Chattanooga's Smart Infrastructure for Safe and Efficient Mobility Systems

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TS Department of Technology Services

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CUIP Center for Urban Informatics & Progress

Scenic City

→

Gig City

→

Smart and Connected City

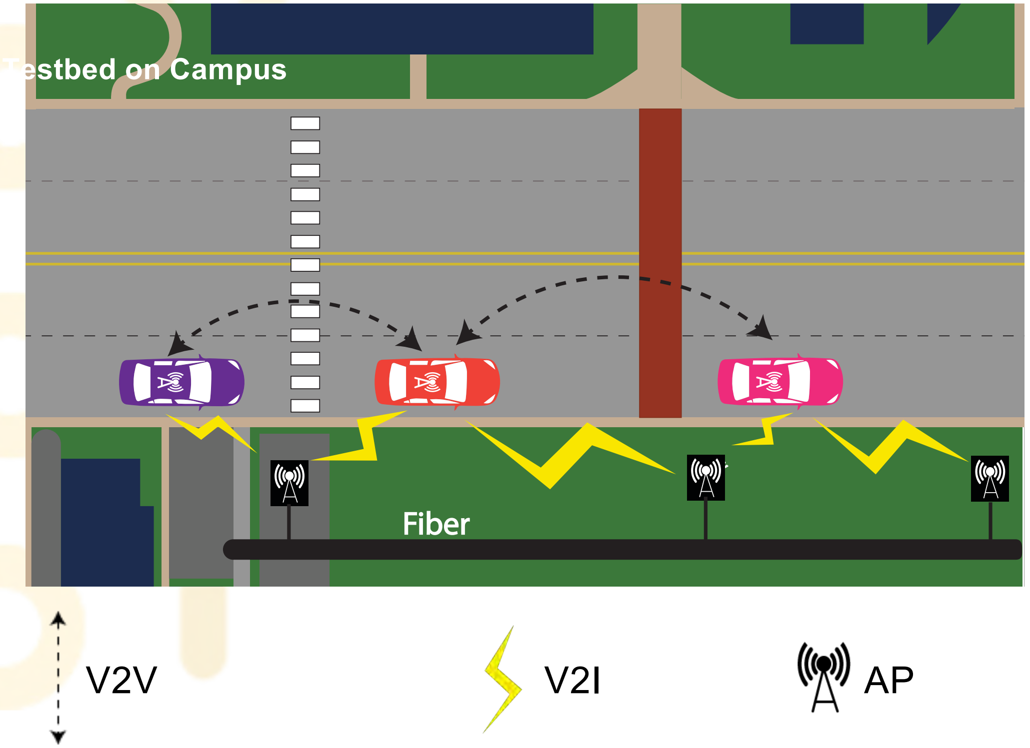
Chattanooga's Vision: Chattanooga be the city-wide testbed to next-generation smart city and transportation (electric, connected, and automated vehicles)

Partners/ Collaborators

- City of Chattanooga
- Hamilton County
- Electric Power Board (EPB) of Chattanooga
- CDOT/ TDOT
- The Enterprise Center in Chattanooga
- Tennessee Valley Authority (TVA)
- Tennessee American Water
- Siskin Hospital for Physical Rehabilitation
- Erlanger Health Systems
- Co-Lab
- US Ignite
- MetroLab Networks
- South Big Data Hub
- Next Generation Internet (NGI) - European Commission initiative to shape the development and evolution of the Internet into an Internet of Humans
- Oak Ridge National Lab (ORNL)
- Georgia Tech Research Institute (GTRI)
- Georgia Tech
- University of Pittsburgh
- Vanderbilt University
- University of Arizona
- University of San Francisco
- Colorado School of Mines
- Virginia Tech
- University of Tennessee at Knoxville
- University of Memphis
- LeMoyne-Owen College
- l3s Research Center - Leibniz University (Germany)

