

Scaling up the Realtime Data, Simulation and Artificial Intelligence (AI) and Control for Optimizing Regional Mobility

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Date: 6/22/2021 1:40:00 PM EDT

2021 DOE Vehicle Technologies Office Annual Merit Review

Project ID #: eems061

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Overview

Timeline

- Project Start: Jan. 2021
- Project End: Dec. 2022
- Percent Complete: 10%

Budget

- Total: \$4M
- FY2021 Funding:
 - ORNL: \$1.2M
 - NREL: \$800K
- FY2022 Funding:
 - ORNL: \$1.2M
 - NREL: \$800K

Barriers and Technical Targets

- Disparity, lack of openness, and heterogeneity of transportation data from sensors, controls, and probes leading to lack of real-time situational awareness and observability
- Significant computational complexity for the application of situational awareness, advanced data science, and simulation to impact energy savings at regional scale
- Rigorously identifying control decisions and actions and overcoming technological challenges to implement cyber-physical control

Partners

- Tennessee Department of Transportation (TDOT)
- City of Chattanooga (CDOT)
- University of Tennessee, Knoxville (S. Chakraborty, A. Kohls)
- Wayne State University (Steve Remias)
- New York University (Zhong-Ping Jiang)
- TomTom, Siemens Mobility, Covenant Transport, Freightwaves

Relevance

- **Key target:** Achieve 20% energy savings at the regional level.
 - Highways, linked arterials, and freight present an opportunity at the systems level
 - Framework is 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 stationary and mobile 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
 - Artificial Intelligence-based algorithmic control decisions for orchestration of control at system scale
 - Data science approaches to inform intersection performance, incidents, truck/freight movement for real-time control decisions and routing optimization

2021 Milestones

Milestone Name/Description	Criteria	End Date	Type
Develop integrated project plan with updated budget for "Scaling up Regional Mobility."	Quarterly report documenting activities and milestone	3/31/2021 Completed	Quarterly Progress Report
Ingest 50% of real-time data feeds from GDOT; Identify methodology for ingesting data feeds from Chattanooga Public Works, Covenant, and Freightwaves.	Quarterly report documenting activities and milestone	6/30/2021	Quarterly Progress Report
Expand HPC and AI to prototype expanded simulation area, truck volume counts from video analytics, generation of ATSPMs for signalized intersections, and incident detection. Conceptualize a routing strategy scenario and evaluate possible control/routing strategies.	Quarterly report documenting activities and milestone	9/30/2021	Quarterly Progress Report
Improve framework for near real-time hourly volume and energy estimation, and methodology to integrate truck counts, intersection performance, and incident detection into CTwin tool. Develop a functional AI-based control algorithm using available data sources as input with performance reducing delay by 10%.	Quarterly report documenting activities and milestone	12/31/2021	Quarterly Progress Report

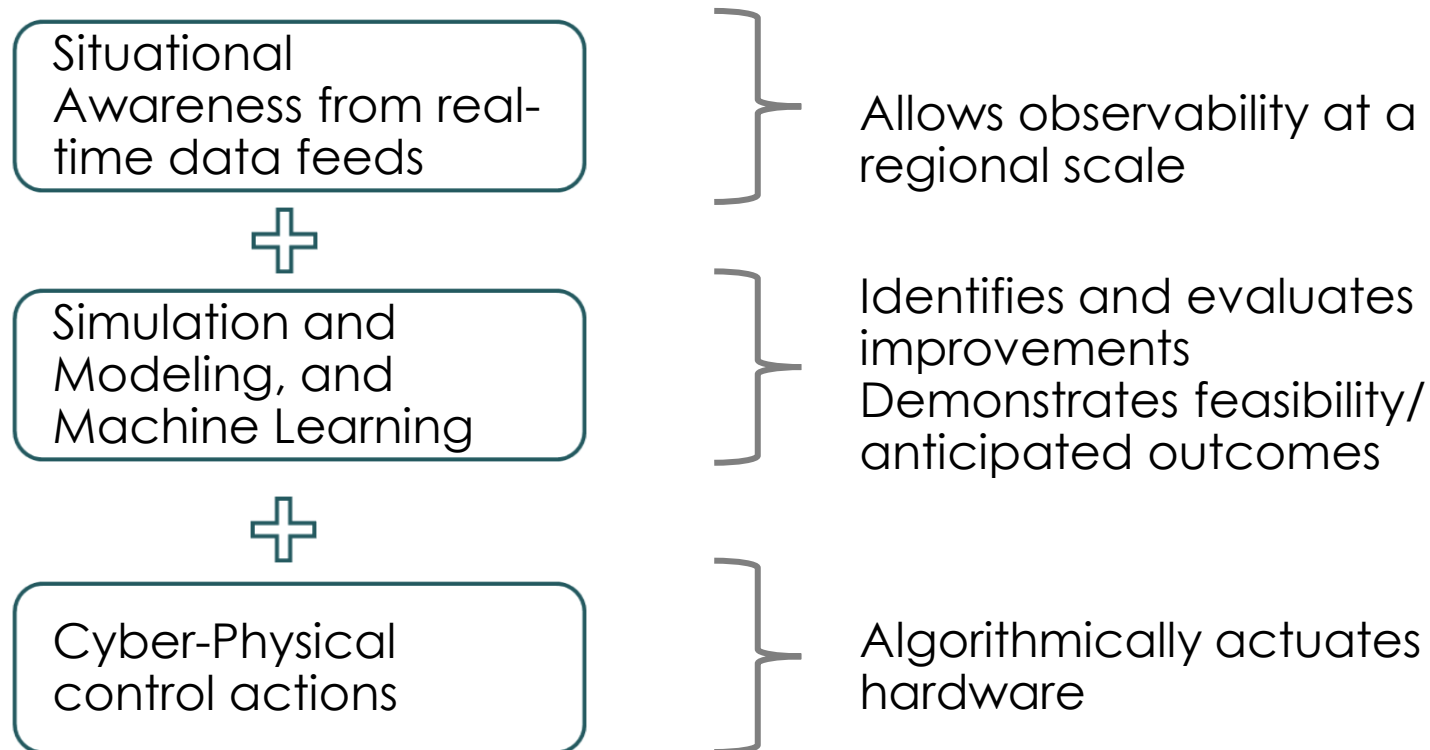
2022 Milestones

Milestone Name/Description	Criteria	End Date	Type
Develop API framework capable of ingesting and serving 90% of available data feeds for use by situational awareness and data science. Use available AI enhanced data streams to scale up the simulation model to represent 80% of the study region.	Quarterly report documenting activities and milestone	3/31/2022	Quarterly Progress Report
Produce an action list, a verification checklist, and execute preliminary field tests for deploying traffic control algorithms in the field based on available controllers and data sources covering 80% control points. Produce routing strategy demonstration approach.	Quarterly report documenting activities and milestone	6/30/2022	Quarterly Progress Report
Scale up and enhance the signal performance assessment with AI methodology and estimate for >90% of signals in the region. Demonstrate detection of incidents within 2 minutes and with >75% confidence. Demonstrate outcome of real-time truck/freight detection.	Quarterly report documenting activities and milestone	9/30/2022	Quarterly Progress Report
Deploy the control algorithm in the field for 85% of hours for two months. Complete analysis and evaluate the performance of the proposed control algorithm.	Quarterly report documenting activities and milestone	12/30/2022	Quarterly Progress Report

Technical Approach

- Create multi-institutional collaboration of transportation science, data science and simulation researchers to build a 'digital twin', enabled by high-performance computing
- Engage the broader to bring to bear transformative approaches to impact mobility at a Regional Scale

CTwin – 'Digital Twin' for Regional Mobility, Chattanooga, TN



Accomplishments – High-Level Highlights

- Real-time situational awareness
 - CTwin real-time tool stood up
 - Collaborators given logins
- Metrics
 - Energy, mobility, safety, and Measure of Energy and Productivity (MEP)
 - Moving Ahead for Progress (MAP21) metrics and Automated Traffic Signal Performance Measures
 - Real-time regional speed and energy estimation achieved
- Modeling & Simulation
 - Microscopic and mesoscopic simulations and simulation-calibration strategies setup
 - Corridor scale control simulation/optimization strategy implemented
- Data Science
 - Novel intersection movement visualization developed
 - Emulated traffic flow from radar sensors derived
 - Signal performance derived from probe data
 - Machine Learning to detect freight prototyped
- Cyber-Physical Control
 - Updated corridor timing implemented through vendor software
 - Direct real-time control of Siemens m60 controllers on Shallowford Rd

Data sources



Real-Time Data

Chattanooga Department of Transportation,
Tennessee Department of Transportation,
Georgia Department of Transportation,
Chattanooga Public Works,
Covenant Transport, Freightways

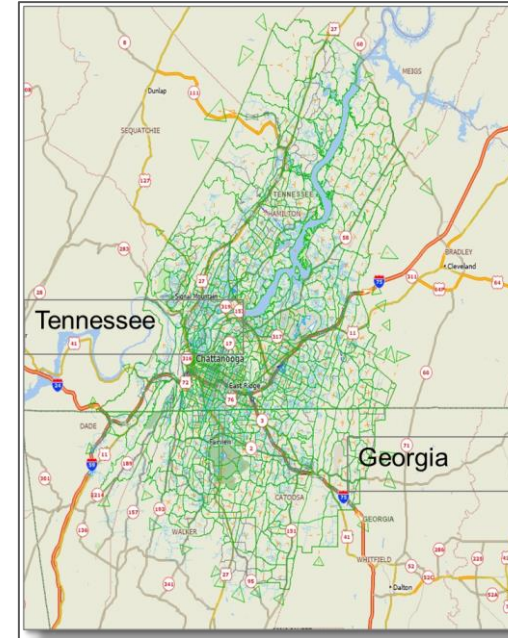
Metropolitan Planning Org, TomTom, American Transportation
Research Institute, etc.

