Project ID: eems102

AI-Engine for Optimizing Integrated Service in Mixed Fleet Transit Operations

Chattanooga Area Regional Transportation Authority

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2021 U.S. DOE Vehicle Technologies Office Annual Merit Review Meeting

Project Overview

TIMELINE

Project Start Date: October 1, 2020
Project End Date: December 31, 2023
Percent Complete: 5%

TEAM MEMBERS

Chattanooga Area Regional Transportation Authority
Vanderbilt University
University of Houston
University of Tennessee at Chattanooga
Cornell University
Siemens
Pacific Northwest National Laboratory

BARRIERS

- Difficulty in operating integrated fixed-dynamic transit services in manner that maximizes energy efficiency
- Optimizing transit efficacy to increase user accessibility
- Community engagement to increase adoption of newly developed lower energy transport options

BUDGET

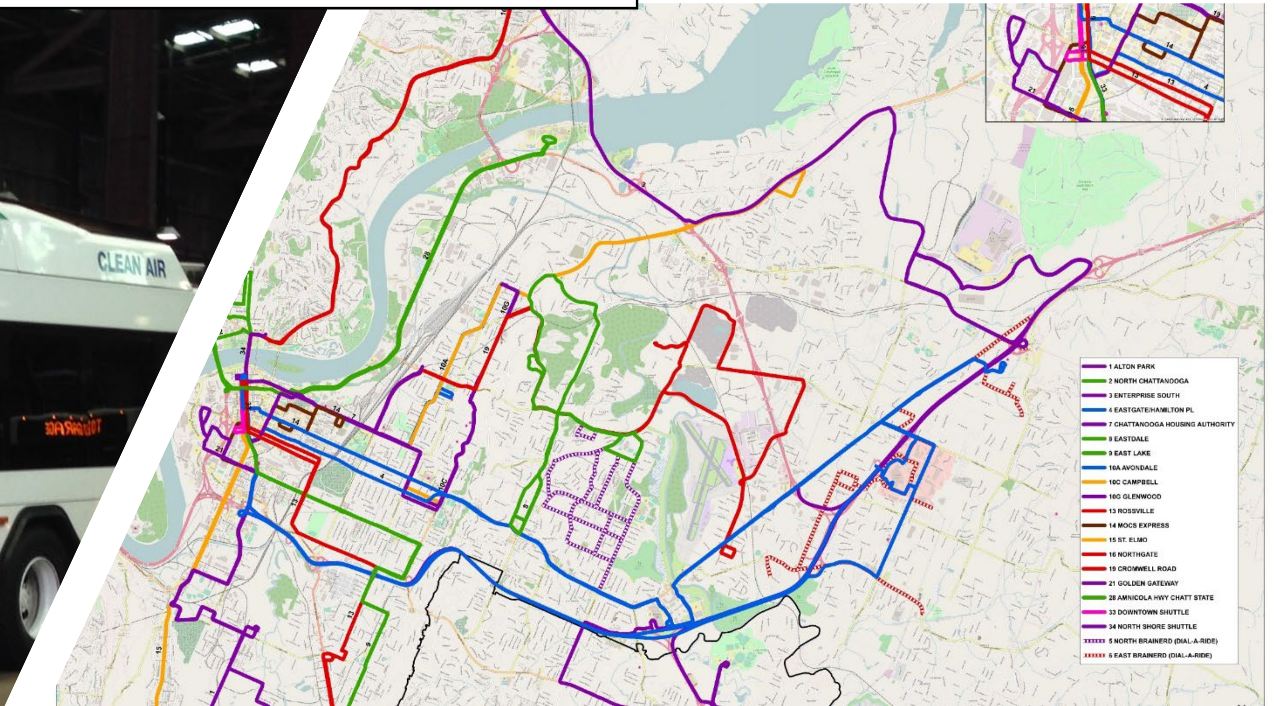
- Total Project: $2,306,858
- DOE Funds: $1,750,155
- Cost Share: $ 556,703

Objectives

- Energy per passenger mile
- Total energy consumed
- Availability of daily trips served by transit

10%

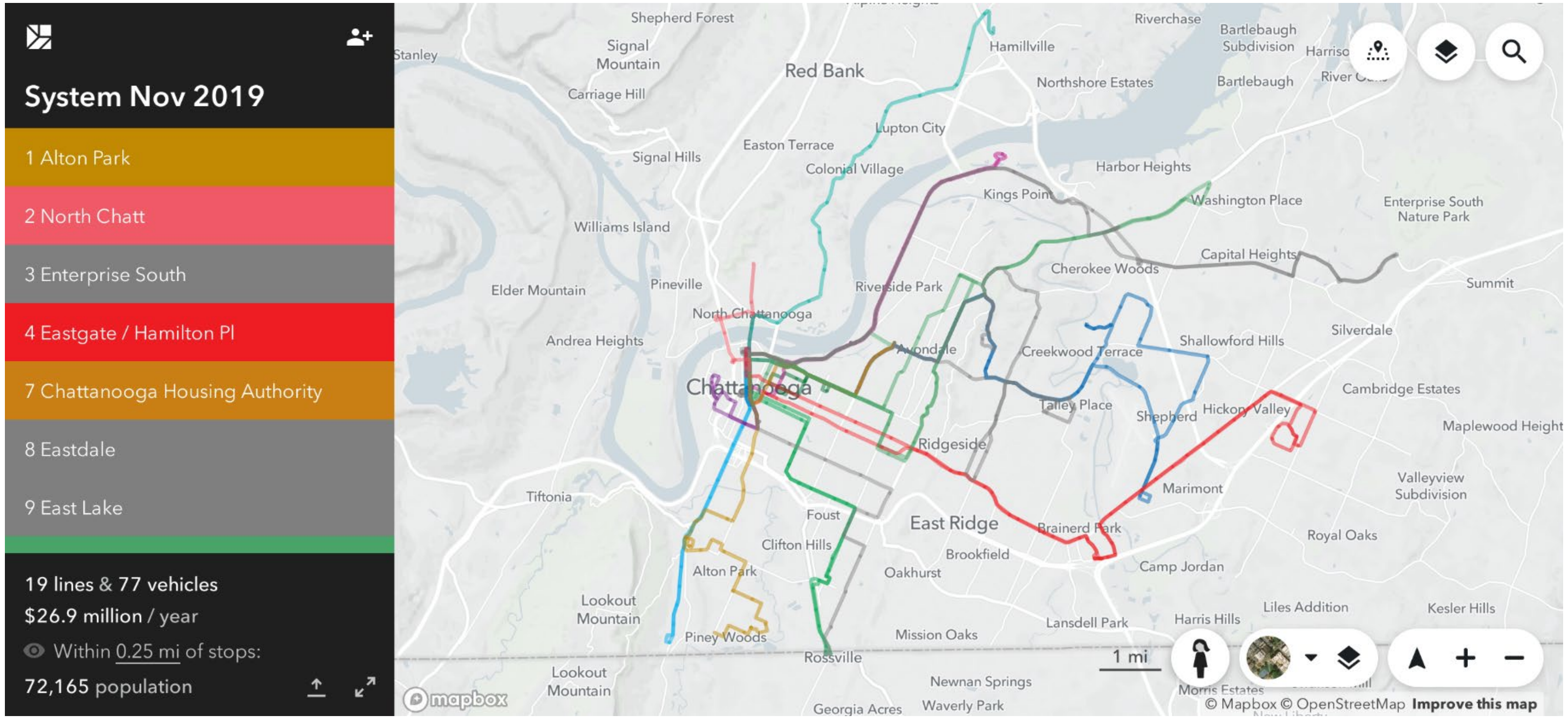
Chattanooga Area Regional Transportation Authority (CARTA)