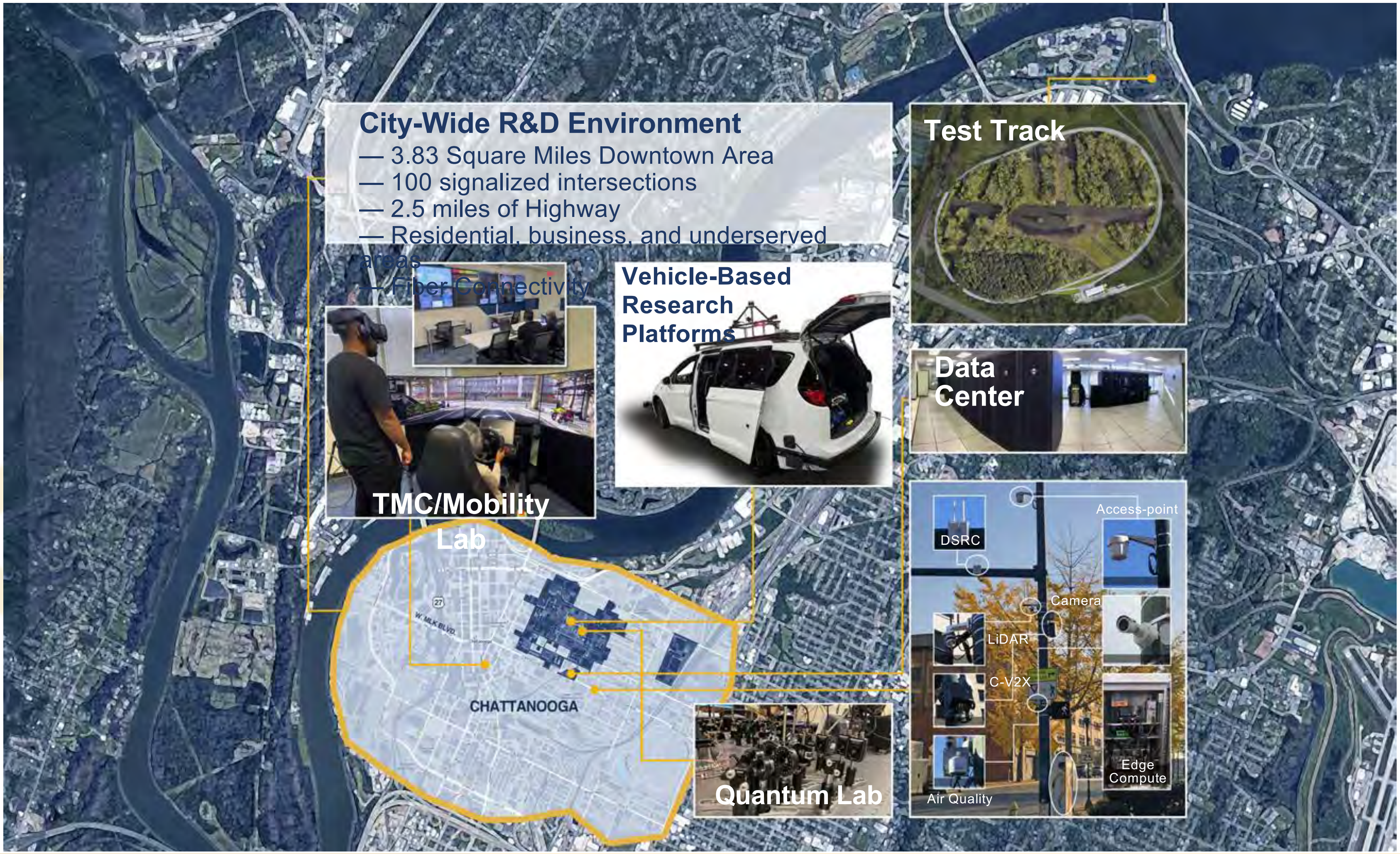
How It Started!

NSF - US Ignite: Fleet Management of Connected and Autonomous Vehicles in Urban Settings – 2016

