Mobility for All - Harnessing Emerging Transit Solutions for Underserved Communities

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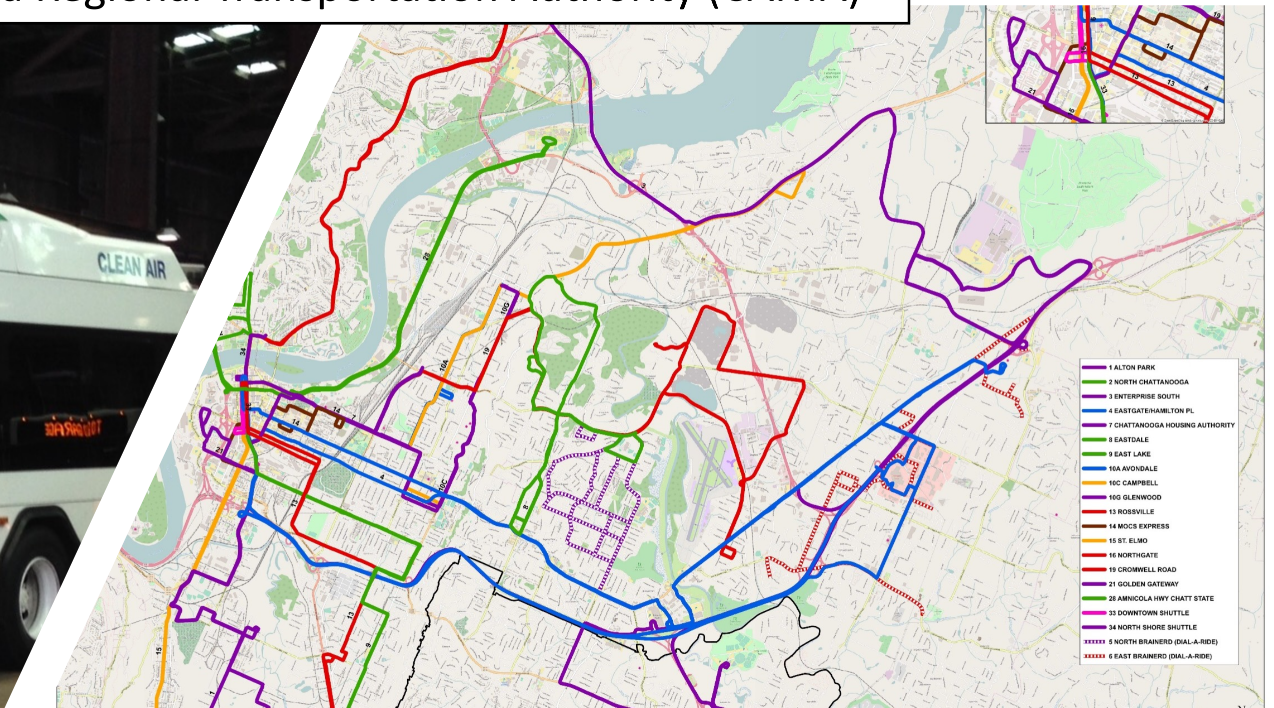
Award # - CNS #1952011. IRG-Track-1. FY 2020

Our Community Partner is Chattanooga Area Regional Transportation Authority (CARTA)