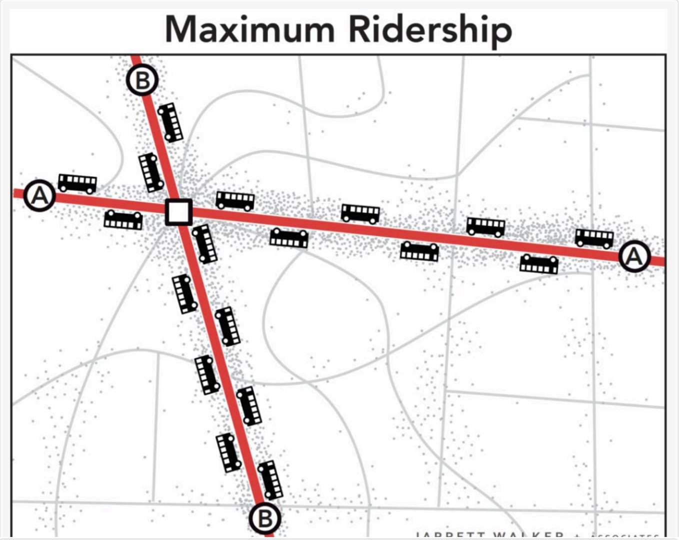


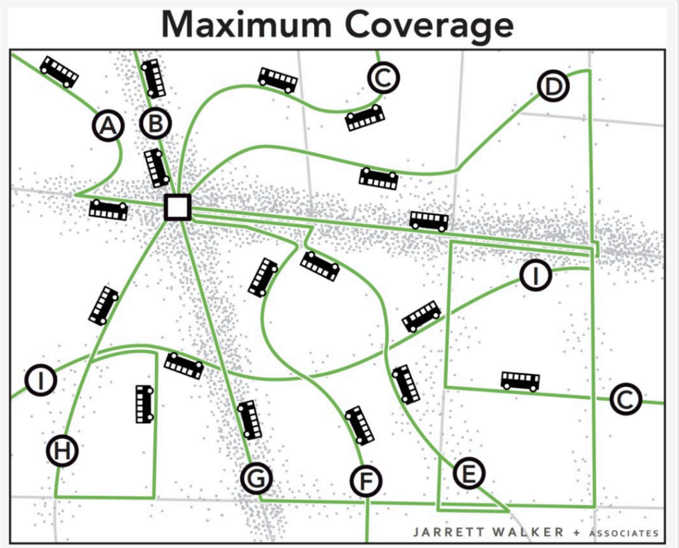
Approach

CARTA supports a multimodal system with a mixed diesel, hybrid and electric bus fleet in addition to public bike share, car sharing, and parking.

Opportunities for redesigning public transit



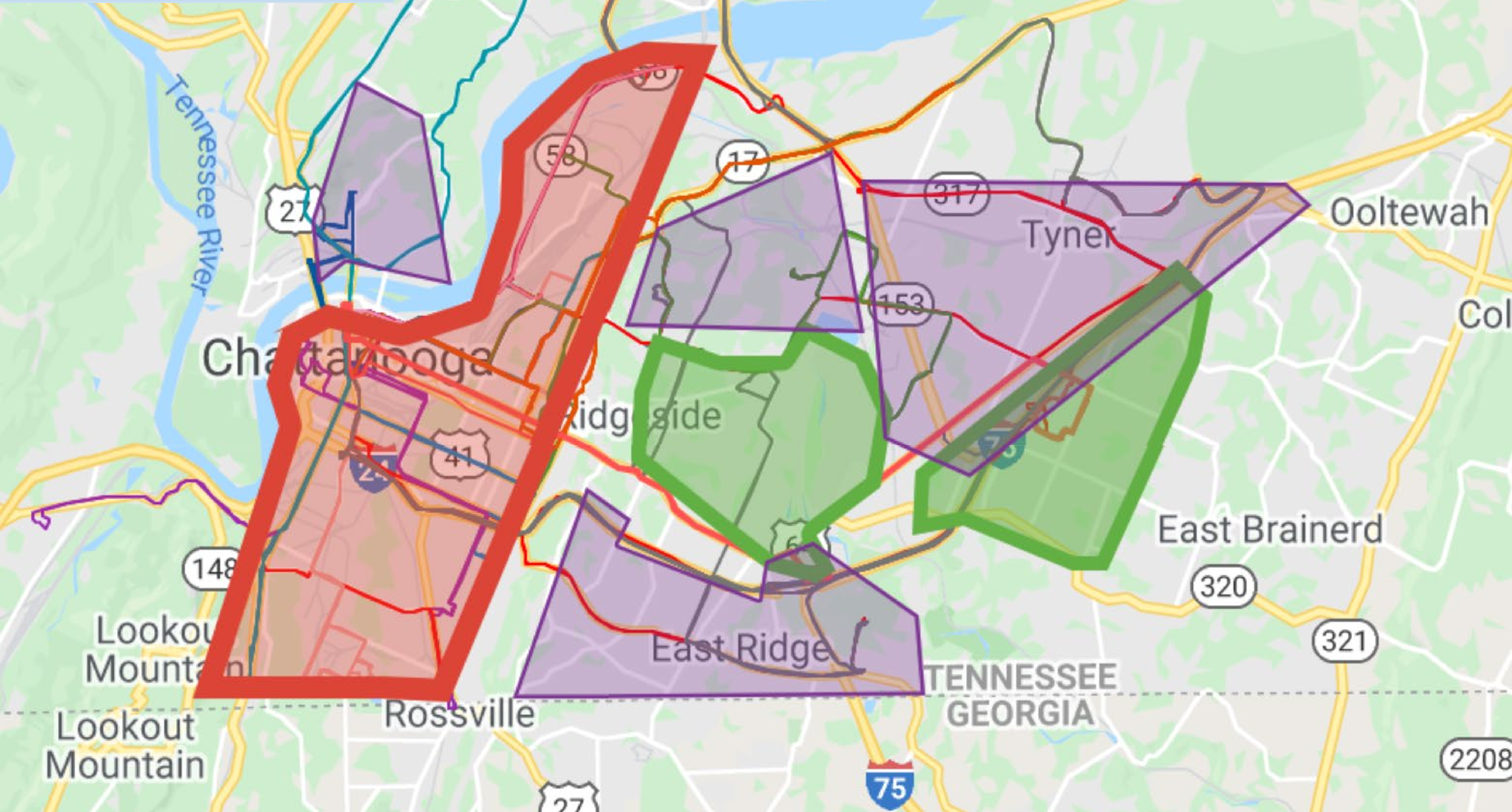




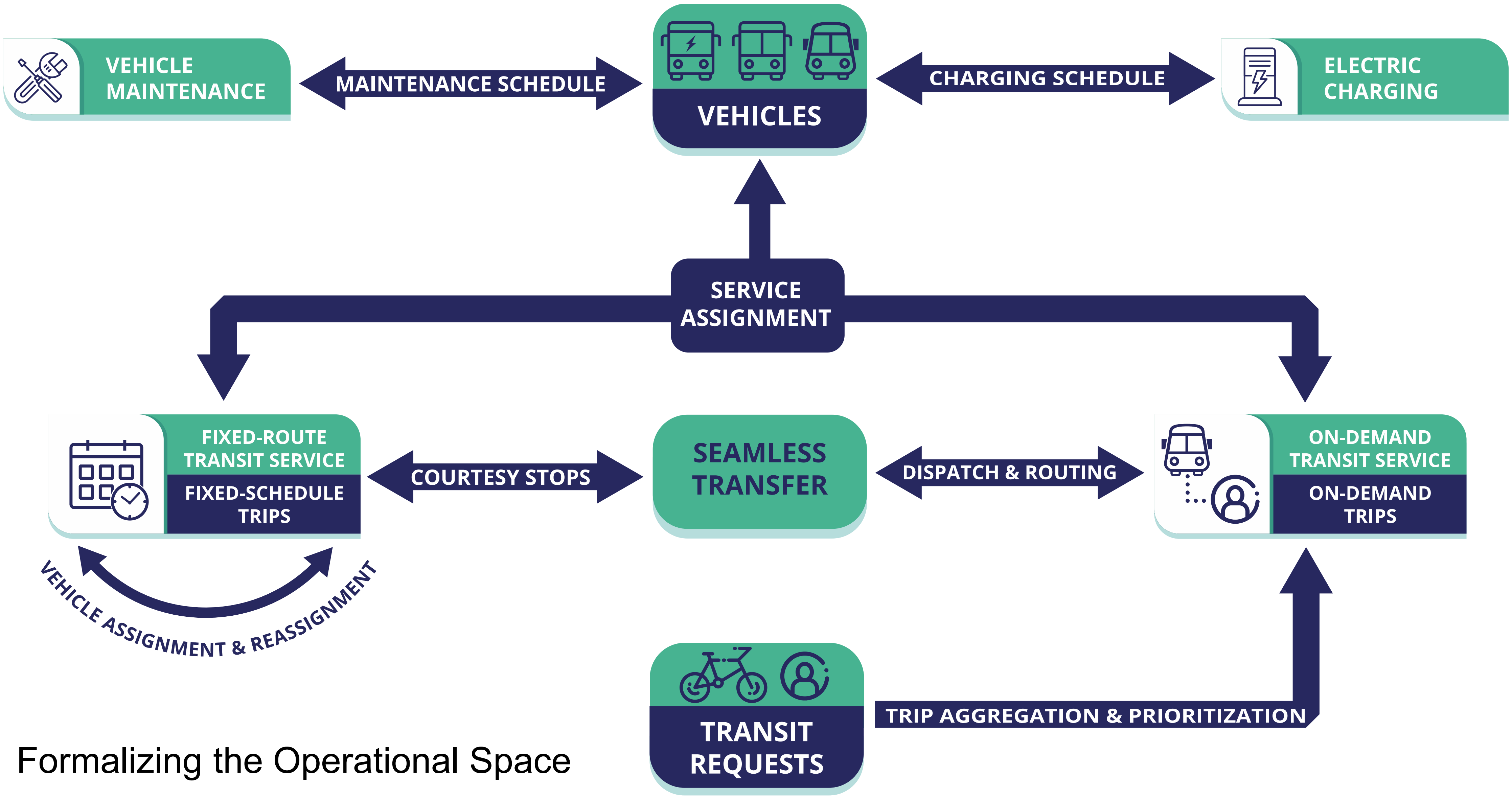
https://humantransit.org/2018/02/basics-the-ridership-coverage-tradeoff.htm