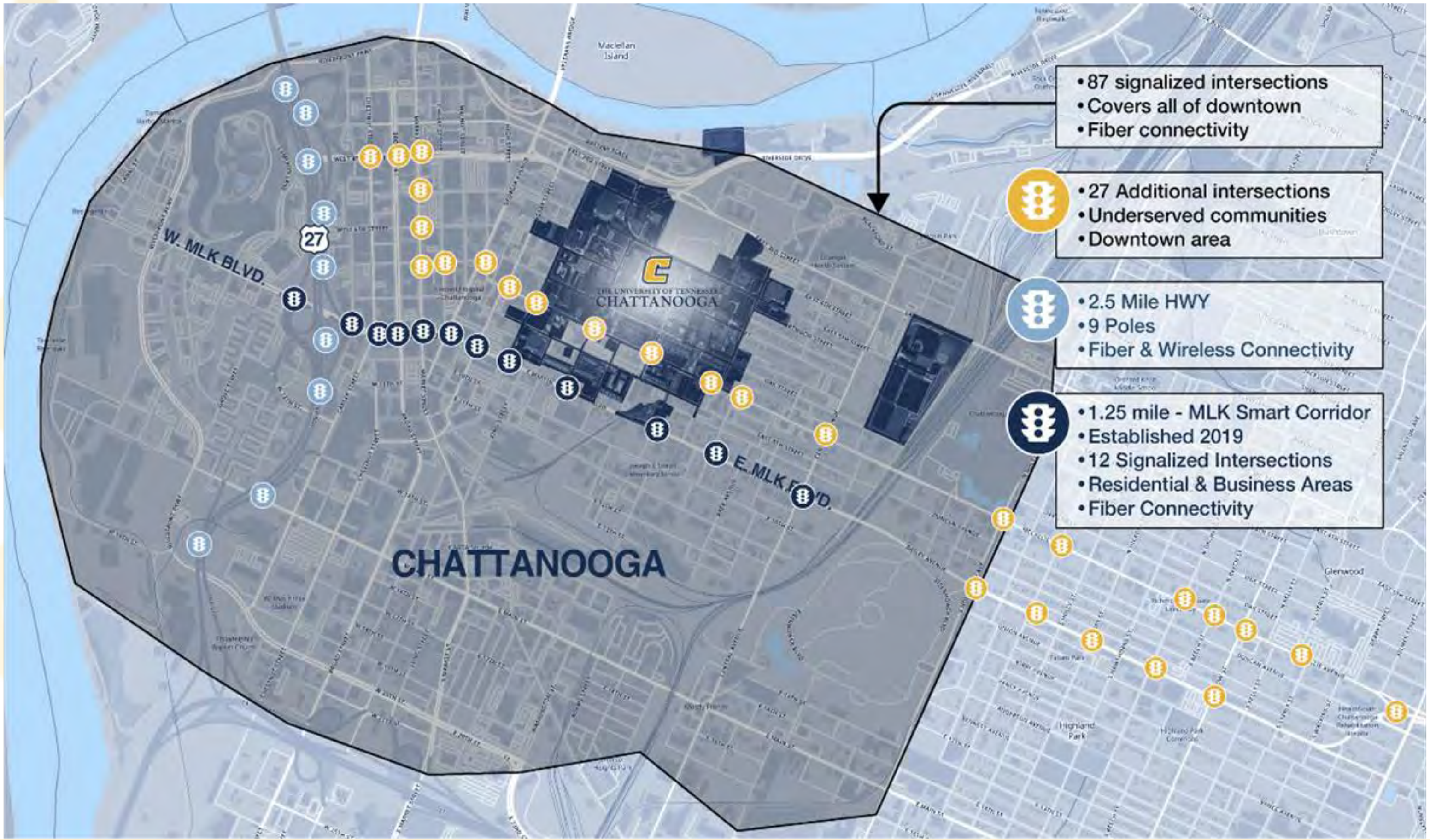


City-Wide R&D Environment

- — 3.83 Square Miles Downtown Area
- — 100 signalized intersections
- — 2.5 miles of Highway
- — Residential, business, and underserved areas
- — Fiber Connectivity



Chattanooga Testbeds



- 87 signalized intersections
- Covers all of downtown
- Fiber connectivity

- 27 Additional intersections
- Underserved communities
- Downtown area

- 2.5 Mile HWY
- 9 Poles
- Fiber & Wireless Connectivity

- 1.25 mile - MLK Smart Corridor
- Established 2019
- 12 Signalized Intersections
- Residential & Business Areas
- Fiber Connectivity

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Testbed-As-A-Service

- TaaS - Cloud-based platform that provides streamlined access to testbed resources and data
- Accessible anywhere
- Software Development Kit - Access to historical streams and real-time data streams
- Hybrid - Event Driven Architecture
  - Data filtered, enriched, and processed at Edge, On-Premise, and Cloud
- Events: SPaT, CV Msg, Approach Arrival, Pedestrian Crosswalk, etc.
- 10,000,000 Events Messages/ Day
- 2 Billion Data Points

Digital Twin

- Real-time data on traffic flow and traffic state using AI/ ML
  - object detection & object tracking
  - multi-target multi-camera tracking
- Real-time speed and travel time
- Real-time data from all traffic controllers
- Collecting data from connected infrastructure and connected vehicles
  - DSRC
  - CV2X
- Real-time data from transit

Digital Twin - MLK Smart Corridor

Applications

Application Categories

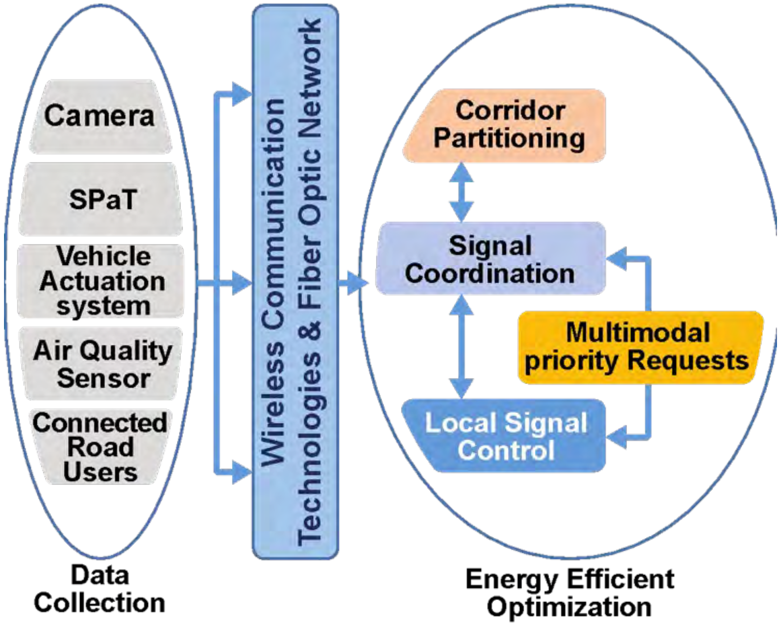
- Safety Applications (VRU and Roadway)
- Traffic Optimization and Control
- Nexus of Transportation, Energy, and People

Safety Applications	Traffic Optimization and Control	Nexus of Transportation, Energy, and People
• VRU Safety • Roadway Safety • Cooperative Perception and Autonomation	• Eco Traffic Signal Timing • Emergency Vehicle Preemption • Transit Signal Priority • Smart Parking	• System-of-Systems Analytics • E2E Decision Support System for EV Charging

Optimizing Traffic Control Systems

Improve corridor-level fuel consumption and GHG emissions

- Ecological Adaptive Traffic Control System (**Eco-ATCS**) that minimizes an Ecological Performance Index (**Eco-PI**)
- A bi-level signal control system: a lower-level at local intersections and a global-level, enabling coordination
- A flexible priority system ready to accommodate transit priority and vulnerable road users (VRU)