City of Chattanooga

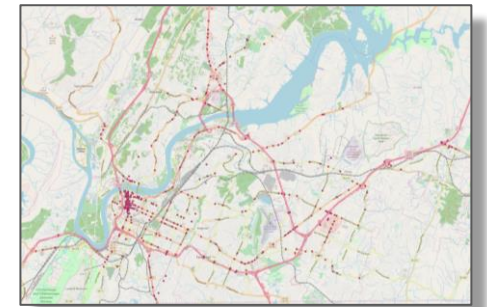
- GridSmart cameras
 - 100 + 50 planned
- Signalized intersections
 - 350 intersections; ~275 signal control, 1/10th second
- Incident data
 - 911, Titan, Waze, etc

TDOT

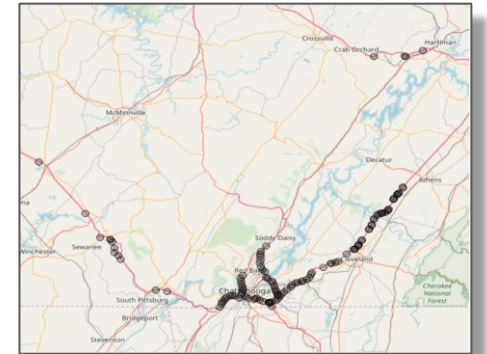
- Radar Detector Sensors (RDS) - ~214
 - Located every ½ mile on average
 - Every 30s data, by each lane of traffic
 - Lane occupancy, speed, classification
- Weather sensors, Dynamic Message Signs, Video
- Smartway camera feeds



Study region



Traffic signal locations in region



RDS locations in the region

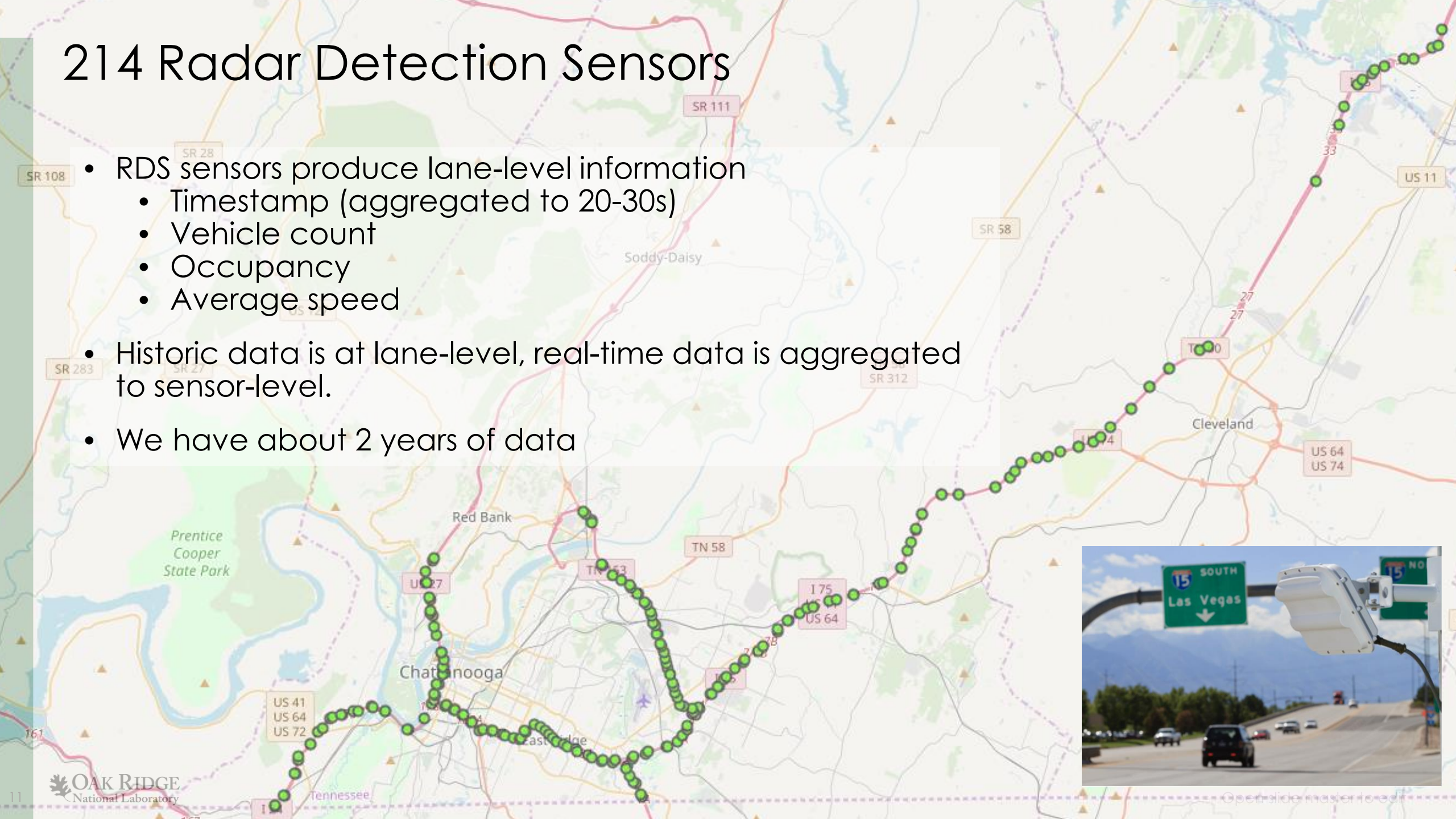
500+ primary data streams from 7 proprietary vendor systems across 3 institutions
Additional 40+ distinct secondary data layers

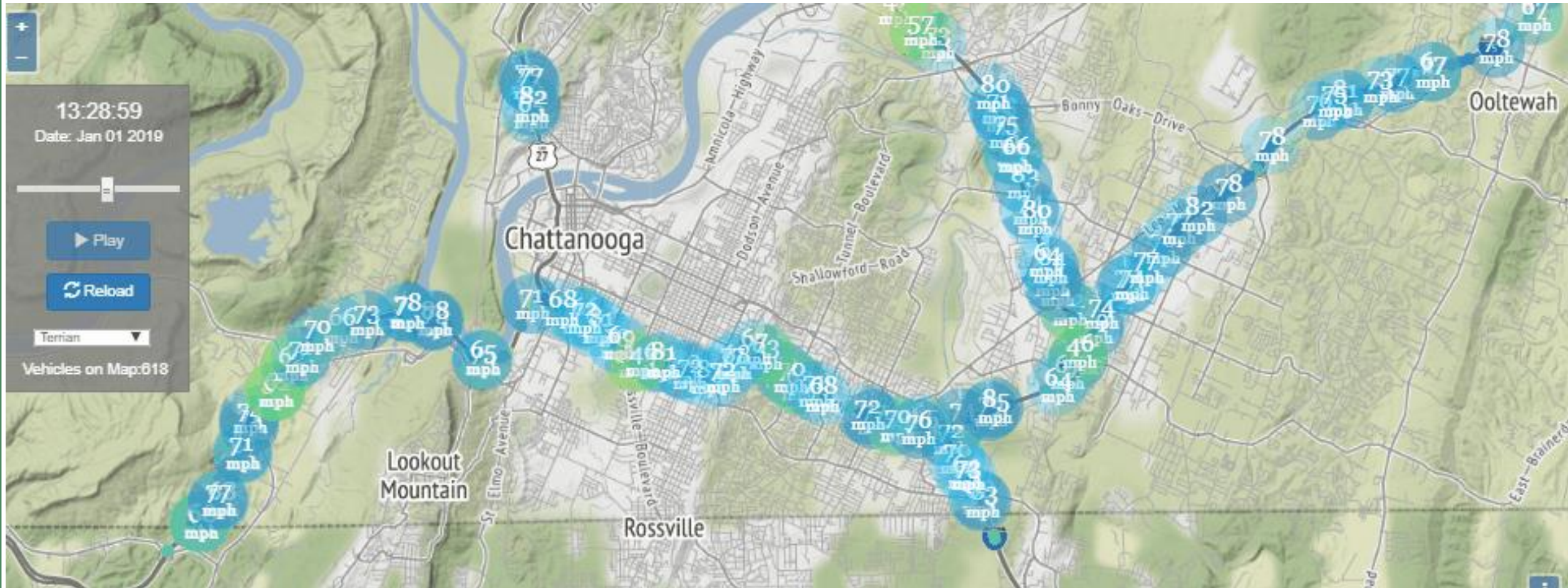
Radar Detector Sensors (RDS)



214 Radar Detection Sensors

- RDS sensors produce lane-level information
 - Timestamp (aggregated to 20-30s)
 - Vehicle count
 - Occupancy
 - Average speed
- Historic data is at lane-level, real-time data is aggregated to sensor-level.
- We have about 2 years of data