The challenge is to design a transit system that maximizes the mobility while minimizing the total energy consumed.

Study Areas

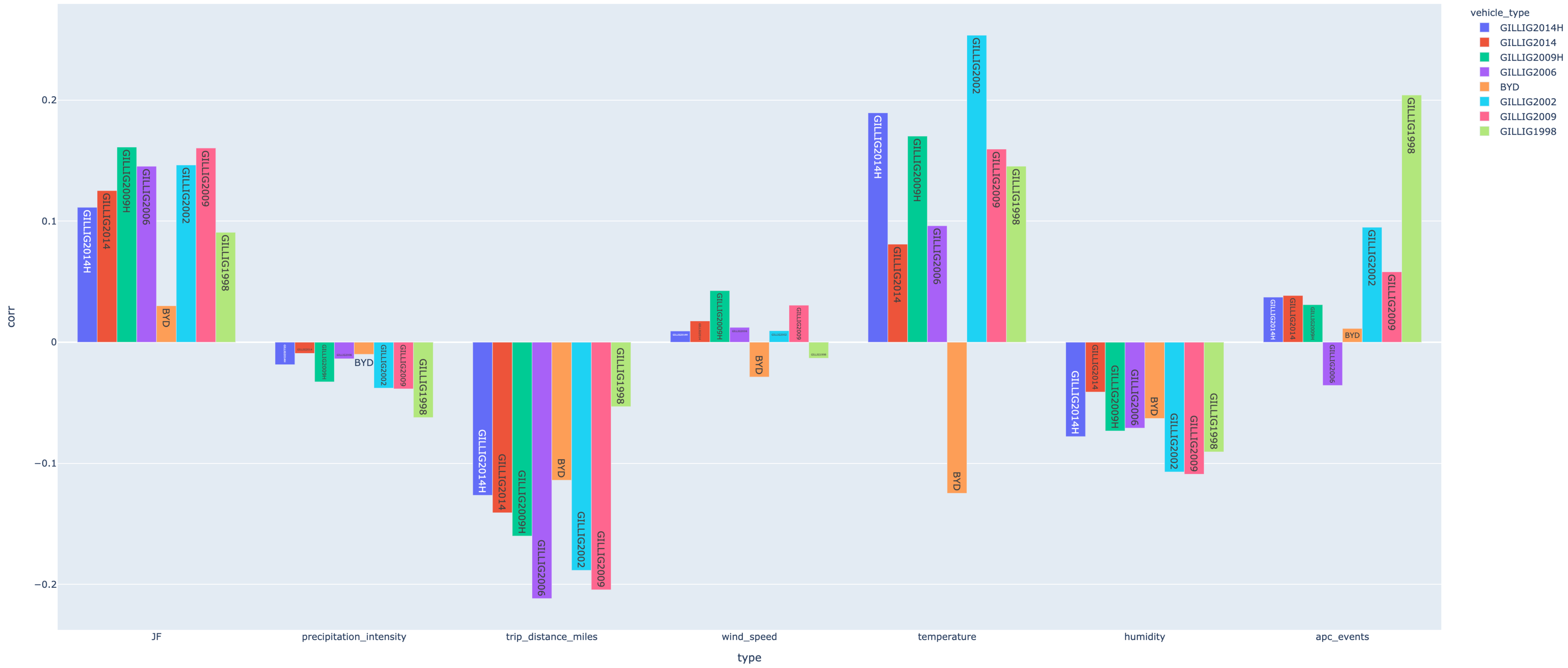

Harrison
Ooltewah
Tyner
Chattanooga
Ridgeside
East Ridge
East Brainerd
Tennessee River
Lookout Mountain
Lookout Mountain
Rossville
TENNESSEE
GEORGIA
17
317
153
58
27
41
148
320
321
75
2208

Approach



Formalizing the Operational Space

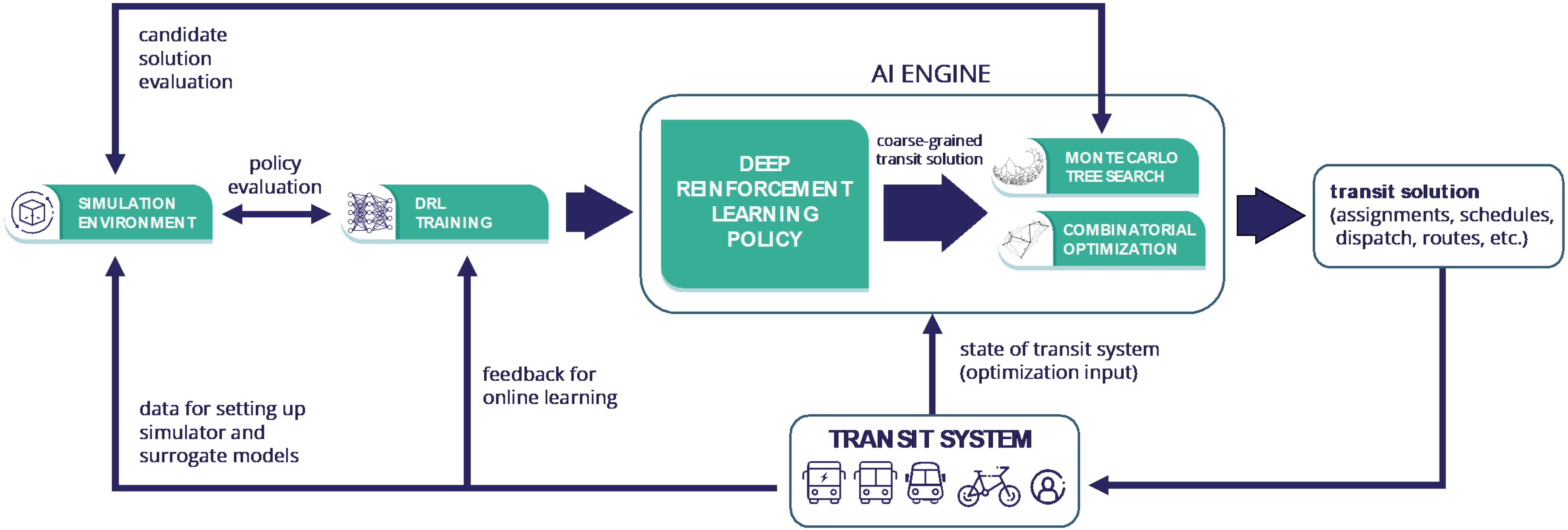
Approach



The project builds upon the project ti100:

High-Dimensional Data-Driven
Energy Optimization for Multi-Modal Transit Agencies