Camera
SPaT
Vehicle Actuation system
Air Quality Sensor
Connected Road Users
Data Collection
Wireless Communication Technologies & Fiber Optic Network
Corridor Partitioning
Signal Coordination
Multimodal priority Requests
Local Signal Control
Energy Efficient Optimization

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University of Pittsburgh

Georgia Tech

OAK RIDGE National Laboratory

- Ecological Performance Index (Eco-PI)
- Adaptive Traffic Controller Optimization Algorithm
- GHG and Energy Consumption
- Hardware-in-the-Loop (HIL)
- Software-in-the-Loop (SIL)
- Field Test

Eco-PI

Development of Ecological Performance Index (Eco-PI) for Various Vehicle Types

- Stop penalty (*k*) is defined as function of following parameters:

$$K = f(S_A, S_D, G_A, FC_I, T_D, A)$$

S_A : *accelerating (final) speed (mph)*
S_D : *decelerating (initial) speed (mph)*
G_A : *accelerating grade (%)*
FC_I : *idling fuel consumption rate (g/sec)*
T_D : *decelerating duration (sec)*
A : *acceleration (ft/sec²)*

$$k_{LDV} = \frac{1.321e-2 \cdot {S_D}^2 \cdot T_D + 0.3979 \cdot {T_D}^2 - 5.102 \cdot FC_I \cdot T_D}{FC_I \cdot T_D} + \frac{1.608 \cdot S_D + 0.2311 \cdot S_D \cdot T_D + 4.966e-3 \cdot {S_D}^2 \cdot G_A \cdot T_D + 3.073e-2 \cdot {S_D}^2 \cdot FC_I \cdot T_D + 7.796e-3 \cdot S_A \cdot S_D \cdot T_D}{FC_I \cdot T_D \cdot A}$$

$$k_{bus/HDV} = 6 \cdot \left(\frac{8.674e-19 \cdot S_D \cdot \left(1.574e14 \cdot S_A \cdot {G_A}^2 + 1.574e14 \cdot S_A \cdot S_D \cdot G_A + 7.553e17\right)}{FC_I \cdot A} - \frac{\left(8.314e-3 \cdot {S_D}^2 \cdot {FC_I}^2 \cdot {T_D}^2 + 8.977 \cdot {S_D}^2 \cdot FC_I + 5.725e23 \cdot {FC_I}^2 + 2.983 \cdot (S_A \cdot FC_I \cdot T_D) + 4.946 \cdot T_D\right) \cdot 1.694e-3}{FC_I^2} \right)$$

- If the fleet consists of both categories (LDVs and buses (HDVs)) final *K* for the movement should be adjusted by the percentage of each vehicle category in the fleet:

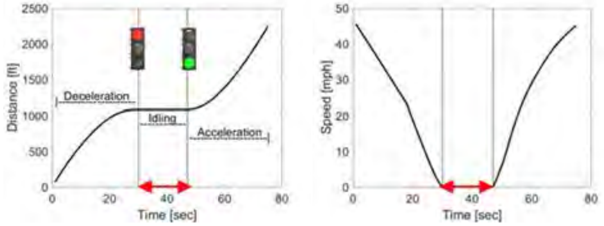
$$K = (1-p)k_{LDV} + p \cdot k_{bus/HDV}$$

- Eco-PI is a combination of mobility and sustainable measures to be minimized during the optimization, which can be mathematically expressed as:

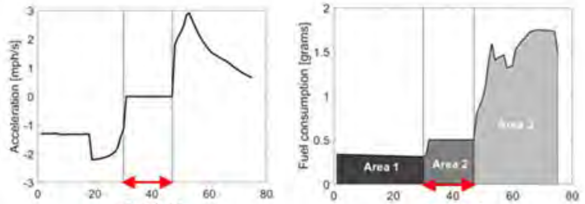
$$Eco-PI^i_{total} = \sum_{m=1}^{n} D_{m_i} + K_{m_i} * S_{m_i}$$

i: Observed intersection
n: Total number of eligible movements
m: An eligible movement in the network
D: Stopped delay for movement
K: Stop penalty of the fleet
S: Number of stops

- Eco-PI considers the impact of several operating conditions (e.g., vehicle type, speed, grade) that impact vehicular fuel consumption footprints at signalized intersections.



