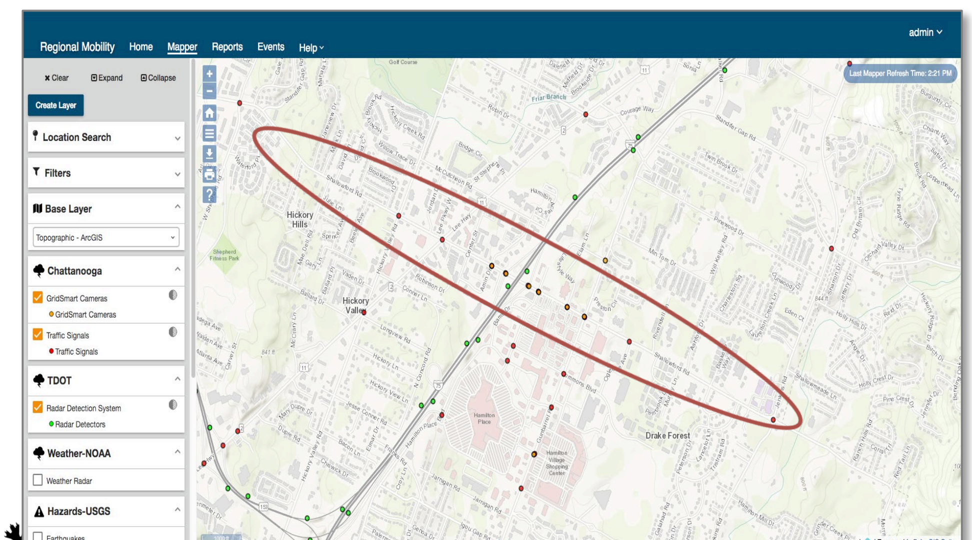
- Opportunity to study impact of control measures
- GridSmart Cameras
- Signalized Intersections with timing information
- Radar Detection Systems from highways
- Traffic Incidents for year 2018

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



Temporal scope: frequency of adjusting signal settings	Signal settings optimization -standard techniques	Performance-based optimization	Near real-time optimization
5-15 minutes	Yes	No	Yes
Hourly	Yes	No	Yes
Time-of-day	Yes	Flexible	No
Daily	Yes	Yes	No
Weekly	Yes	Yes	No

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

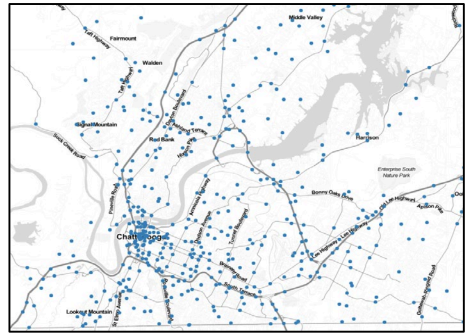
Calibrated Volume Estimates

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

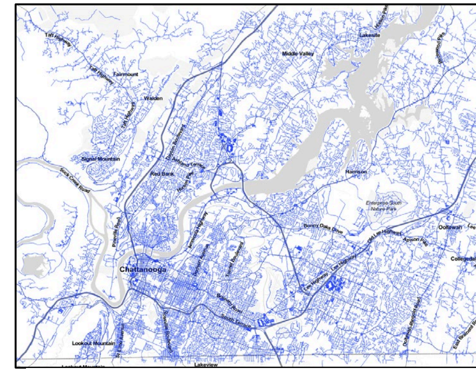
Using machine learning to fuse probe data with local infrastructure give a powerful tool for creating volume estimates.

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

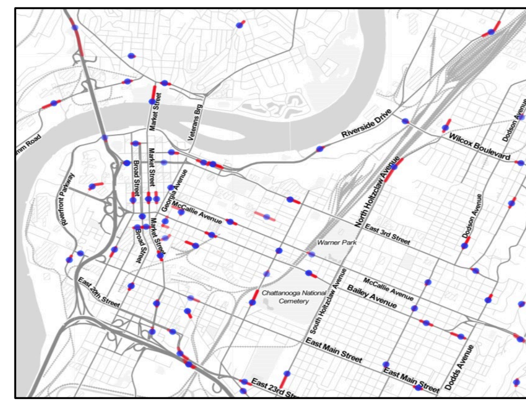


Step 1: Volume count stations.

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.

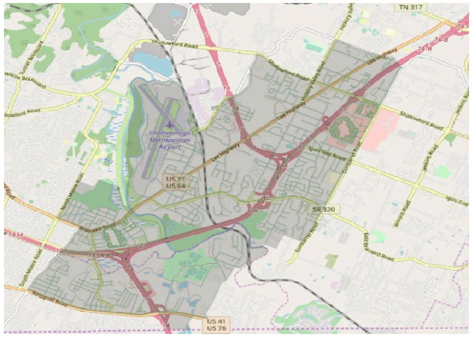


Step 2 TomTom network.



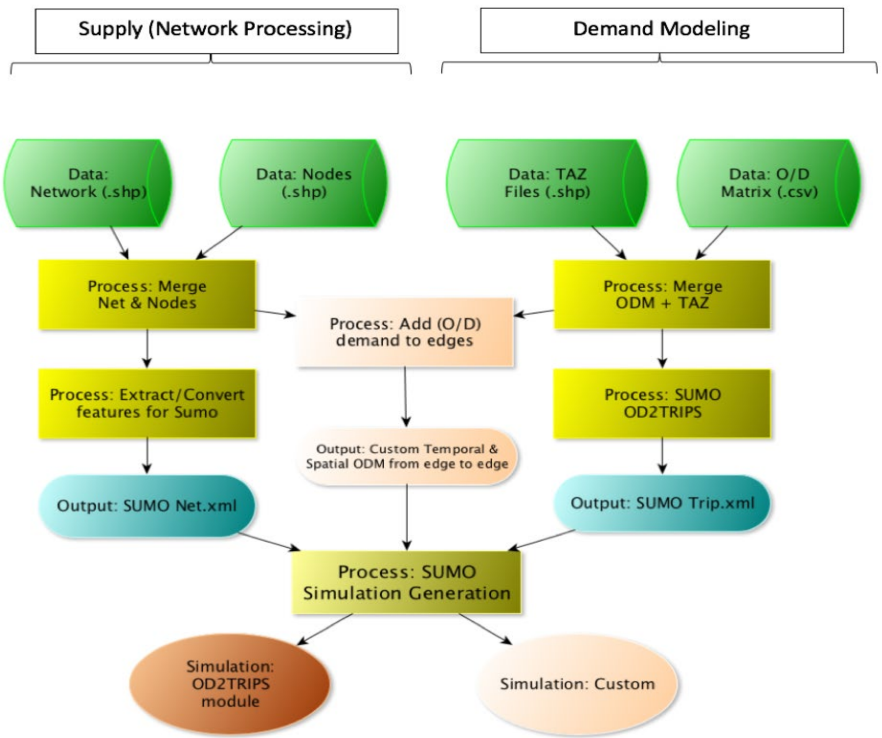
Step 4 Matched TomTom segments.

Focused HPC Simulation of Chattanooga



Lee HWY: Area of Study in Dark in Shapefile Format

Showing TAZ's overlaid on area of study



Data Pipeline and workflow into SUMO Simulator

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 Ugirumurera, Sarah Tenille, Wesley Jones, Jibonananda Sanyal
    Status: In planning