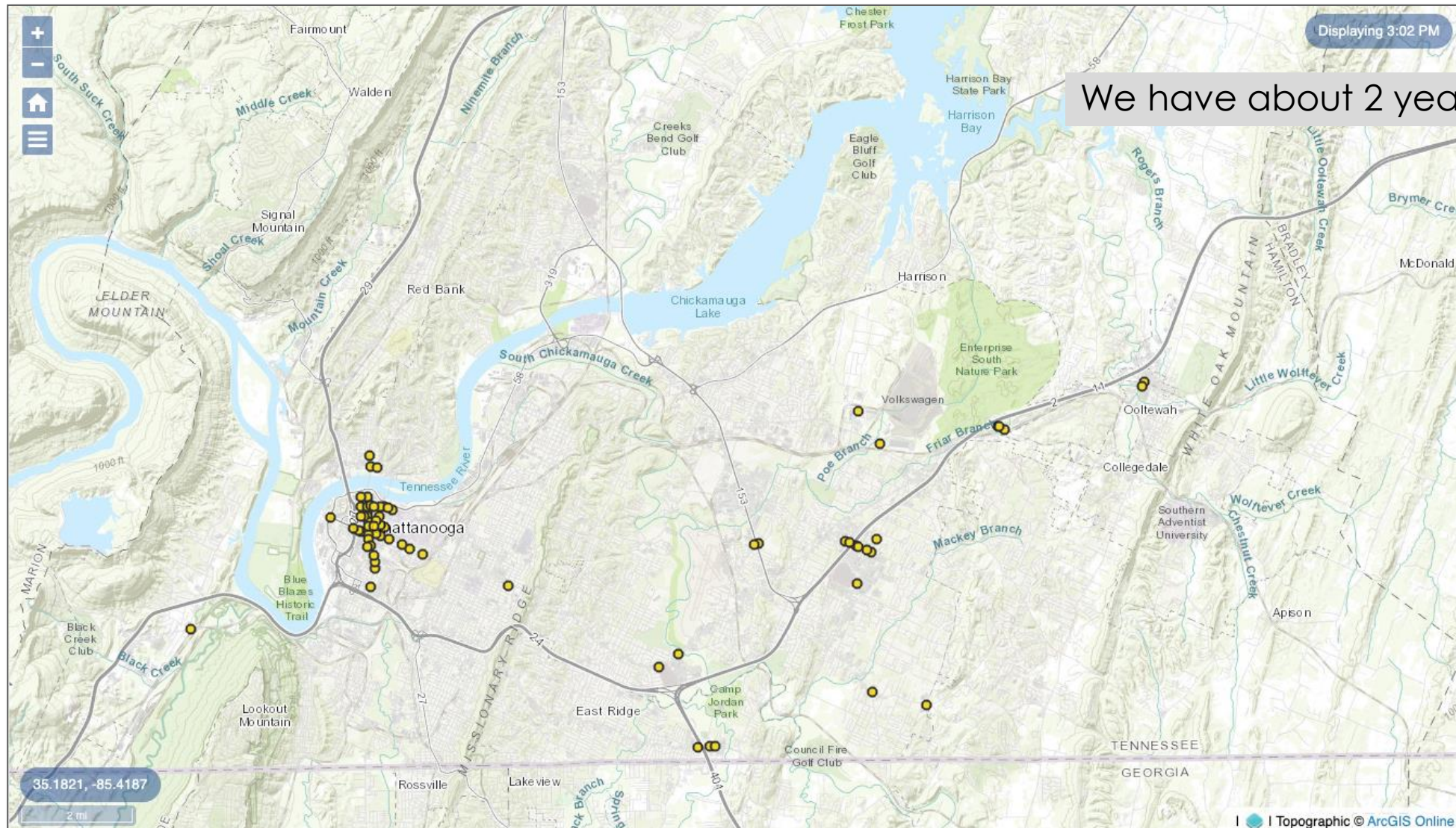




GridSmart Fisheye Cameras

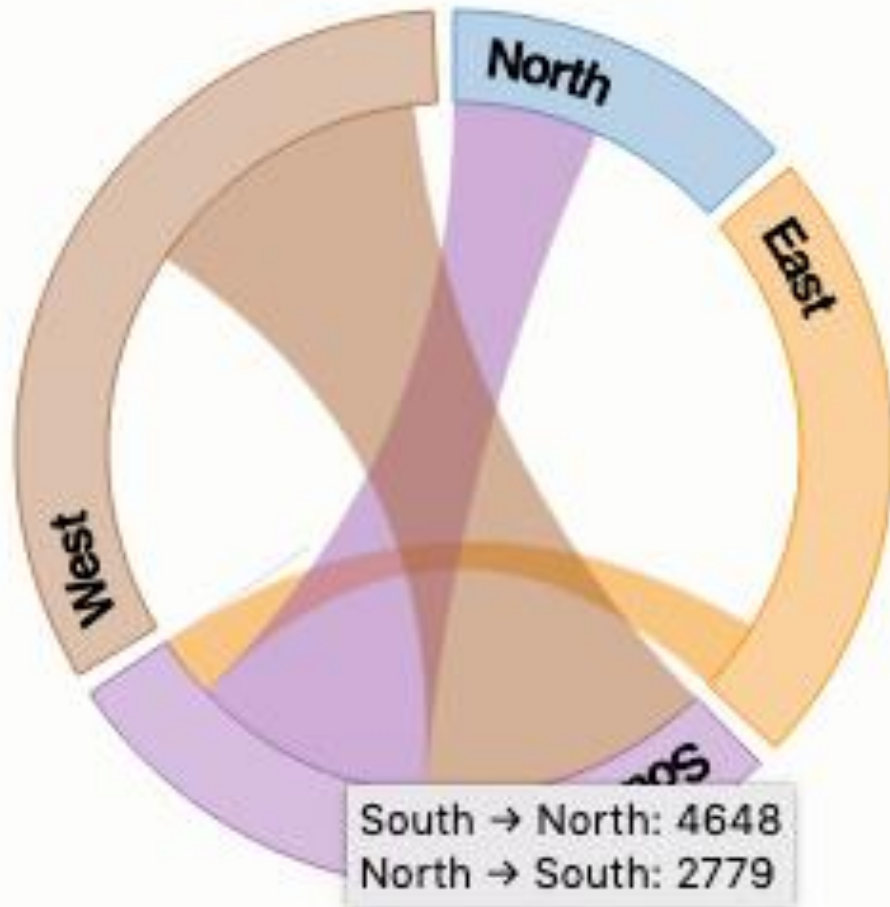


~100 GridSmart Sensors in Chattanooga



Showing 72 here, ~100 deployed, the number is growing

About GridSmart Sensors



- Sensors are fisheye lens cameras
- Most traffic data is collected using computer vision.
- Signal status is collected from controller
- Detection happens based on defined *detection zones*.
- Pros:
 - Lightweight
 - Easy (and cheap) to change
- Con:
 - Less precise than other methods

Zones on Shallowford Road

Two types of zones:

- **Stopbar detection** zones (long zones) for traffic counts
- **Advanced detection** zones (short zones)
- We cannot have overlapping zones within one sensor, so we take advantage of the overlap in coverage between adjacent intersections' sensors.



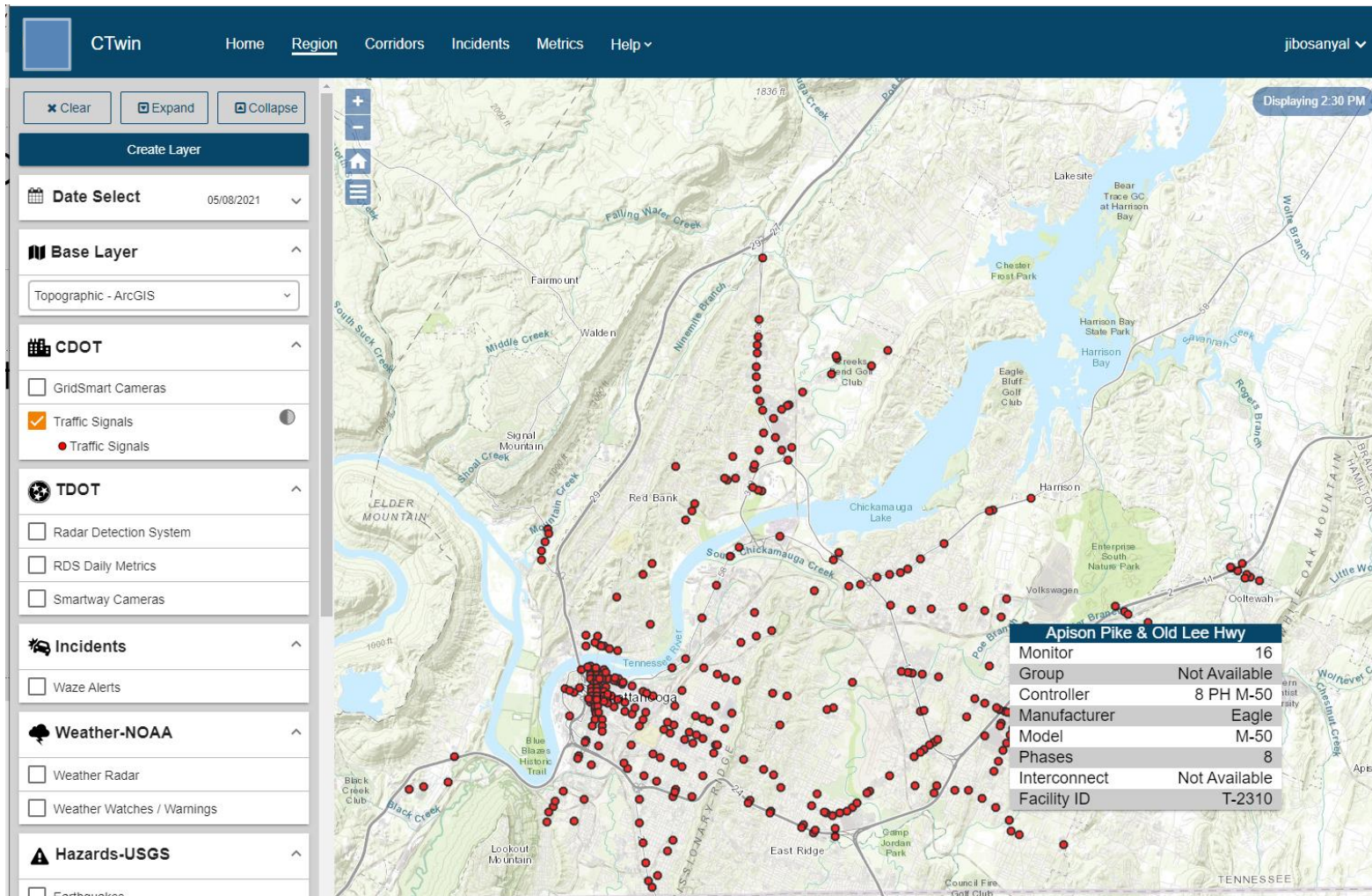
- AminGridSmartDetectionZones
- I-75SBGridSmartDetectionZones
- I-75NBGridSmartDetectionZones
- NapierGridSmartDetectionZones
- LifestyleGridSmartDetectionZones

Actual zone sizes may vary, this is illustrative

Signal Phase and Timing Data



~285 signalized intersections



- Signal Phase and Timing data every 1/10th of a second
- Decryption via National Transportation Communications Protocol for Intelligent Transportation Systems (NTCIP) standard
- Siemens' NTCIP implementation
- Signal plans/diagrams available
- Live data is not saved