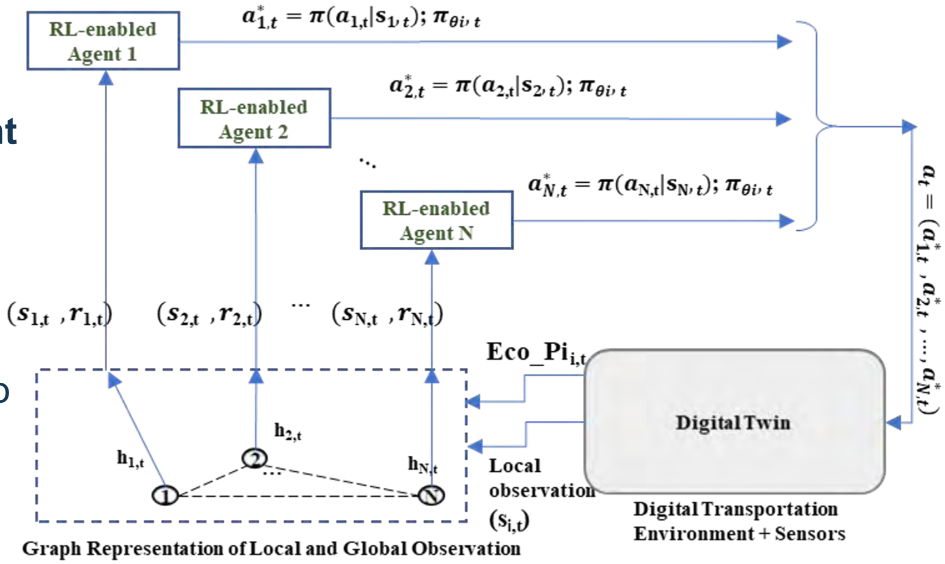
Stop profile　*Speed stop profile*



Acceleration profile　*Fuel consumption profile*

Global Optimization – RL

- **Using Decentralized Graph-based Multi-Agent Reinforcement Learning (DGMARL) to optimize signal timing**
  - **Objective Function**: Eco_PI
  - **Input**: Vehicles occupancy, Signal State
  - **Output**: Switch or Stay in current phase
  - **Signal Phase Control:** Phase sequence free, priority given to the phase with highest occupancy;
  - **Constraints Enforced:** Minimum green, Pedestrian recall, Pedestrian, Yellow and red clearance time

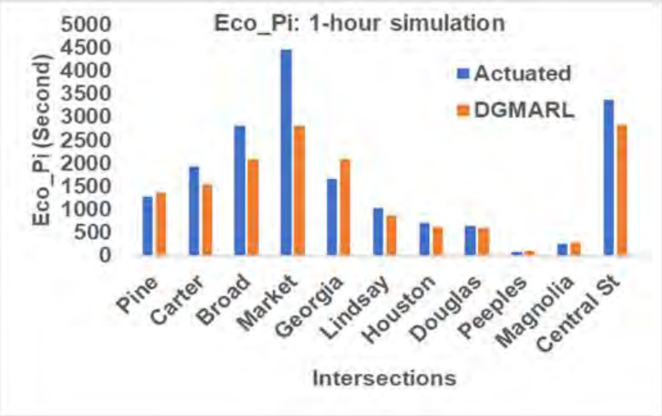


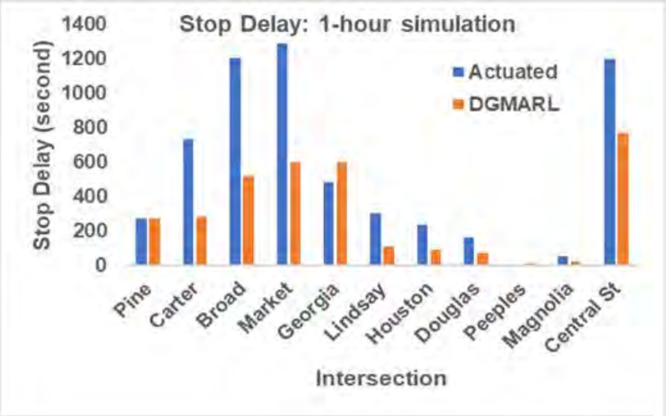
Test Scenario:

- Data: PM-peak hour, Dec-15-2022

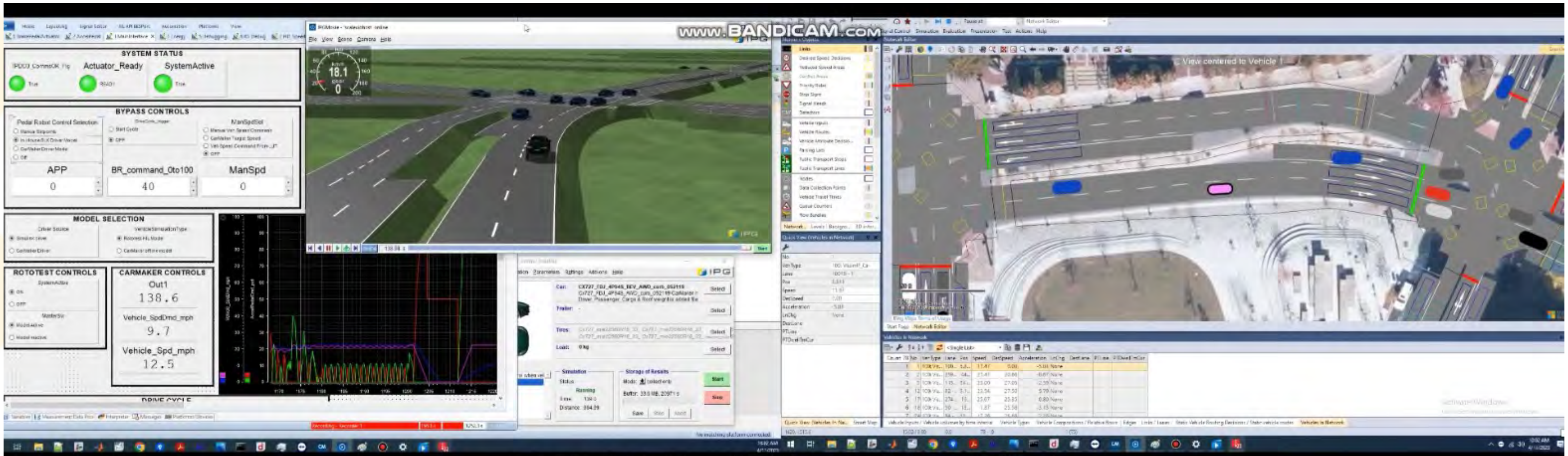
Summary of Results

- Overall Eco_Pi improved by **16.63%**
- Overall stop delay improved by **43.80%**
- Number of stops reduced by **15.13%**






