CTwin – Chattanooga Digital Twin

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Group Leader and Senior Scientist
Computational Urban Sciences Group

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Washington, DC

ORNL is managed by UT-Battelle, LLC for the US Department of Energy
DOE’s National Laboratories
About ORNL

- Staff: 4,950, including scientists and engineers in more than 100 disciplines
- 3,200 users and visiting scientists
- Budget: $1.95 billion
- Established in 1943 as part of the Manhattan Project
- 665 patents since 2005
- 149 active licenses since 2015

Supporting national missions of **scientific discovery, clean energy, and security**

Leadership in computing, neutrons, materials, and nuclear
Computational Urban Sciences Group: Complex Interdependent Urban Systems

- Impacts of greenhouse gases (GHG) on local climate
- Resulting impacts on city function
- Incorporation of renewables into city energy portfolio
- Resilience of physical infrastructure
- Economic protection, resilience, and enhancement
- ...
Supporting the nation’s emergency response

Do people have power?
EAGLE-I: Environment for Analysis of Geo-Located Energy Information

- US DOE’s operational energy-sector situational awareness tool
- Outage monitoring for over 128 million customers; 87%+ coverage of US
- Serves the ESF#12 function under the National Response Framework
- Users are from DOE, DHS, NGA, DOD, FEMA, USDA, White House, state emergency responders, among others
- Updates every 15 minutes
EAGLE-I: Environment for Analysis of Geo-Located Energy Information

Graphic illustrates electric outages from 2019 with several active hurricanes

US DOE’s operational real-time energy-sector situational awareness tool

Outage monitoring for over 128 million customers; 87%+ coverage of US

Users are from DOE, White House, DHS, NGA, DOD, FEMA, USDA, state emergency responders, among others
Over 7 million impacted electric customers who were out of power in the morning of 9/11/17 during Hurricane Irma after landfall. Majority of the ~7 million impacted electric customers were from Florida, Georgia, and South Carolina.
Real-time ‘Digital Twin’ for Regional Mobility

- ORNL: Lead lab
- NREL: Supporting lab
CTwin 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
‘Digital Twin’ for Regional Mobility, Chattanooga, TN

- Situational Awareness from real-time data feeds
  - Allows observability at a regional scale

- Simulation and Modeling, and Machine Learning
  - Identifies and evaluates improvements
  - Demonstrates feasibility/anticipated outcomes

- Cyber-Physical control actions
  - Algorithmically actuates hardware

Significant opportunity as a live testbed for connected fleets, CAVs, V2I, and active control
Real-Time Data and Simulation for Optimizing Regional Mobility using HPC

Phase 1
Situational Awareness
- Visualize real-time data
- Quantify baseline energy consumption
- Estimate energy savings for identified corridors

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

Phase 2
Simulation-based signal control
- Develop signal control optimization
- Simulation/AI driven control

Demonstrate feasibility

Phase 3
Scale-up to other areas
Operationalize Connected freight

Phase 4
Light duty commercial; Partnership; Transport "App"

Phase 5
Autonomous Vehicles; Advanced powertrain

Out years

Partnership with CDOT, TDOT, County
Data: 112 CCTV cameras
25 existing, 34 planned GridEye;
RDS data every ½ mile, On-street controllers, incident data, etc.
Provides Vehicle counts, types, lane occupancy, air quality, etc.

Geodatabase

Control Optimization

Control Actuation

Situational Awareness
Real-Time Data

- 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
- Reference data, signal info received
- Real-time access to GridSmart cameras working (72 + 70 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
Metrics Implementable 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)
  – $f(\text{mobility weighted by [energy, cost, trip purpose]})$
Candidate Corridor for Simulation

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

- GridSmart Cameras
- Signalized Intersections with timing information
- Radar Detection Systems
- Traffic Incidents for year 2018

Spatial scope: Signalized Arterial

Temporal scope: frequency of adjusting signal settings

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RDS Highway Data: Shallowford Road Corridor

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

- 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

RDS sensors  Gridsmart cameras  Interstate on/off ramps  TDOT SmartWay Traffic cameras

I-75 Northbound

I-75 Southbound

SmartWay

OAK RIDGE
National Laboratory

Computational Urban Sciences Group
Phase 2: Delivering intelligence at the edge

Can we control these in a swarm?

How much ‘control; do we really have?

Can we run AI on the device?
  • How much compute resource are needed?
  • How much power?
  • How much bandwidth?

How do we degrade gracefully?

How do we assure sensor sanity?
Integrated Simulation of Travel Behavior

Traveler Behavioral/Decision Modeling

- Activity Planning
- Activity Generation
- Activity Scheduling
- Vehicle Choice
- Route Choice
- Housing Choice

Performance

- Congestion
- Safety/Incidents
- Energy Use
- Emissions

People

- Activity Engagement
- Traveler Movements

Vehicle Energy Use

Transportation Network

Communication Infrastructure

Sensor Networks

Traffic Management
Digital Twin of an Electric Utility – Virtual EPB

Graphic Courtesy: Joshua New
Towards Integrated Co-Dependent Smarter Systems
Smart Decisions in Practice

Graphic Courtesy: Airton Kohls
Thank you!

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