Incident data

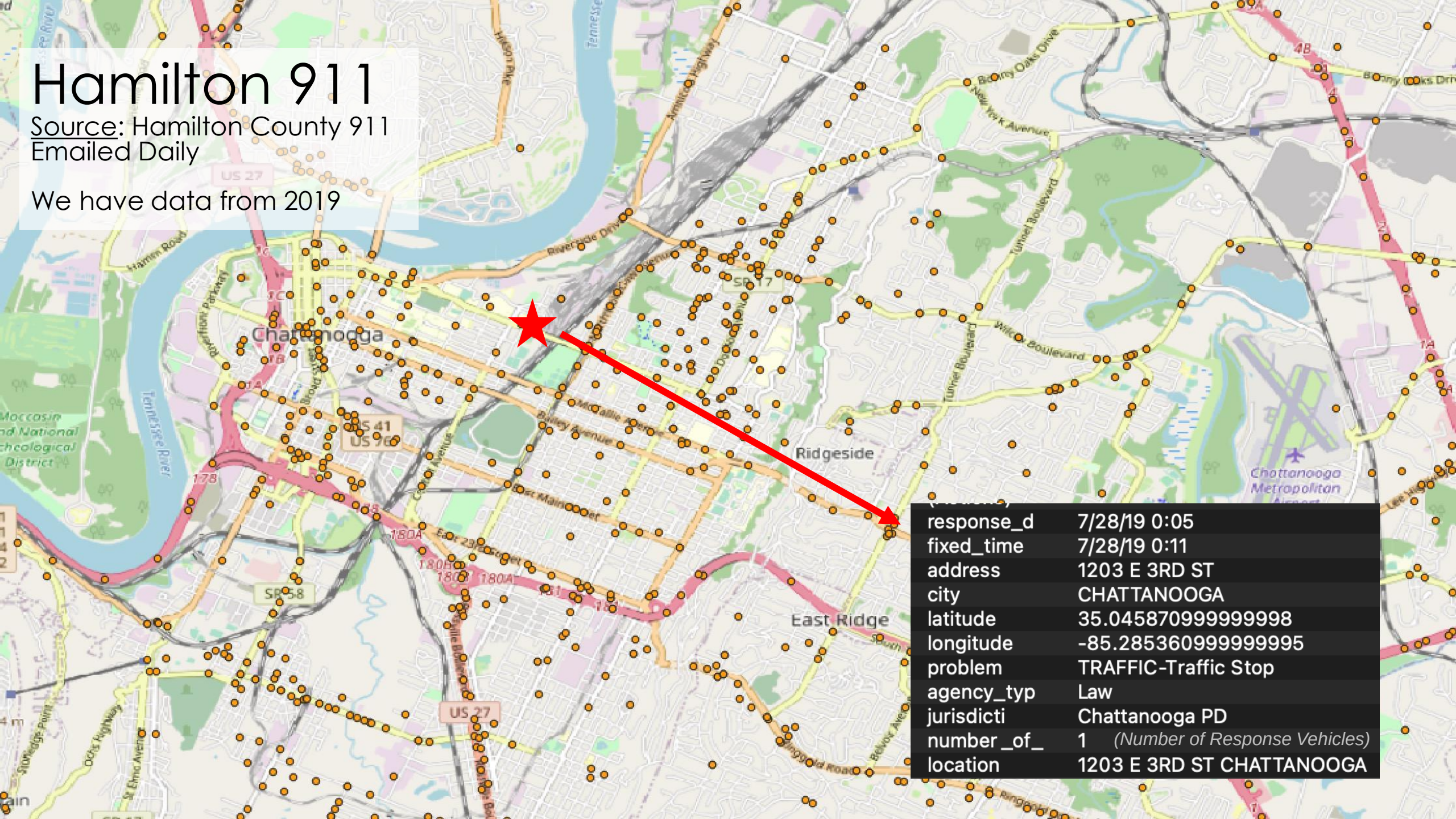


Hamilton 911

Source: Hamilton County 911

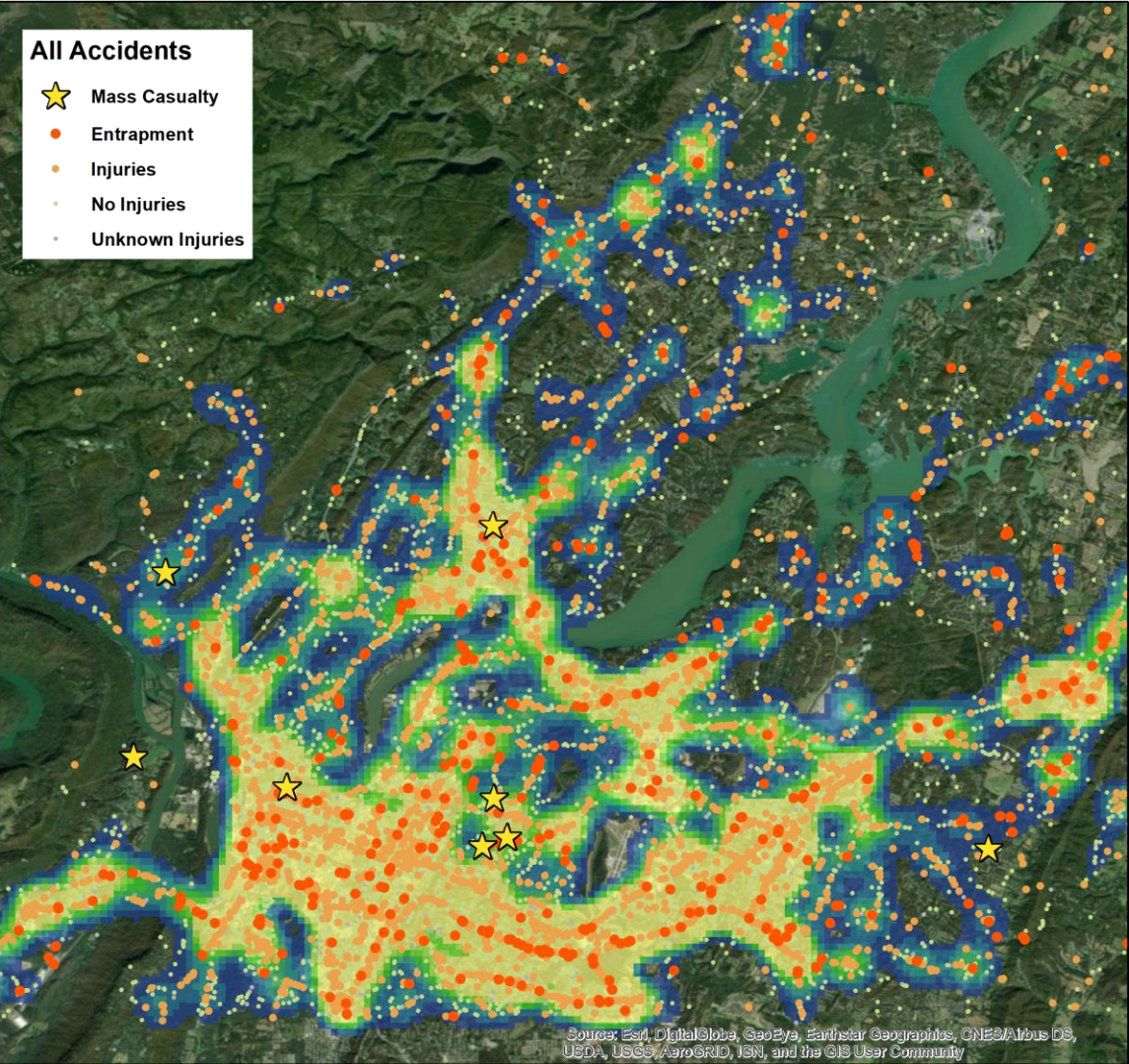
Emailed Daily

We have data from 2019



response_d	7/28/19 0:05
fixed_time	7/28/19 0:11
address	1203 E 3RD ST
city	CHATTANOOGA
latitude	35.045870999999998
longitude	-85.285360999999995
problem	TRAFFIC-Traffic Stop
agency_typ	Law
jurisdicti	Chattanooga PD
number_of_	1 (Number of Response Vehicles)
location	1203 E 3RD ST CHATTANOOGA

Incident Visualization



Vehicle Incidents

Vehicle Incidents by Day of Week

Monday	855	376	318	20382	2516	4243	234	1427
Tuesday	1018	740	391	22149	3536	6888	225	1865
Wednesday	1252	722	371	27735	4422	8776	342	2098
Thursday	1086	733	291	20146	3478	6782	274	1729
Friday	1127	670	389	25340	3803	7648	304	1909
Saturday	1065	664	390	25638	3371	7158	256	1950
Sunday	946	417	371	25638	2994	5341	288	1627

MVC Unknown Injuries MVC Delayed Vehicle Fire Traffic Stop MVC Injuries MVC No Injuries MVC Entrapment Auto Broken Down

Traffic Stop has 25638 occurrences on Sunday for the past fiscal year

0 10k 20k 30k

Data: Hamilton County 911

Non-Vehicle Incidents

Non-Vehicle Incidents by Day of Week

Monday	0	39	55	78	1	153	44	506	82	213	102
Tuesday	2	27	74	153	1	281	61	533	87	201	178
Wednesday	1	62	75	176	3	326	70	472	48	251	180
Thursday	3	17	76	136	11	267	72	472	65	156	208
Friday	2	32	62	157	6	290	57	539	78	213	127
Saturday	1	127	74	150	8	328	64	439	57	168	181
Sunday	6	57	58	74	4	320	48	481	72	253	151

Nursing Home Fire Flooding Commercial Fire Spill Hospital Fire Pedestrian Struck Commercial Building Fire Residential Fire Apartment Fire Brush Fire Gas Leak

0 100 200 300 400 500 600

Data: Hamilton County 911

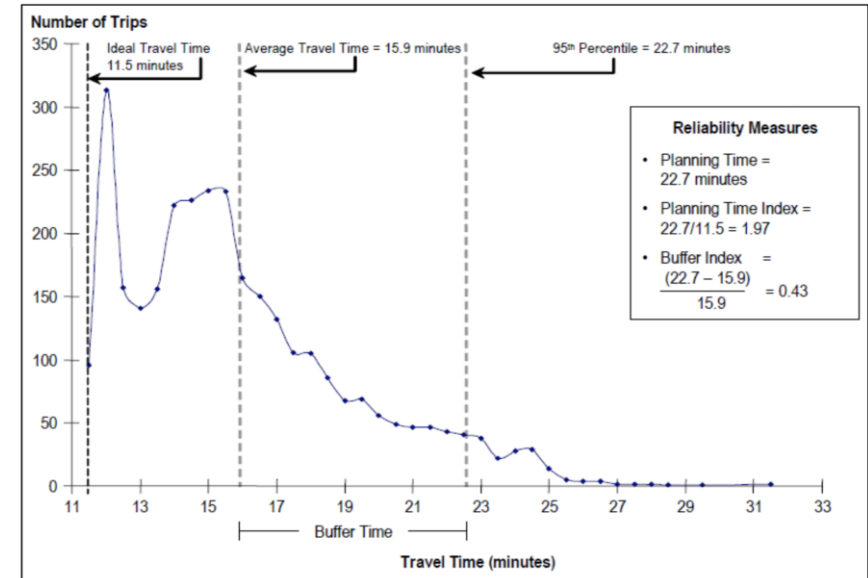
Data: Hamilton County 911

Measurement

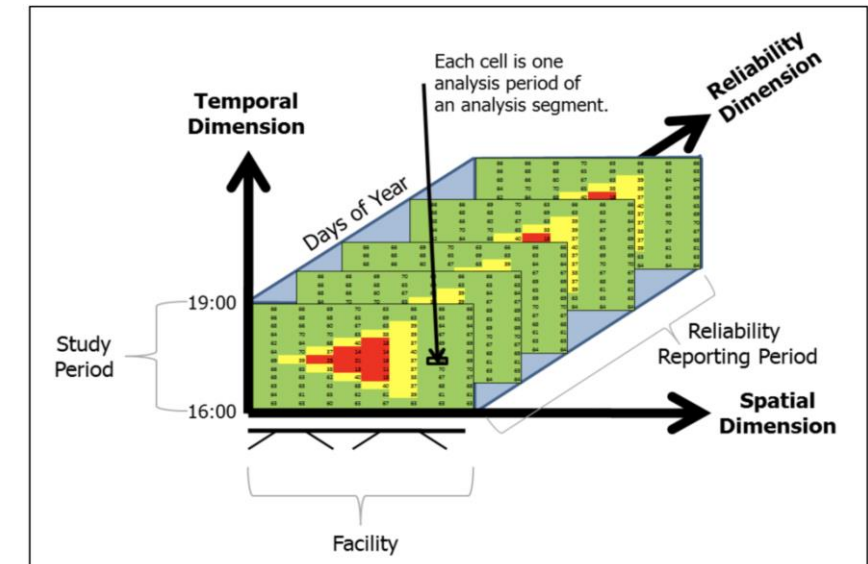


Metrics in C-Twin

- Primarily driven by USDOT MAP-21 measures
- Mobility Dynamics
 - Macroscopic – Freeway travel time reliability, level of service (average speed and volume to capacity ratio), vehicle miles of travel (VMT) by passenger and freight.
 - Microscopic – Level of service (vehicle delays, queue length and signal delays) from signalized intersections.
- Traffic Safety
 - Roadway segment level – fatalities per capita and serious injuries per capita (crashes per VMT)
 - Intersection level – crashes per 100,000 vehicles
- Energy Usage
 - Minute by minute on-road vehicle fuel consumption & cost
 - RouteE – Energy estimation over roadway segments
- Mobility – Energy – Productivity (MEP)
 - $f(\text{mobility weighted by } [\text{energy, cost, trip purpose}])$