Proposed Approach

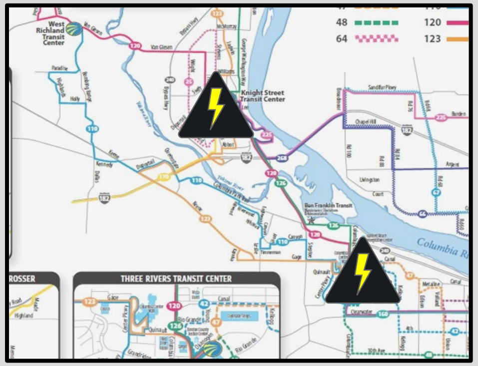


Proposed Approach

Planning the use of of electric transit services while ensuring the extra power demand does **not overload the power grid**

Problem: schedule bus charging at chargers located along route

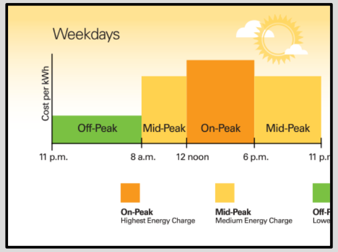
Electric Buses



Geo-located chargers

Constraints:

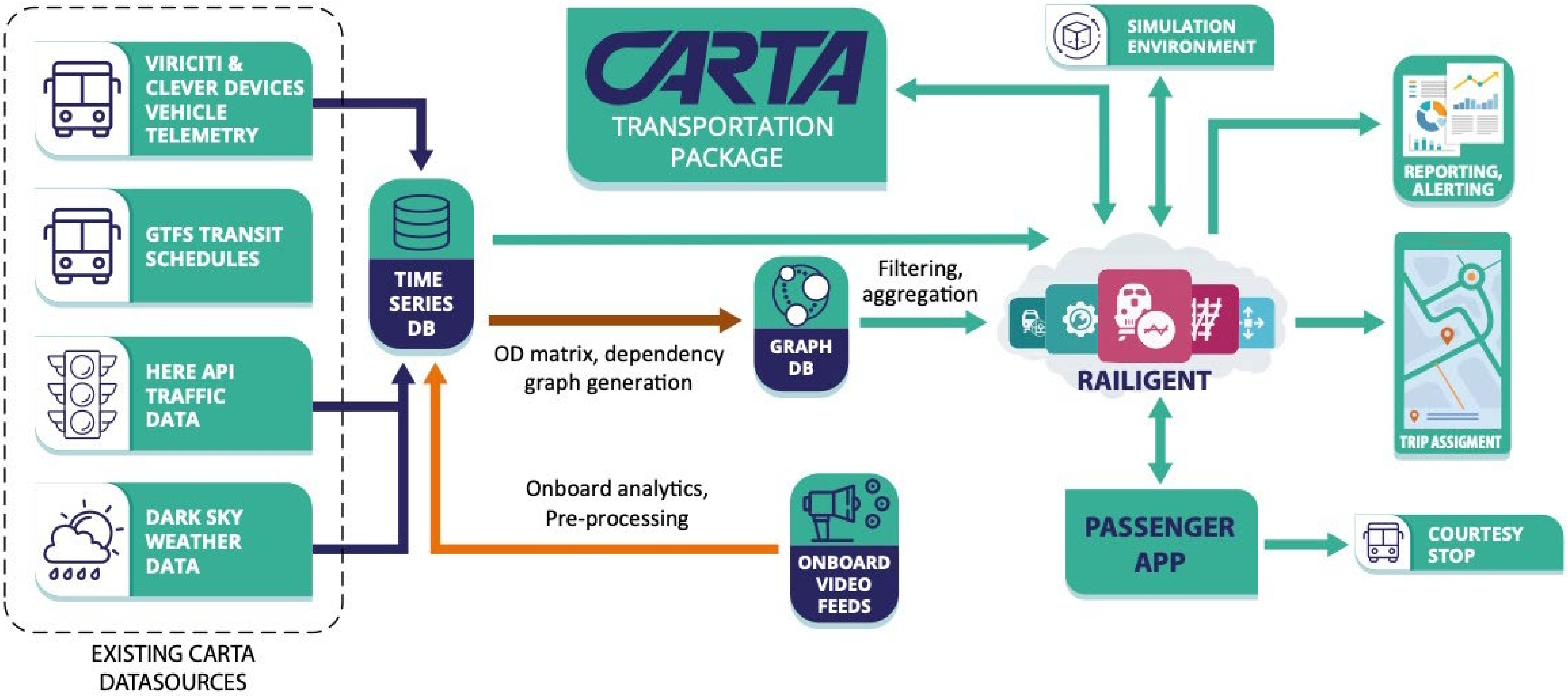
EVs increase grid demand: avoid grid overloading and failures

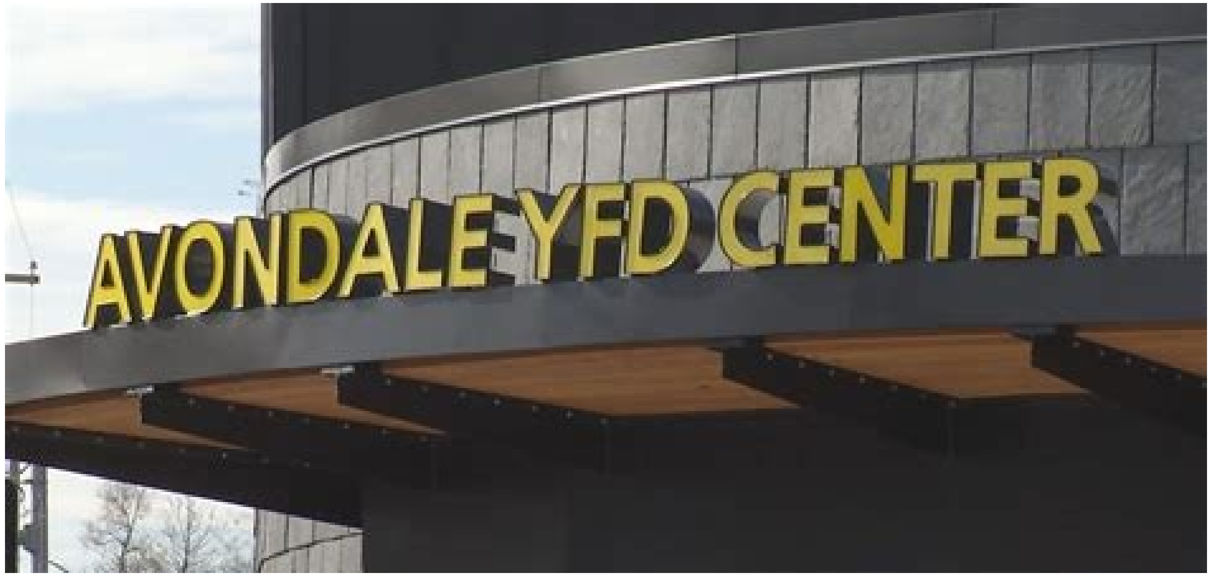


Energy prices fluctuate: avoid over-spending on energy

Must maintain level of service => avoid delays or running out of charge

Integrated System Concept





Community Engagement

Identification of local community institutions composed of existing relationships. Settings to likely include:

- Community Centers
- Schools
- Signal Centers
- Public Housing
- Local Community College

Community Engagement

- Conduct focus group with key community members on how people access, use and think about transit.

- Design and disseminate survey based on data gathered from focus groups to larger sample of community.