Actuated
DGMARL
200 ft
200 ft



SYSTEM STATUS

IPDDI_CommOK_Flg

True

Actuator_Ready

READY

SystemActive

True

BYPASS CONTROLS

APP: 0

BR_command_0to100: 40

ManSpd: 0

MODEL SELECTION

ROTOTEST CONTROLS

CARMAKER CONTROLS

Out1: 138.6

Vehicle_SpdDmd_mph: 9.7

Vehicle_Spd_mph: 12.5

DRIVE CYCLE

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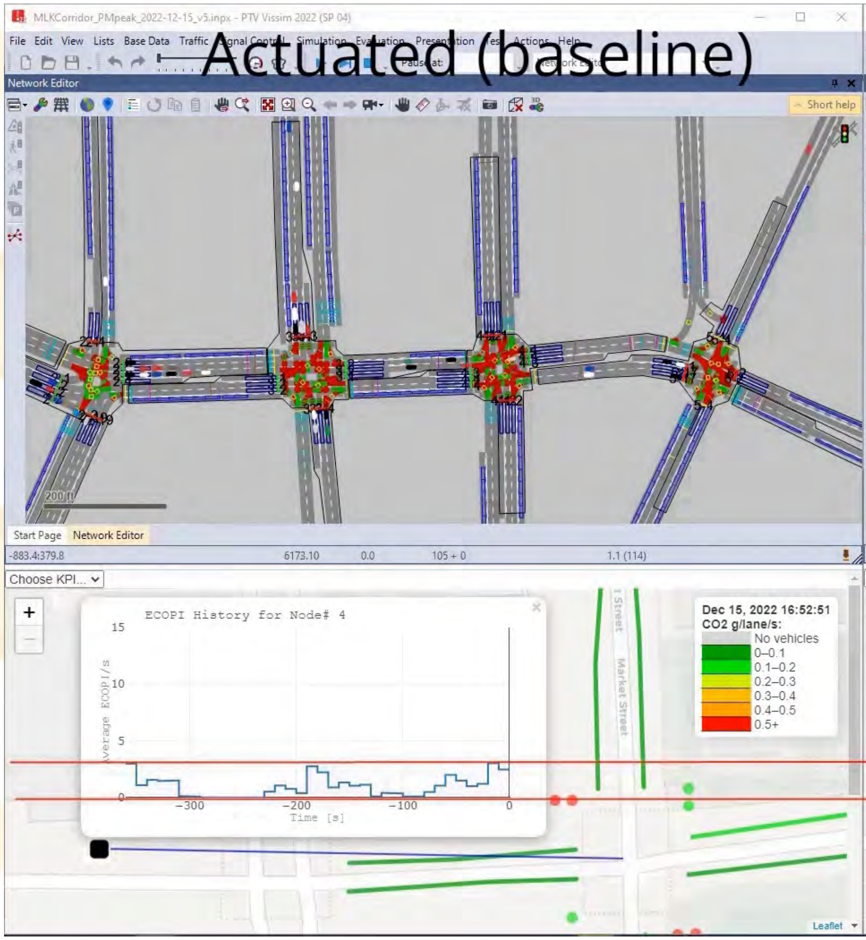
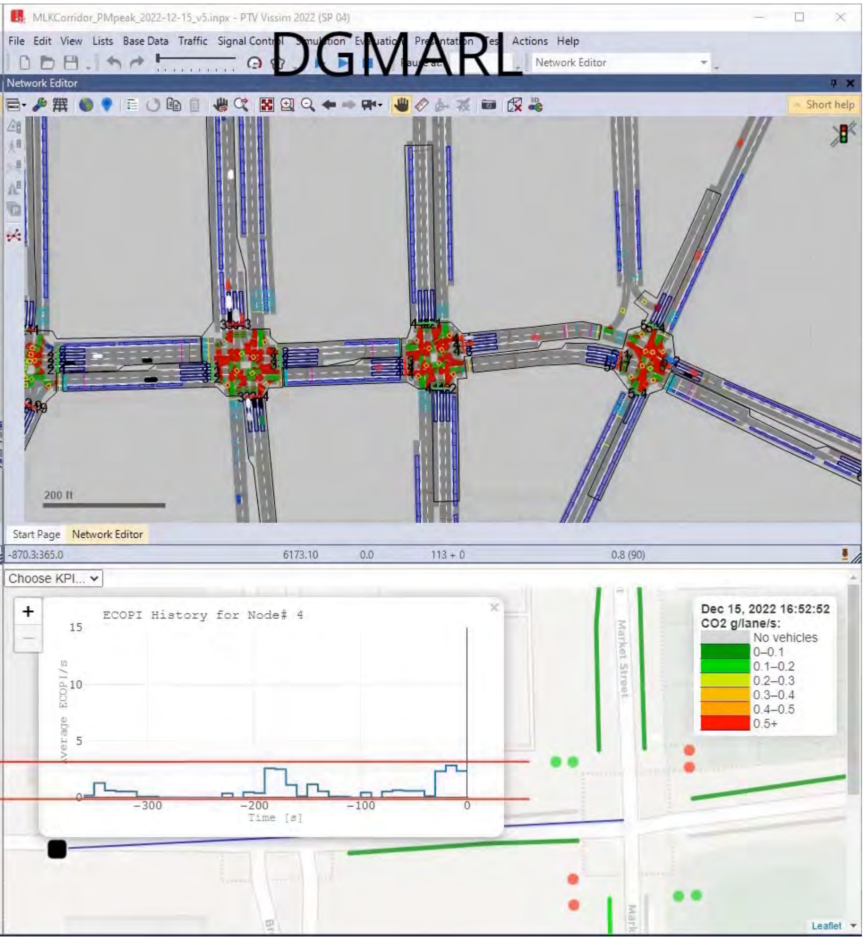
Actuated (baseline)