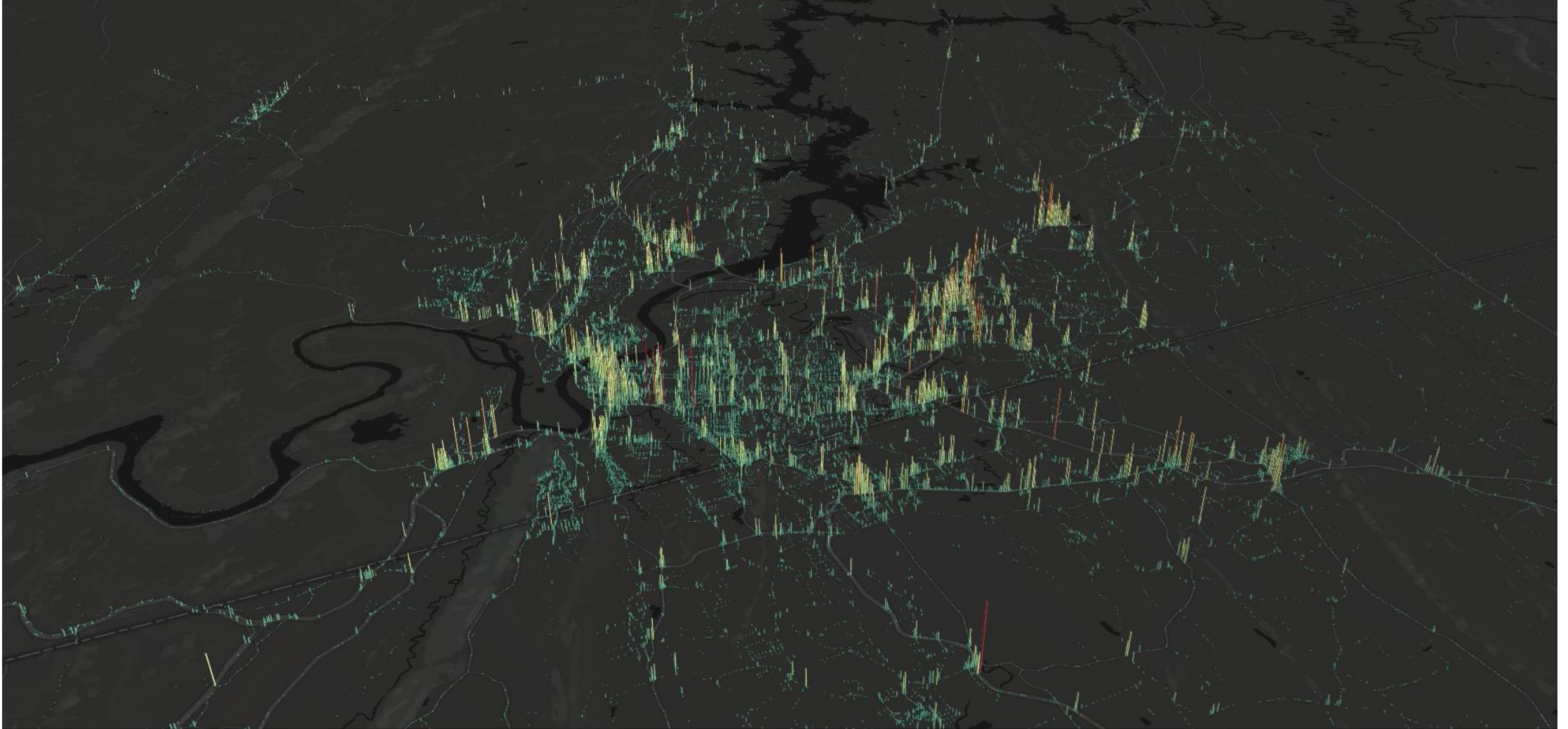


Source: Travel Time Index Measures from Sample Travel Time Frequency Distribution (FHWA 2016)



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

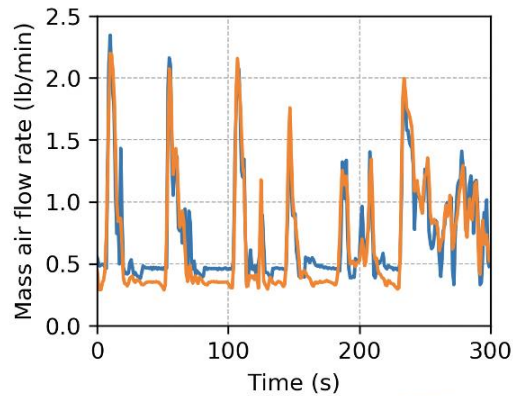
Identifying Areas of Highest Energy Lost Due To Congestion



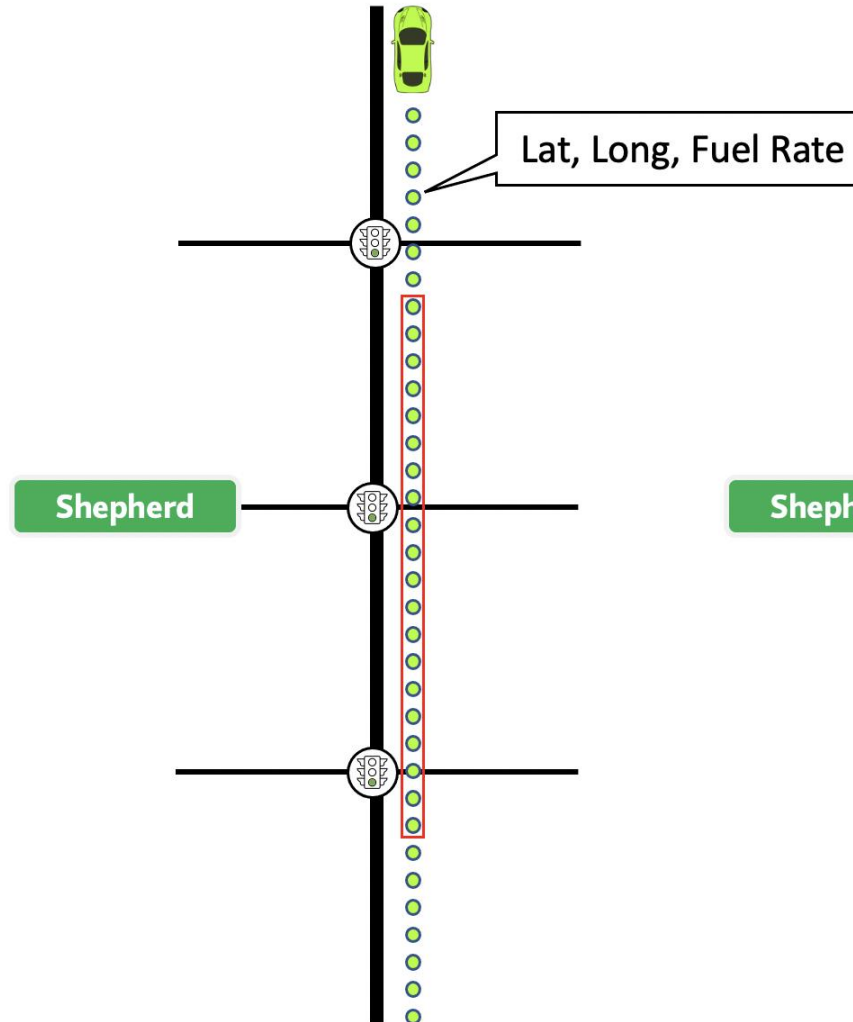
Measured in gallons of gasoline equivalent (gge)

Defining High-Resolution Energy Metrics for Signal Performance

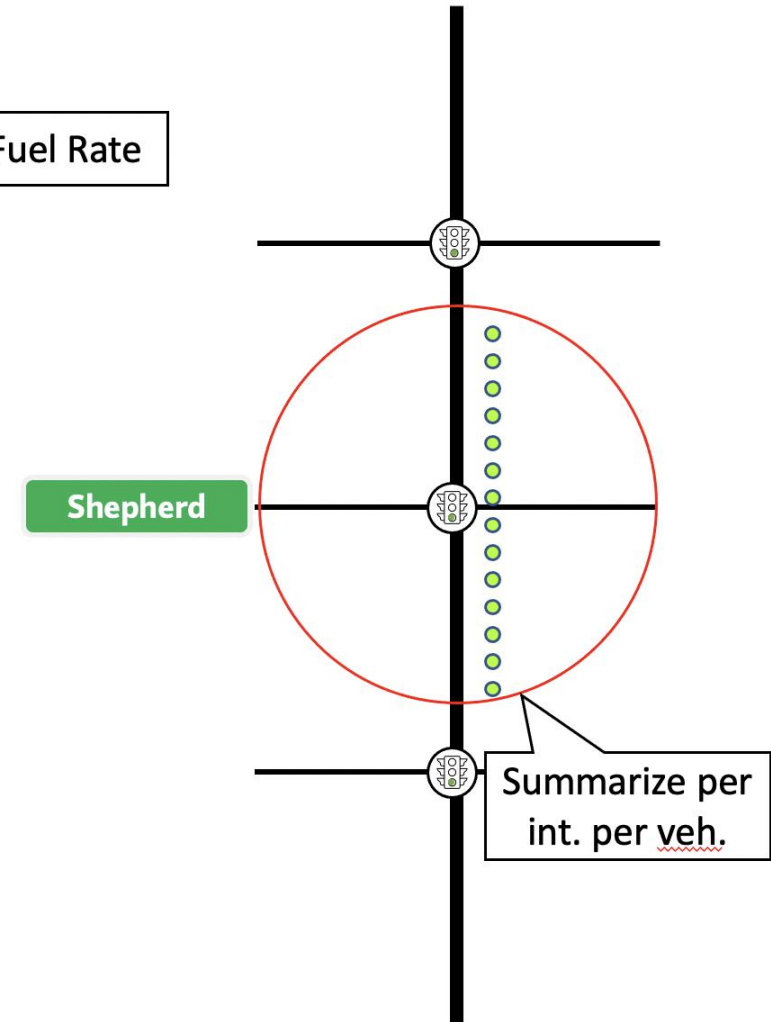
Step 1 – Create fuel model using measured data from OBD or leverage NREL fuel models



Step 2 – Apply the model to available trajectory data from Chattanooga



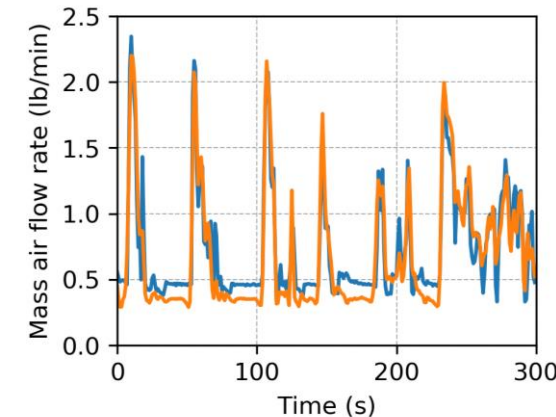
Step 3 – Aggregate the energy metrics at the intersection level



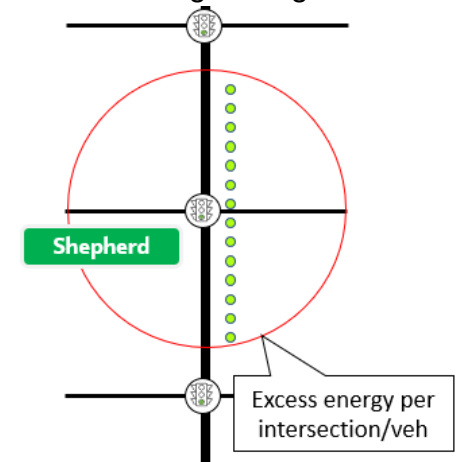
ATSPM Excess Energy Measure

- Define an excessive energy use metric that is the equivalent of 'delay'
- Apply energy metric in similar context as ATSPMs, correlating excess energy with existing vehicle trajectory based ATSPMs for the Chattanooga region
- Publish these findings to the transportation community to improve both intersection performance and energy performance simultaneously
- Provide open-source code for excess energy as part of emerging ATSPMs standards from vehicle trajectory data.
- Stretch goal – integrate ATSPM excess energy into commercial products