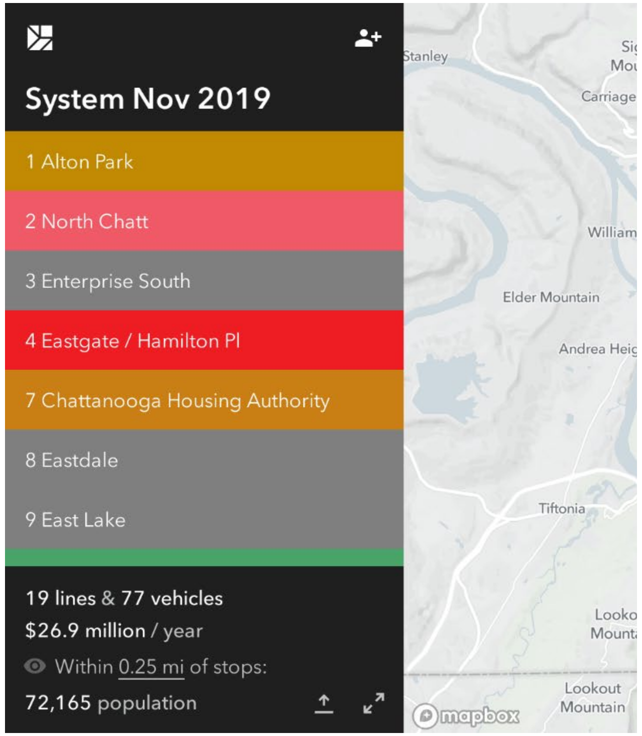
Community Engagement

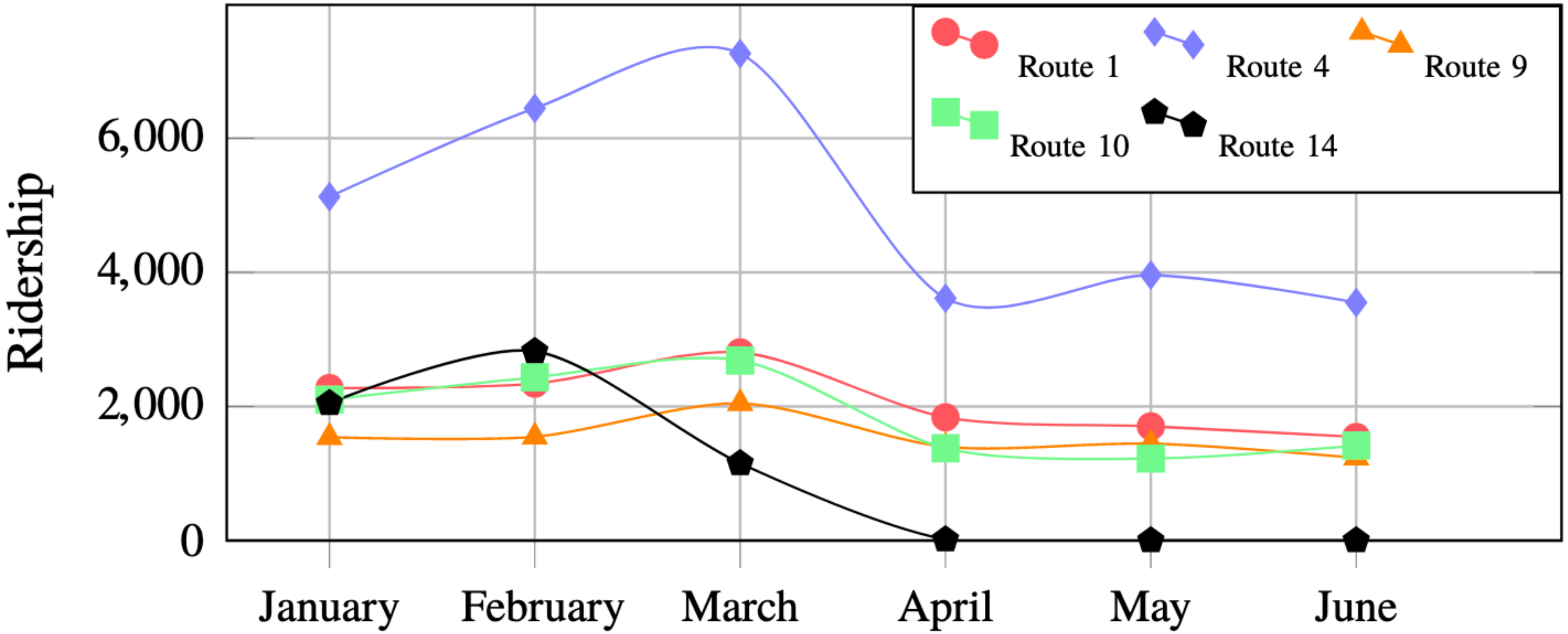
- Sustained engagement through townhalls, information sessions, and online outreach campaigns.

Milestones

Milestone	Type	Description
API Design	Technical	API design of all services is complete and compatibility checked. Final design and compatibility summary sent to DOE Project Officer.
Data Collection Design	Technical	Design and Develop Camera Based OD and CTU Data Collection. Algorithms for camera-based OD and CTU data collection will be deployed and validated with test camera streams with 75% or better accuracy.
First Simulation Table-Top Exercises	Technical	Demonstration with simulation. The results show improvement of coverage and energy efficiency with the AI methods compared to the operation research benchmark optimization. The simulation table exercise report will show a full day transit trip execution scenario.
Initial Concept Report	Go/No-Go	Demonstration with simulation and comparison on the scenario between the AI methods and the benchmark method complete with more than 5% improvement in the coverage and energy efficiency shown using the simulation. The demonstration results will be documented in a report.
Data Collection	Technical	OD Data collection installed and operational on 50% of the fleet
AI Optimization Engine	Technical	Demonstration of the capability of the AI optimization engine to handle uncertainty in trip times, maintenance and trip roster concerns for 10% of the trips. The AI engine will be shown to operate at full trip load of the agency in the simulation.
System Integration and Evaluation	Technical	Demonstration with simulation and comparison on the scenario with the benchmark methods. Analyses to compare energy spent per passenger per mile, passenger wait times, service coverage, and computation costs complete. Results and analysis sent to the DOE Project Officer.
Refined Concept Tested Report	Go/No Go	Report of major finding on the design of the system sent to the program manager. The AI Engine is able to schedule the two-day pilot study trips (2 paratransit vehicles). Plan for the full experiments in BP3 sent to the DOE Project Officer.

Ridership Analysis

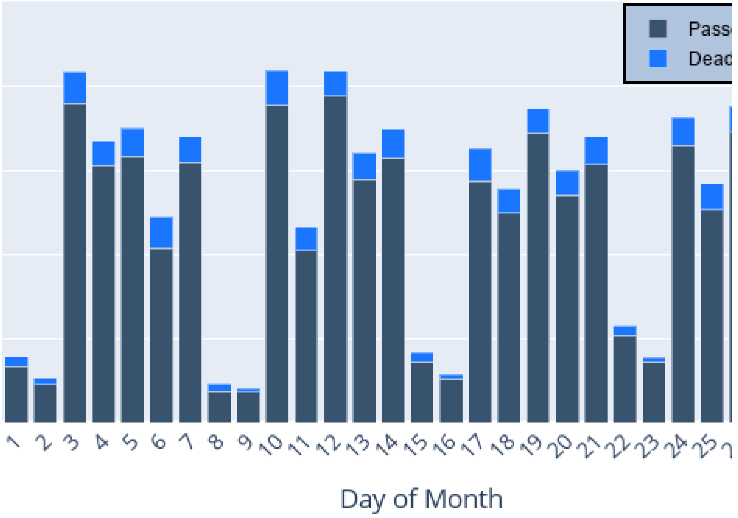




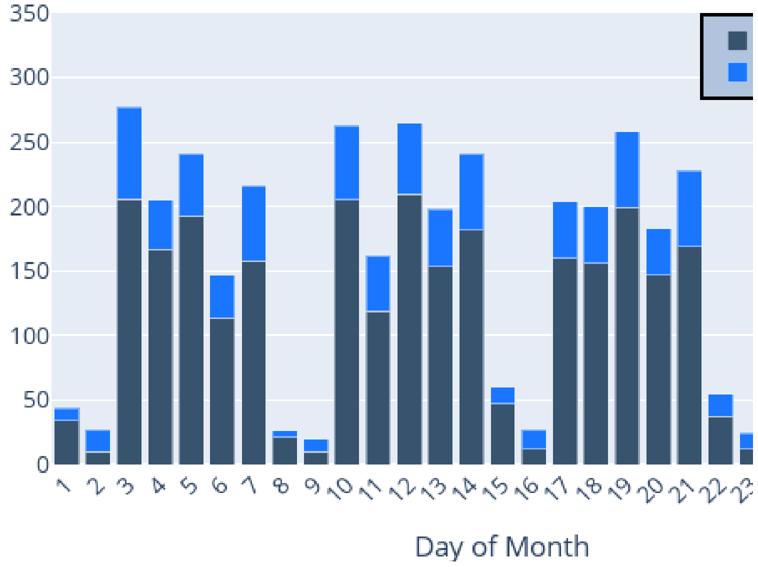
Average weekly ridership per month for the 5 most popular routes in Chattanooga (2020)