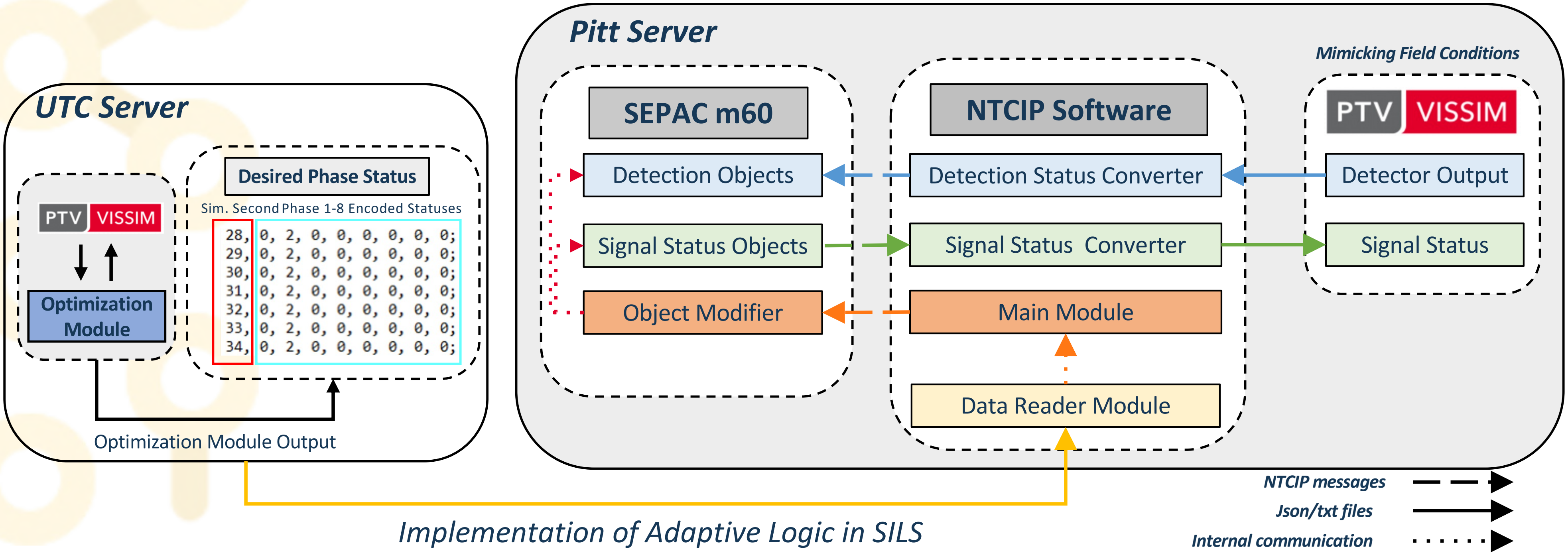


DGMARL



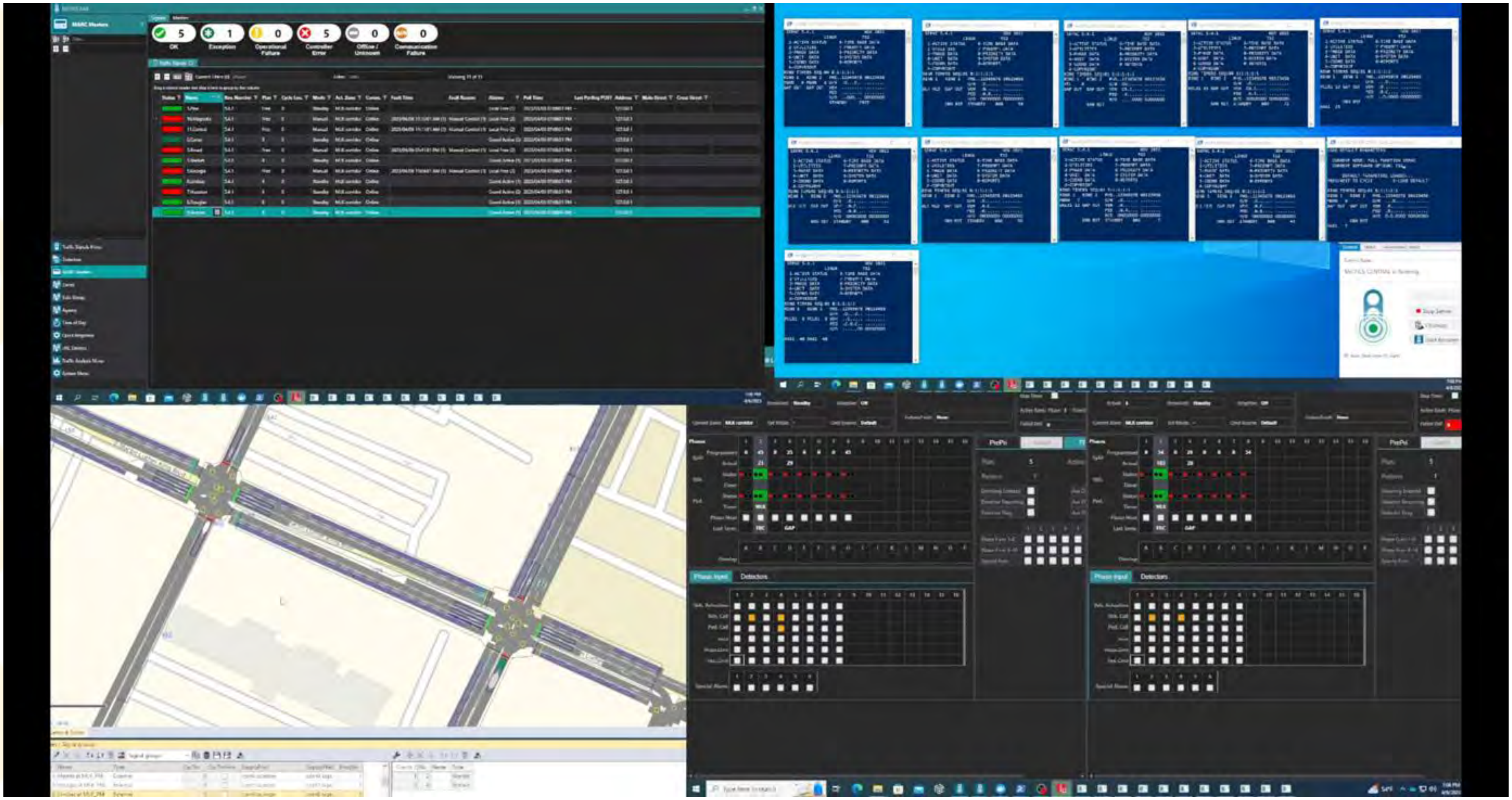
SILS

Three ways of controlling signal timings in adaptive traffic control with the actual field controller (SEPAC):
1. Manipulation of detection actuations; 2. Use of phase holds, omits, and force-offs; 3. ~~Changing time-of-day (TOD) patterns.~~

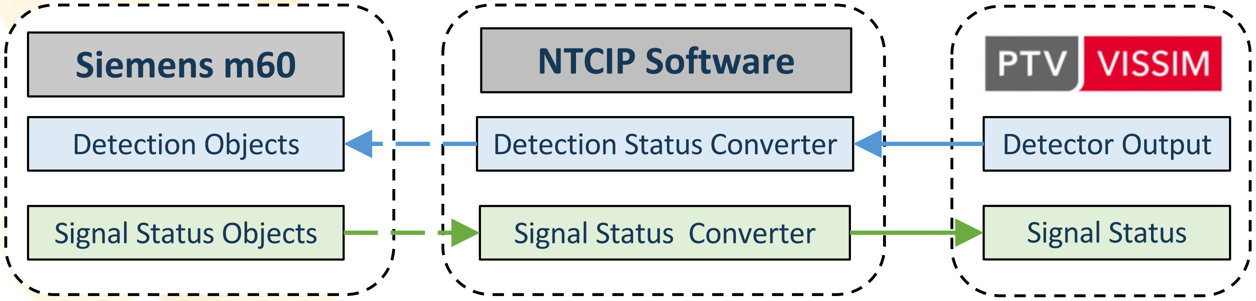


```
28, 0, 2, 0, 0, 0, 0, 0, 0;
29, 0, 2, 0, 0, 0, 0, 0, 0;
30, 0, 2, 0, 0, 0, 0, 0, 0;
31, 0, 2, 0, 0, 0, 0, 0, 0;
32, 0, 2, 0, 0, 0, 0, 0, 0;
33, 0, 2, 0, 0, 0, 0, 0, 0;
34, 0, 2, 0, 0, 0, 0, 0, 0;
```

Implementation of Adaptive Logic in SILS


MAXTIME
MARC Masters
5
OK
1
Exception
0
Operational Failure
5
Controller Error
0
Offline / Unknown
0
Communication Failure

HIL



Siemens m60

Detection Objects

Signal Status Objects

NTCIP Software

Detection Status Converter

Signal Status Converter

PTV VISSIM

Detector Output

Signal Status