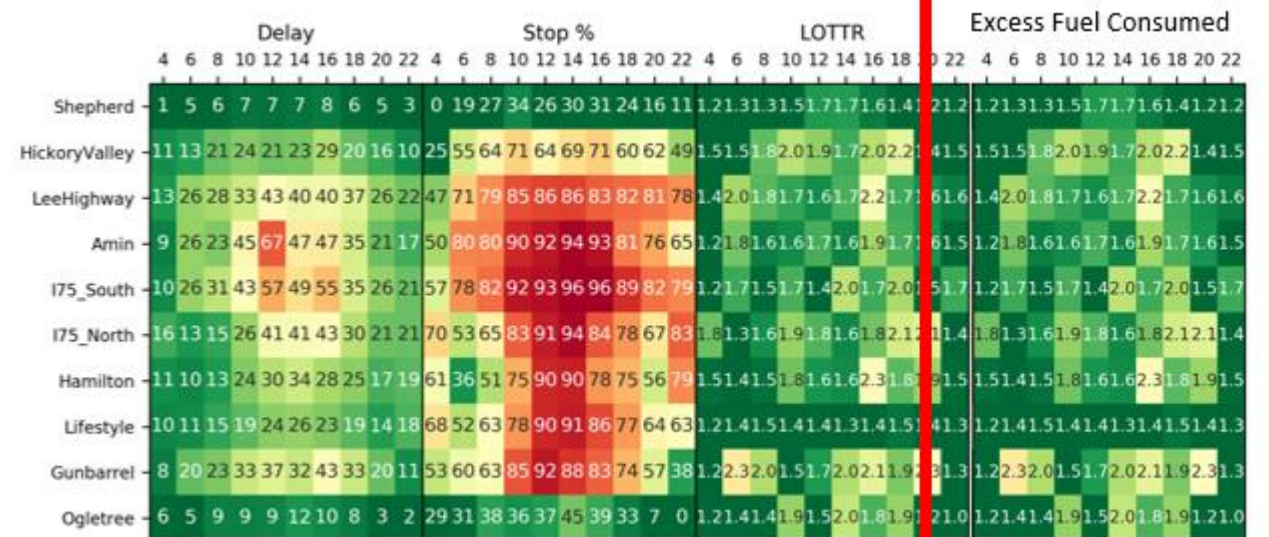
Step 1 – Model fuel using OBD data and/or NREL fuel models



Step 2 – Apply model within Chattanooga using CV data



Step 3 – Aggregate the energy metrics at the intersection level



Determining cars vs. trucks



Cars/Trucks/Tractor-trailer statistics from camera feeds

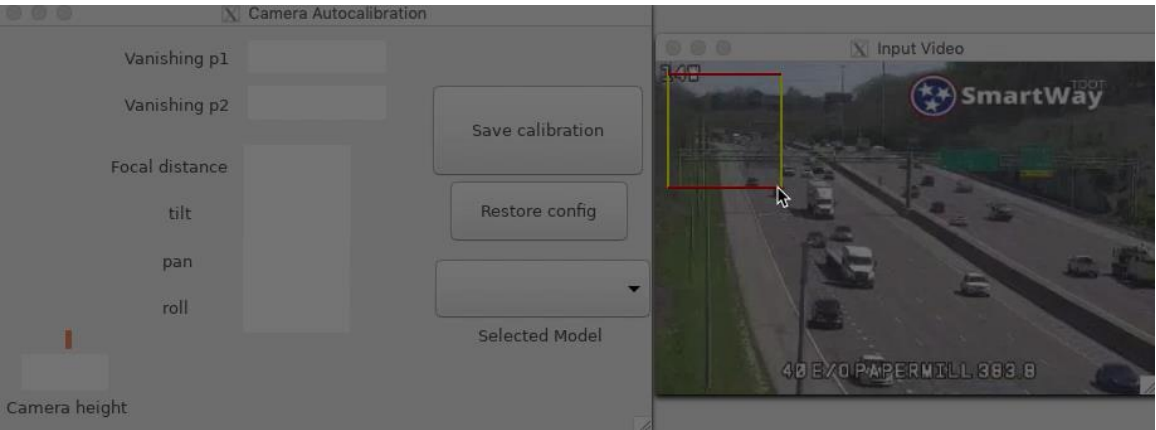
Automatic De-distortion Calibration



Flow Estimation

Un-distorted Views

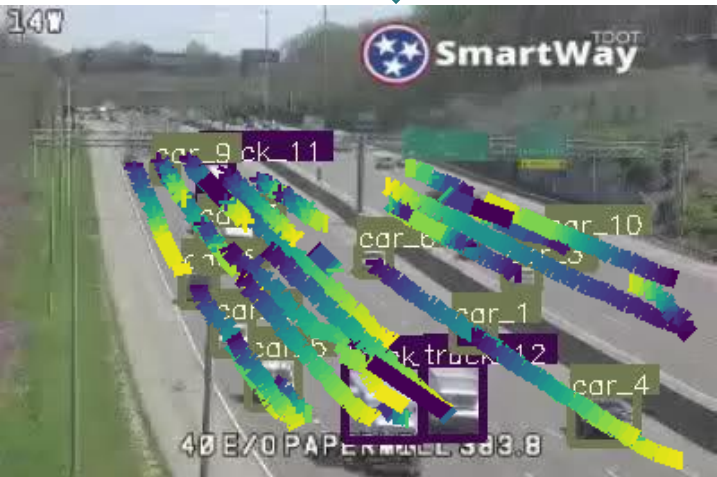
World-View Camera Orientation Calibration



Vehicle Categorization and Tracking



Vehicle Counting And Speed Estimation



Summary Statistics

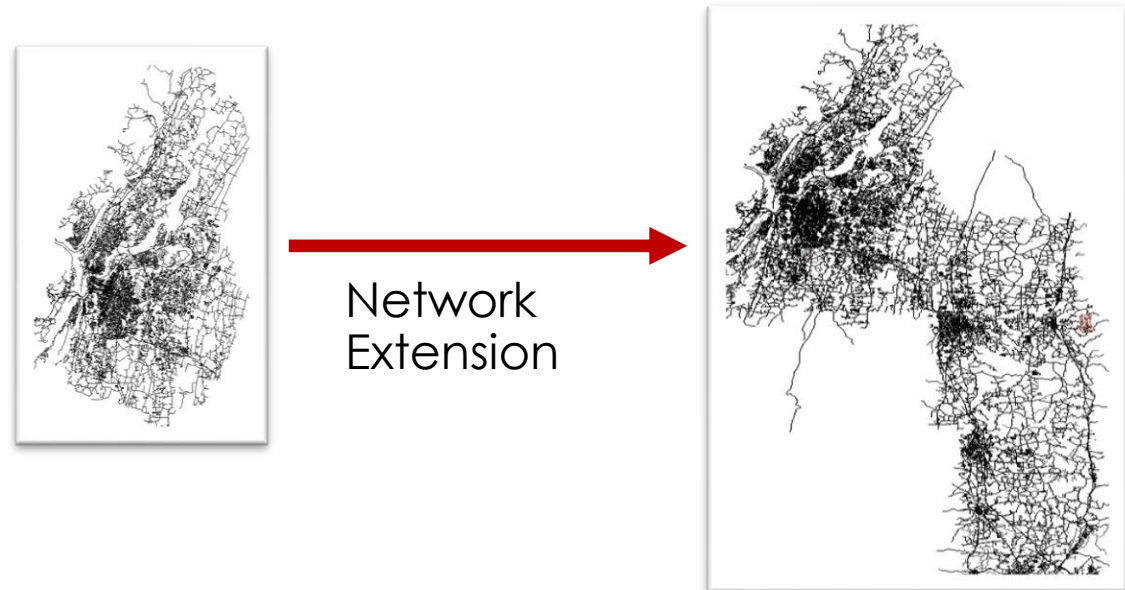
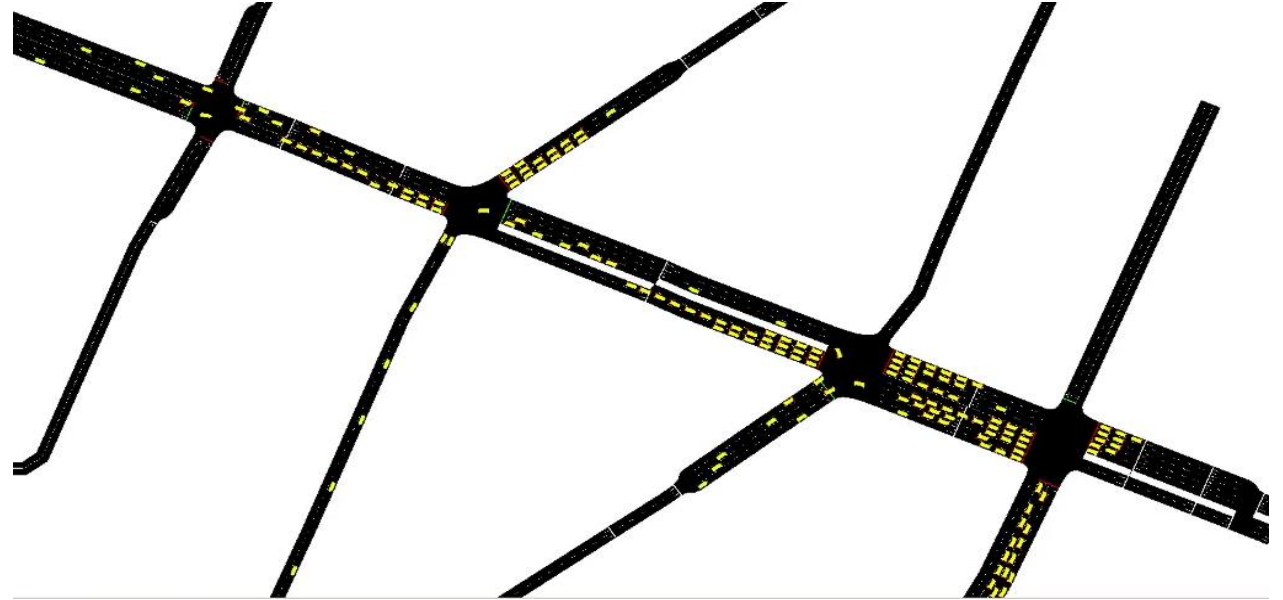
Cyber-Physical Control