Accomplishments & Progress

Paratransit Passenger Miles/ Deadhead Miles

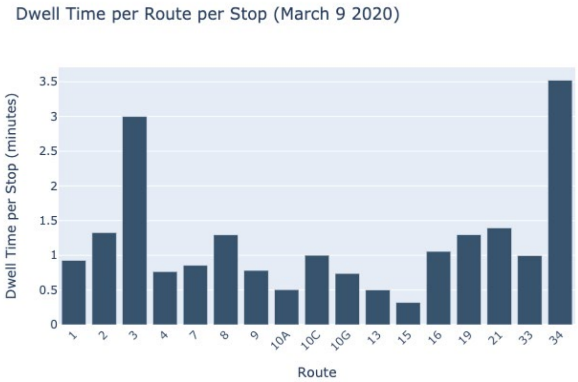


Number of paratransit Passengers

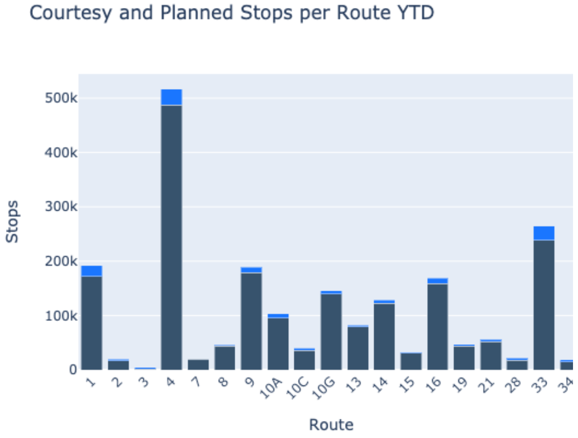


Analysis and Modeling of Ridership Trends

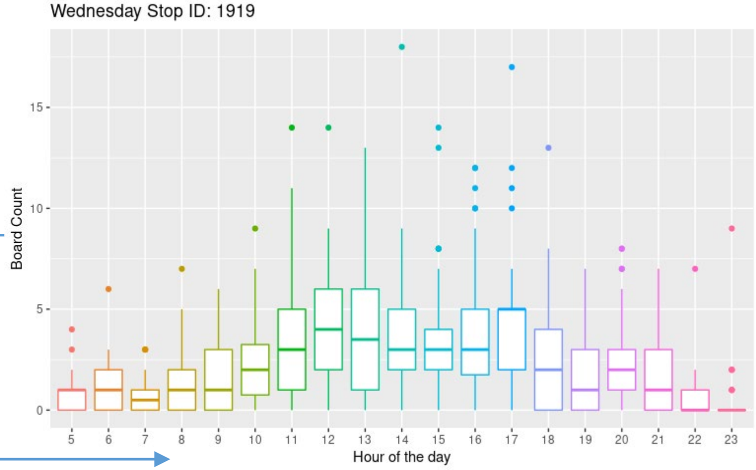
Dwell Time Per Stop



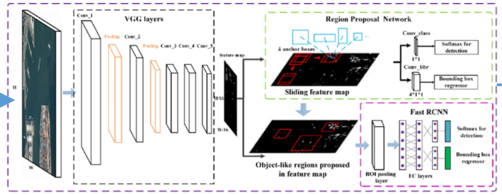
Courtesy Stops



Models for predicting demand per route, per stop

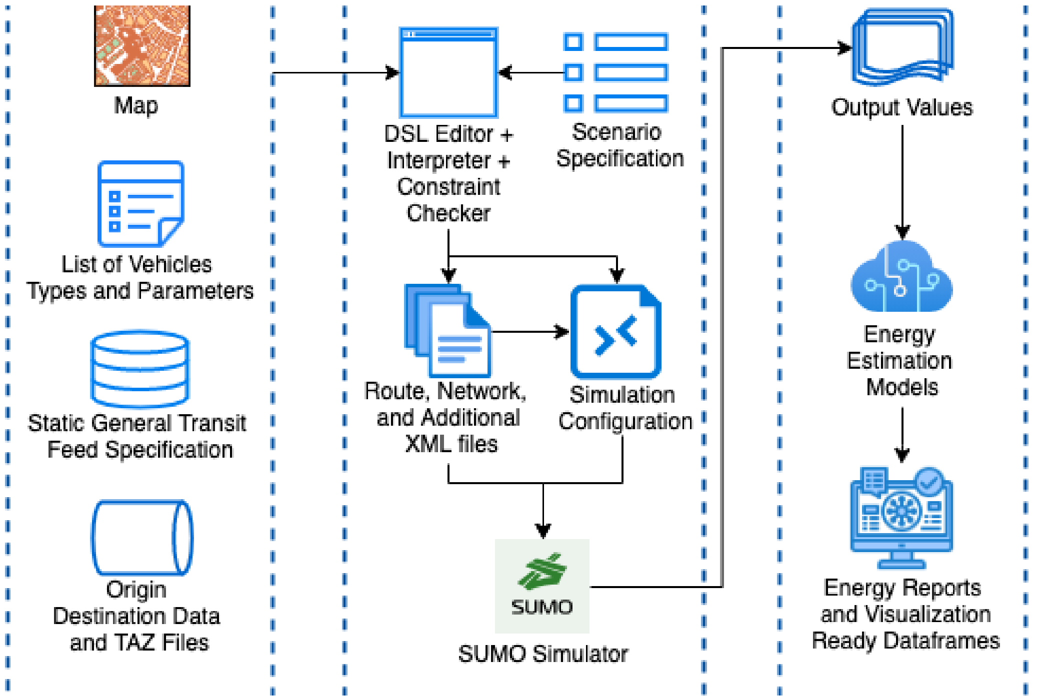


- Automated Passenger Counter (APC Data)
- Farebox Data
- Travel Demand Model Data



Addressing the Complexity of Developing Algorithms

Developing a City Scale Simulator. We are collaborating with the NREL and ORNL efforts in that space



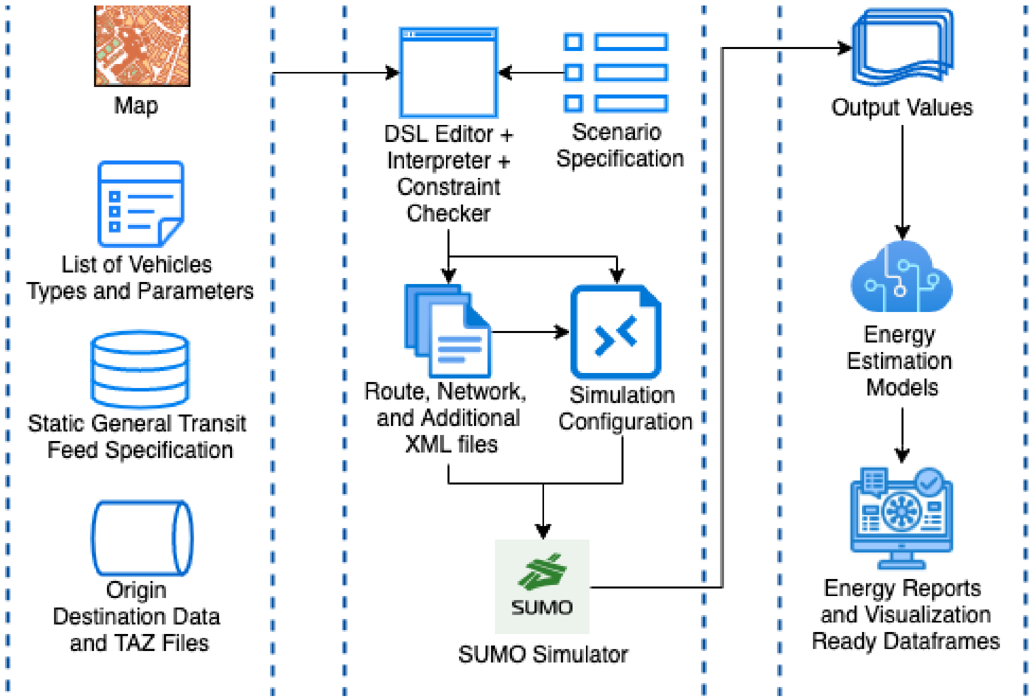

```
import "network.Chattanooga"
import "vehicle.BUS_type.xlsx"
import "gtfs.latest"
import "td.OD_person.od"

simulation configuration 1 {
    time [0000:1200]
    schedule weekday
    output_sampling_period 3600
    vehicleassignment {
        block 101: "Gillig_103"
    }
}

simulation configuration 2 {
    ...
```

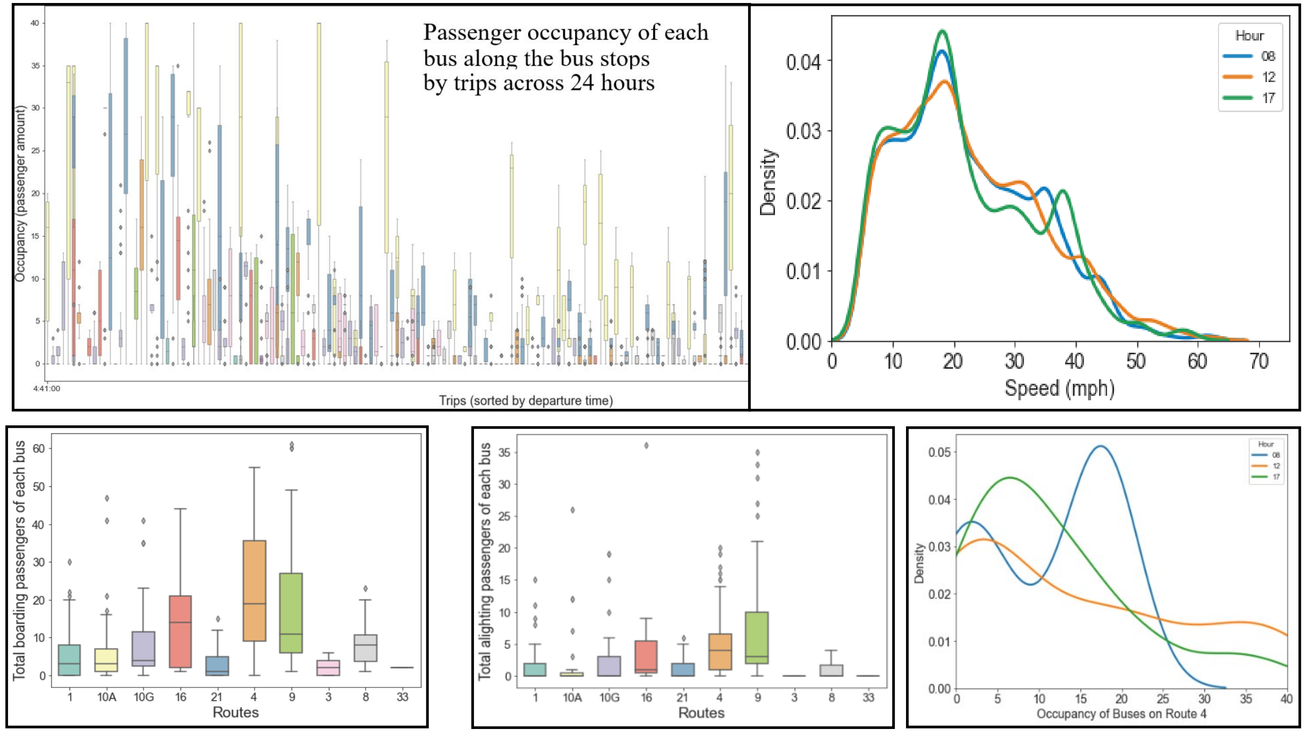
Challenges: multi-scale simulation, scenario specification, calibration of simulation models.

Sun et al. Transit-Gym: A Simulation and Evaluation Engine for Analysis and Optimization of Bus Transit Systems. (submitted) SmartComp 2021

Addressing the Complexity of Developing Algorithms

We need the ability to design different demand scenarios and test the algorithms against changing demand and traffic patterns.





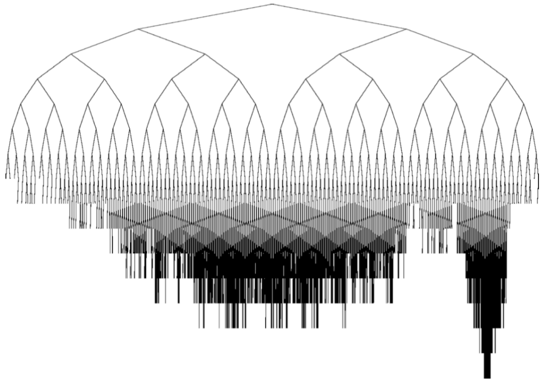
Challenges: multi-scale simulation, scenario specification, calibration of simulation models.

Sun et al. Transit-Gym: A Simulation and Evaluation Engine for Analysis and Optimization of Bus Transit Systems. (submitted) SmartComp 2021

Formulating the paratransit optimization problem and leveraging real-world constraints as we solve the problem

Approach: Design efficient algorithms for allocating, dispatching and scheduling on-demand transit fleet while ensuring it is optimally integrated with the fixed line schedule in the city.

Monte Carlo Tree Search: Game theoretic tree representation of process.
Nodes ➞ states , Edges ➞ actions. The tree grows asymmetrically and uses fast (online), simulated playouts to estimate value of node



Pre-processing

1. Each request is marked as a unique origin-destination pair.
2. A graph of requests and possible service runs is created.

→

Fix Routes

1. Integer Program to optimize day-ahead requests.
2. Minimize energy and labor costs.
3. Maximize service.

→

Real-Time Demand

1. Decision-Theoretic Approach
2. Anytime algorithm to modify existing routes.
3. Fast Monte-Carlo Search for tractability.

→

Two-Stage

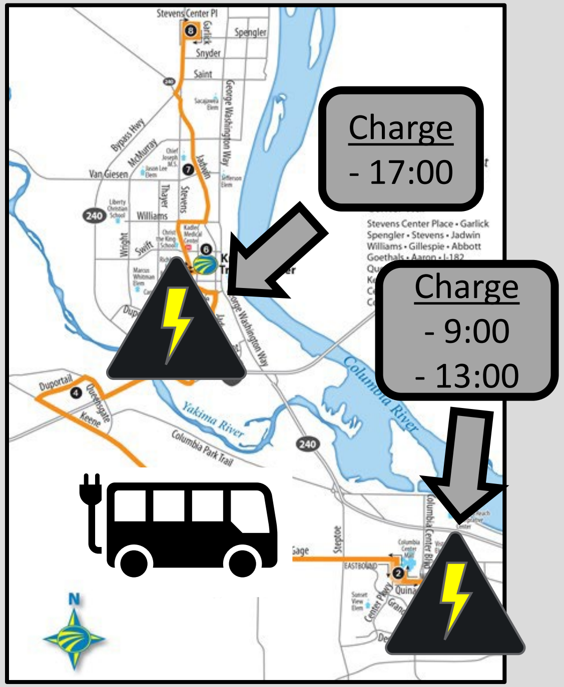
1. Fixed routes generated by IP. Relatively time-consuming.
2. Once routes are decided, real-time requests are considered by an online optimizer.

- **Challenges:** Transit centric online problems also lead to larger problem instances than in ridepooling. Real-world QoS constraints. Larger capacity vehicles. Advanced bookings

Integrating grid models into the simulator

Simulation

Replicates the transit system to estimate the impact of potential charging schedules



Traffic Simulator

Models ***travel times*** and ***battery discharge*** under varying traffic conditions

Traffic network →

SUMO

OpenStreetMaps
- Roadway Network
- Transit Schedules

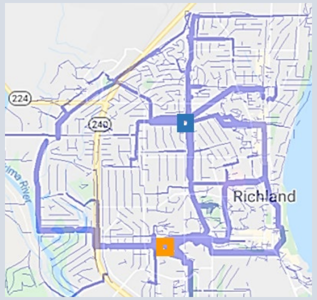
Simulation of Urban MObility
- Micro traffic simulator
- Built in EV bus models

Grid Impact Model

Captures the impact charging actions have on the power grid

GridLAB-D

Impact metric derived from...
- Line losses
- Power phase balancing
- Etc.