Modeling and Simulation for Traffic Control

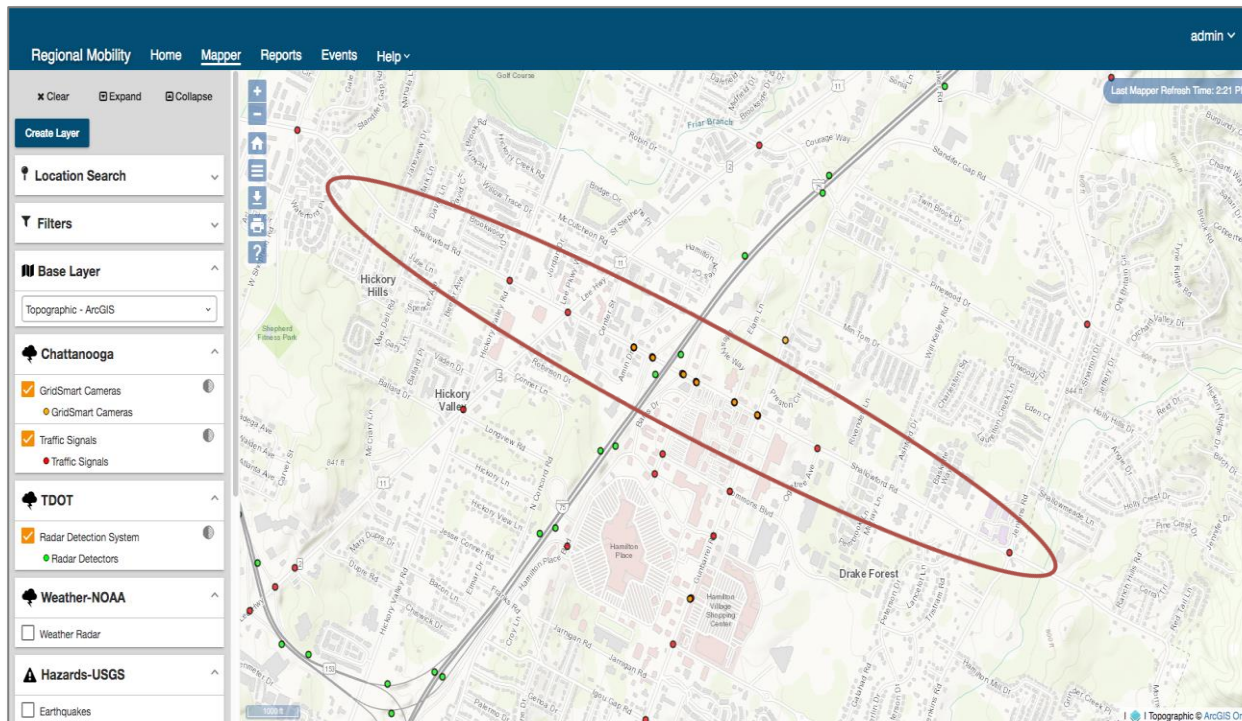
- Simulations to represent and evaluate traffic control methods before deployment
- Data-driven micro simulation for real-time signal control :
 - GridSmart volume and turn ratios for demand generation; TomTom Probe speed for validation
 - Baseline signal timing
- Extend meso simulation to Georgia to complete regional view:
 - Focused on regional freight movement
 - Processed and combined Georgia and Chattanooga networks

Shallowford Rd Corridor – Afternoon Peak



Candidate Corridor for Cyber-Physical Control

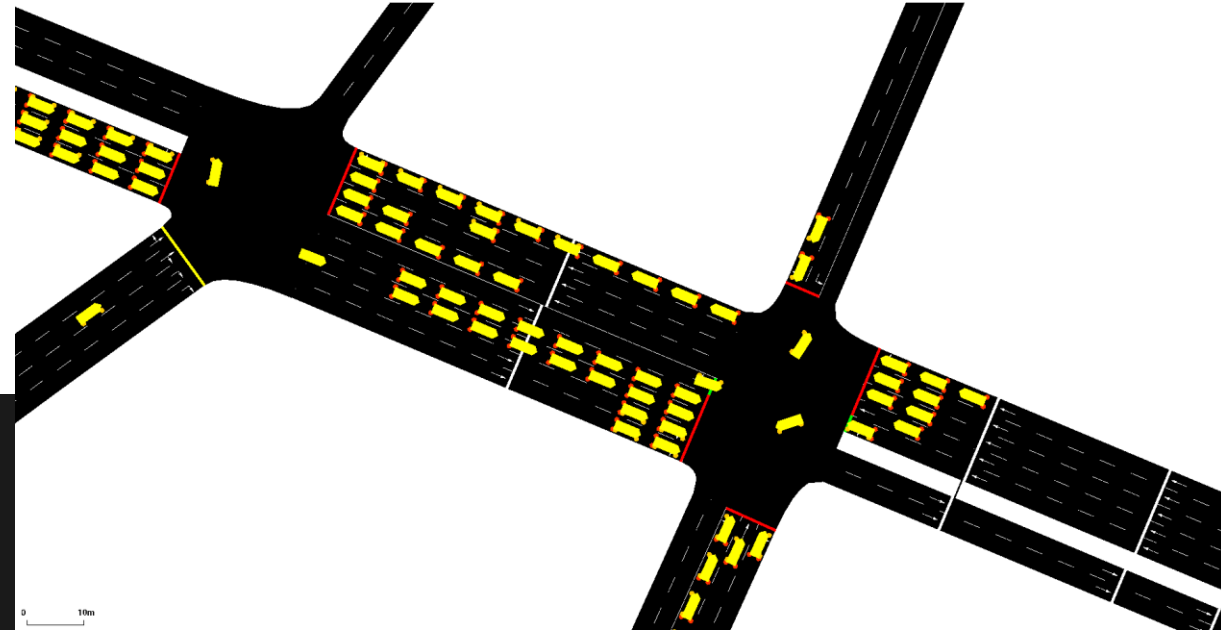
- GridSmart Cameras
- Signalized Intersections with timing information
- Radar Detection Systems
- Traffic Incidents



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

AI-based NEMA control in SUMO

- NEMA diagram / timing – understood by traffic engineers in the US
- Coordinated/non-coordinated/Actuated mode
- Update signal timings during simulations
- Used to support field experiments
- Integrated with FLOW -> RL controller

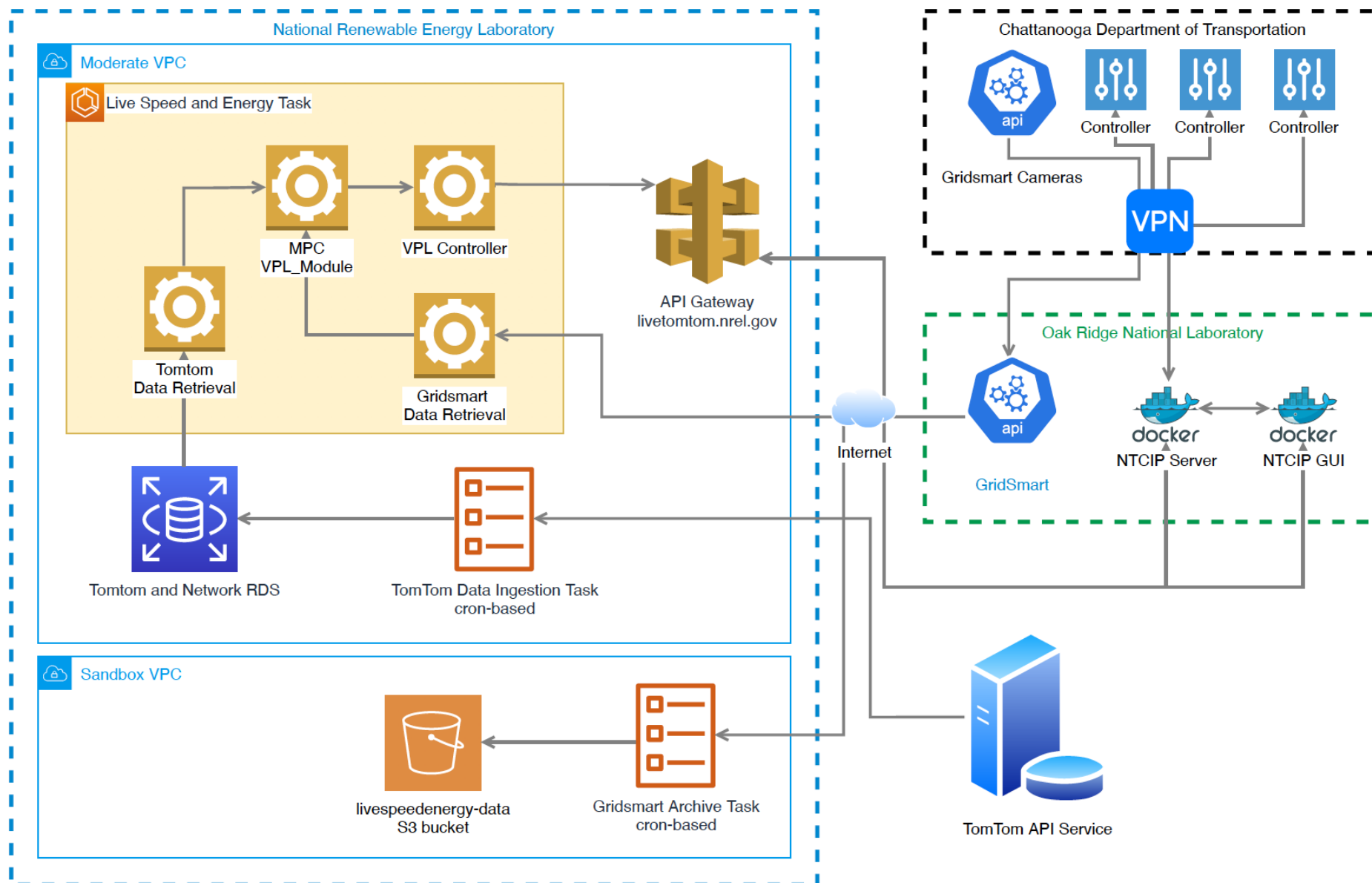


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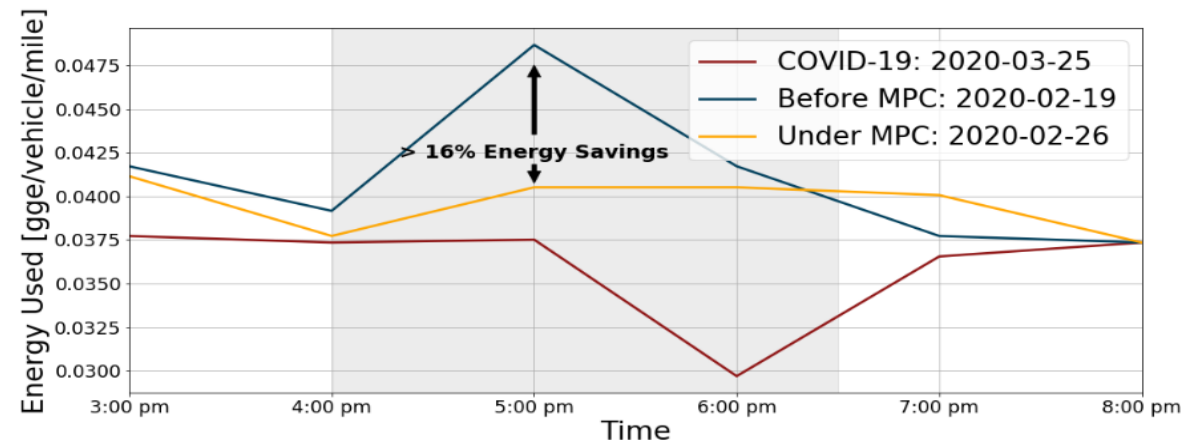
SUMO additional file that defines NEMA signal timing