Case study's feeder network

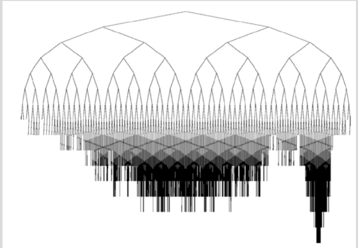
State updates, Estimated rewards →

← Charging actions to evaluate

Decision Agent

Evaluates potential charging schedules by estimating their long-term effects

Monte Carlo Tree Search
- Represents control process as game tree
- Asymmetrically grows tree, balancing exploration and exploitation
- Estimates values of actions using surrogate models
- Online algorithm; no training needed (unlike reinforcement learning). adaptable to dynamic environments



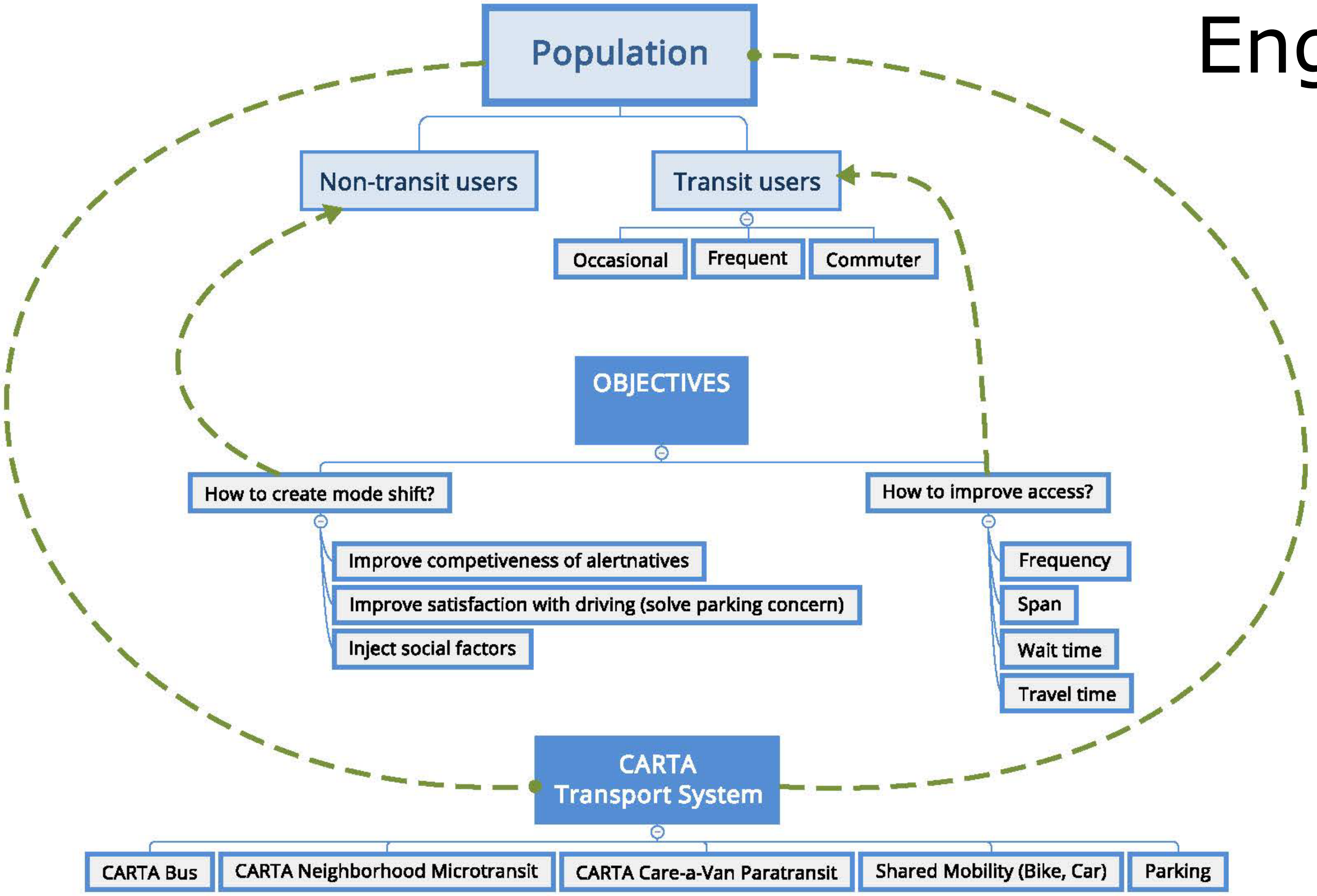
Notable application: world-champion defeating Go program[1]

Reward Function

$$r_c = -e + \beta g + \varphi n_f$$

- energy costs (e)
- power grid impact (g)
- Number of failed buses (n_f)
- Tradeoff parameter (β)

Community Engagement



- Framework development
- IRB Approval

Collaboration and Coordination

Core Team

- CARTA – Prime
  - Operational integration
- Vanderbilt University
  - Data store architecture, Simulation models
- University of Houston
  - Optimization, Simulation models
- University of Tennessee at Chattanooga
  - Simulation models, Community Engagement
- Cornell University
  - Optimization
- Siemens
  - Railigent integration
- PNNL
  - EV Charging optimization

Community Coordination

- City of Chattanooga Department of Transportation and Smart Cities office
- The Enterprise Center
- East Tennessee Clean Fuels Coalition

Collaboration

- Weekly video conference call
- Shared data access
- Conference collaboration
- Bi-weekly call with NREL and ORNL

Challenges and Barriers

- **Outcomes Achieved**
  - ✓ Data Collection and Training Framework
  - ✓ Data-Driven Predictors for Contextual Energy Consumption
  - ✓ Dashboard development at www.smarttransit.ai

- **Pending accomplishments for FY21-FY22**
  - API design completed
  - Camera integration to data collection
  - Simulation table-top exercises
  - Siemens onboarding delayed due to approval process

Project updates available at www.smarttransit.ai

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

Proposed Future Research

- **Key Challenges**
  - Restoration of routine transit operations post-COVID-19 restrictions
  - Community engagement in light of any continued COVID-19 restrictions and limitations on public outreach

- **Future / On-going Work FY21-22**
  - Conceptual framework completed
  - Development of AI optimization engine
  - System integration and evaluation
  - Community engagement activation

Project updates available at www.smarttransit.ai

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

Summary

Relevance

Reduce transportation energy consumption through optimization of public transit operations and increased utilization.

Approach

Collaborative partnership with transit agency operating multimodal, mixed-vehicle fleet.

Accomplishments

- Data collection framework developed.
- Prediction models developed.
- Community engagement framework developed.

Technical Back-up Slides

Optimal Vehicle Assignment Problem

- We consider a mixed transit fleet.
- We assume that electric vehicles have a limited capacity and needs charging
- We assume that charging is only available at specific locations and there is a limit to how many vehicles can charge at the same time.
- We assume that the cost of charging is different at different times of the day.
- We use the predictive models we have constructed to determine the energy cost of operating a vehicle of specific type on a route at a given time when the weather is known.
- Our problem formulation determines optimal assignment of vehicles to trip such that overall energy consumption is lowest.
- The constraint is primarily the availability of electric vehicles and time it takes to charge them.

The Data Store Challenge and Approach

ISIS OpenStack

- HERE
- Viriciti
- Weather
- Clever

Pulsar Cluster

Brokers & Bookies – 5 Nodes
- 2 VPUs
- 8 GB Ram
- 40 GiB Root Disk
- 128 GiB Volume

Zookeeper – 5 Nodes
- 1 VPUs
- 8 GB Ram
- 40 GiB Root Disk
- 64 GiB Volume

mongoDB

MongoDB – Replica Set
- 2 storage nodes
  - 8 VPUs
  - 16 GB Ram
  - 150 GiB Root Disk
  - 4 TB Volume
- 1 arbitrator
  - 1 VPU
  - 2 GB Ram
  - 40 GiB Root Disk

- Features of the architecture
  - Distributed storage
  - Replicated Data
  - Real-time stream processing
  - Spatial queries
  - Integrated visualization
  - Temporal queries
  - Integrated joins for analysis across different data features
    - Weather
    - Traffic
    - Vehicle Telemetery