Real-time traffic signal control architecture

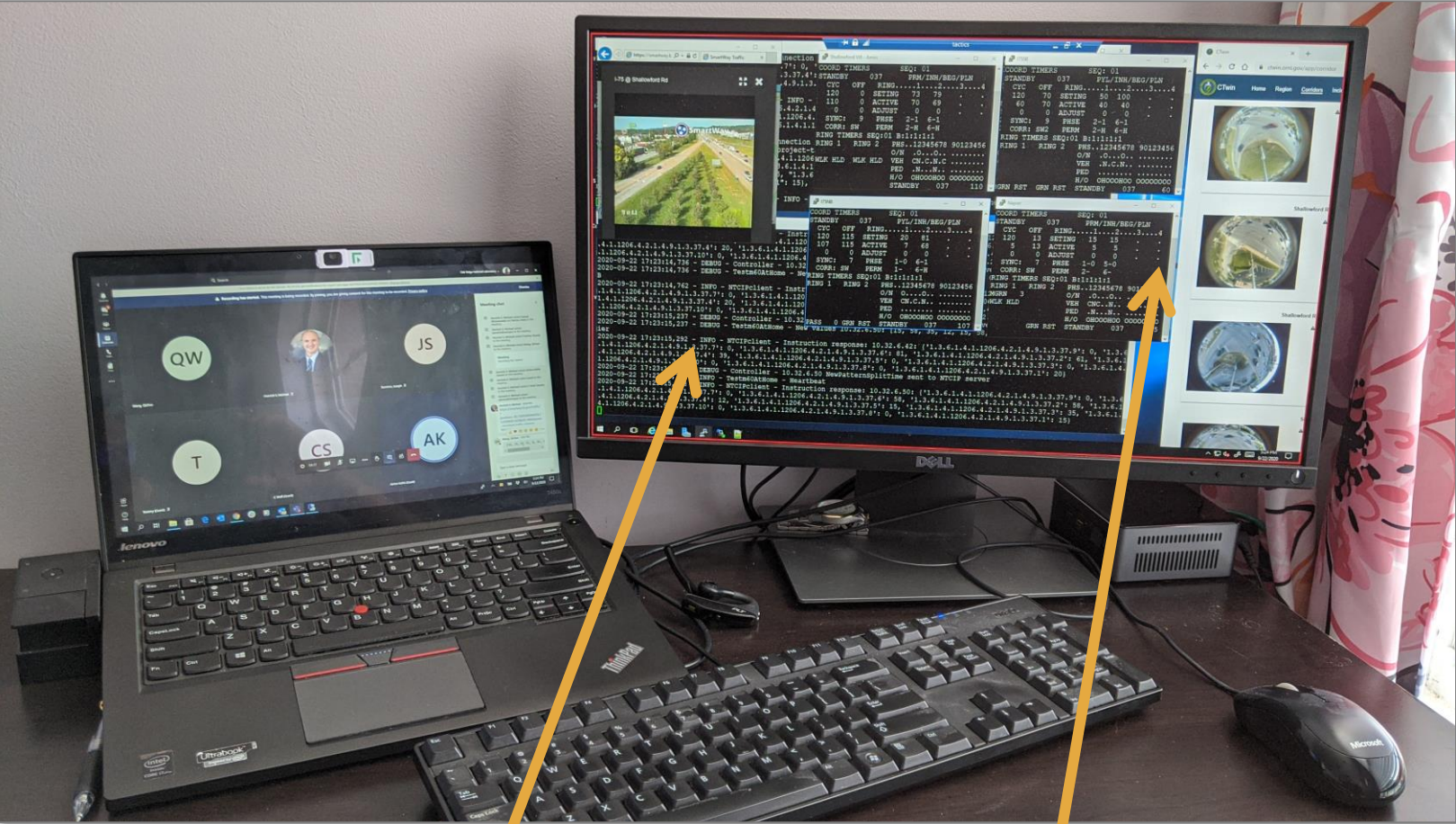


Cyber-physical control of Shallowford Rd signals

- In February 2020, we ran an initial 'soft test' for 3.5 hours
 - **18% energy reduction in simulation**
 - Implemented one new timing value in the city using existing vendor interface
 - Some tweaks and several on-ground practical constraints
 - **Up to 16% energy saving in the field**
 - Positive feedback from CDOT

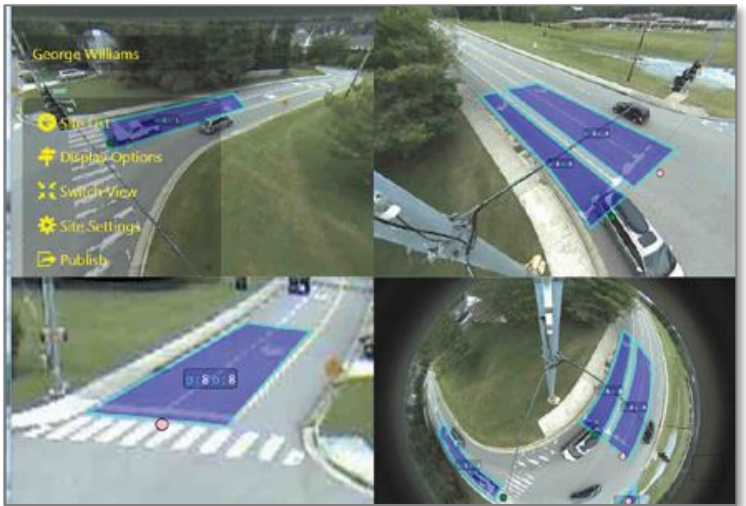


Full control orchestration – Photo from 22 Sep 2020 with control running – everything is remote!

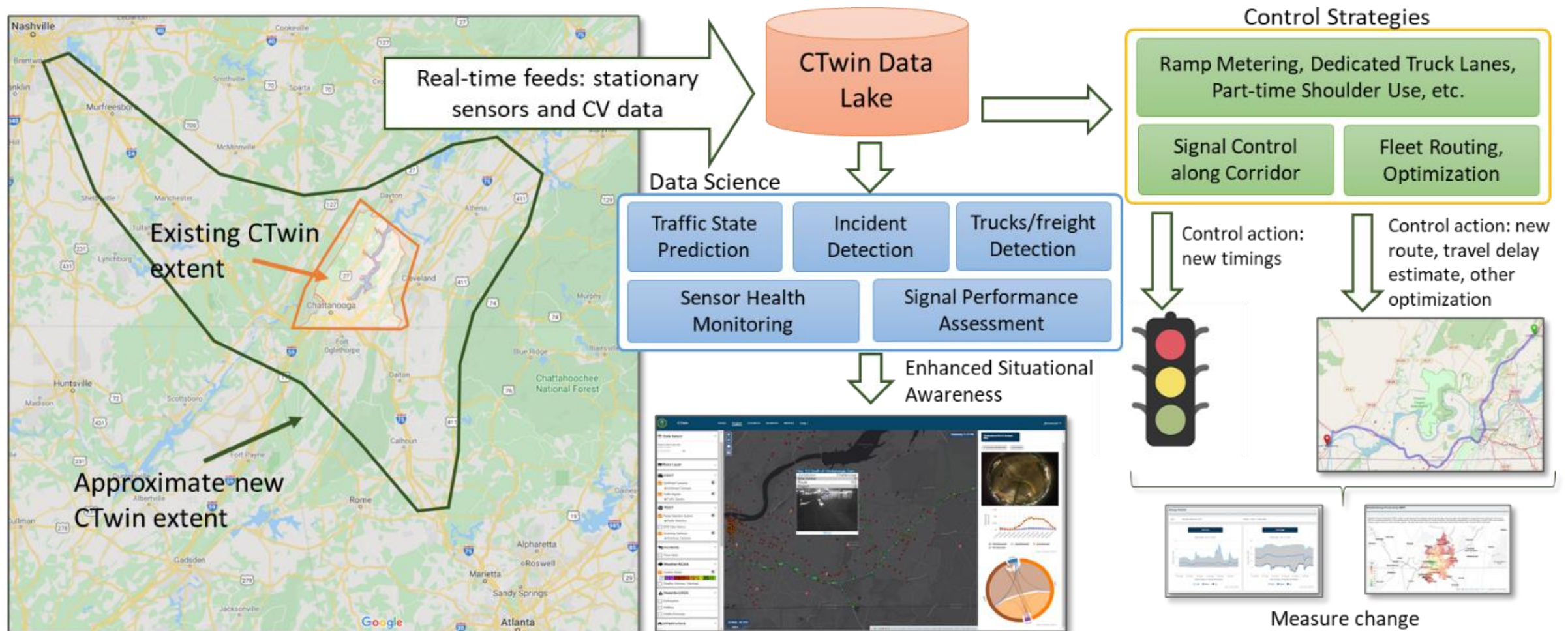


ORNL control code

Watching the signals change



Current phase work – Scaling it up!



Prior AMR Comments/Questions

Main comments

- Reviewer 1: include all modes; include induced demand; vehicle power train connection
 - Partnership with sister projects on multi-modal transit ongoing, the PI is a Co-I on a powertrain optimization project to connect the infrastructure data with the vehicle
- Reviewer 2: lack of good data for tractor-trailers; pandemic effect; cellphone probe data; boundary of analysis around energy could be limiting; insufficient resources for moving to a large area
 - Significant focus on deriving data for tractor-trailers made
 - Traffic flows have been coming back and were at 90% of pre-pandemic levels
 - Thanks to Prasad Gupte, we have a broad set of metrics that go beyond energy

Thank you for the feedback!

Collaboration and Coordination

- City of Chattanooga
- Tennessee Department of Transportation
- University of Tennessee, Knoxville (*S. Chakraborty, A. Kohls*)
- Wayne State University (Steve Remias)
- New York University (Zhong-Ping Jiang)
- TomTom, Siemens Mobility, Covenant Transport, Freightwaves

Remaining Challenges and Barriers

- Data access and ingestion continues to be challenging
 - Primarily because of proprietary systems
 - Data partners extremely forthcoming
- Freight/trucks and fleet data availability is an issue
 - Data science techniques employed
- For cyber physical control
 - Measurement using GridSmart, SPaT, and TomTom have discrepancies
 - Confluence of cyber-physical control and fleet routing is complex

Proposed Future Research

2020

- Expanding to inter-regional ingestion of real-time data sources
- Enhancement of situational awareness
- Computing system performance at multiple geospatial and spatiotemporal scales
- Scale up signal performance assessment
- Real-time incident detection and truck movements in the region
- Expand modeling and simulation into Georgia
- Evaluate and vet AI based signal control

2021

- Improve upon and scale up the control algorithms, mechanisms and strategy within the city
- Advance volume estimation to real-time, use real-time connected vehicle data
- Streamline and scale vehicle classification from video analysis
- Staged scale up and deployment of AI-based control strategies at regional level
- Optimize and enhance connected freight and fleet flows

Summary

- **Key target:** Achieve 20% energy savings at the regional level.
 - Highways, linked arterials, and freight present an opportunity at the systems level.
 - Framework is 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 stationary and mobile 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
 - Artificial Intelligence-based algorithmic control decisions for orchestration of control at system scale
 - Data science approaches to inform intersection performance, incidents, truck/freight movement for real-time control decisions and routing optimization

Thank you