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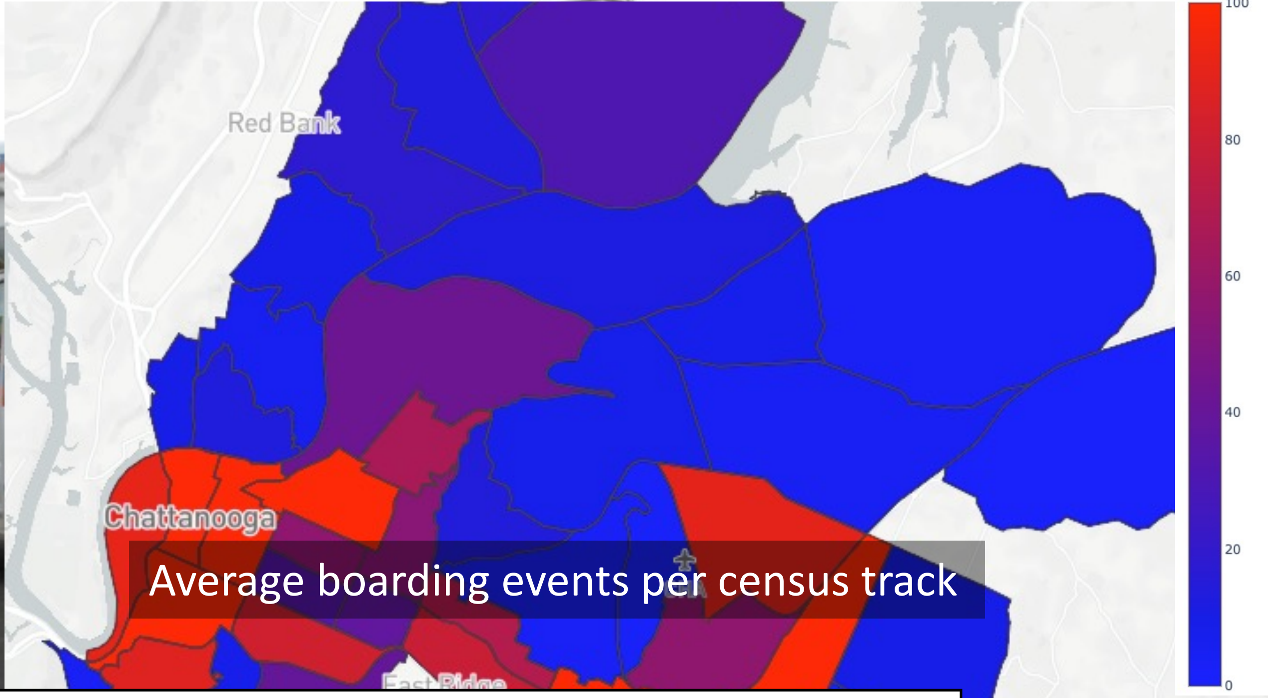
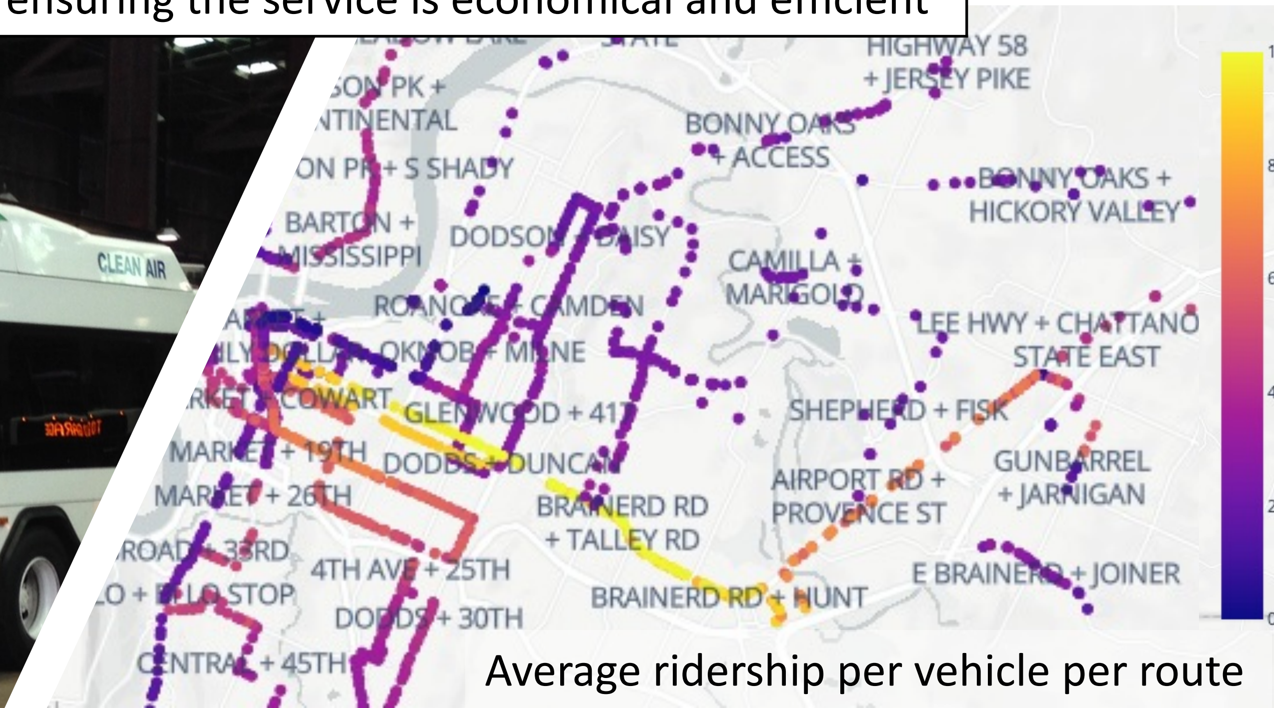


Average boarding events per census track

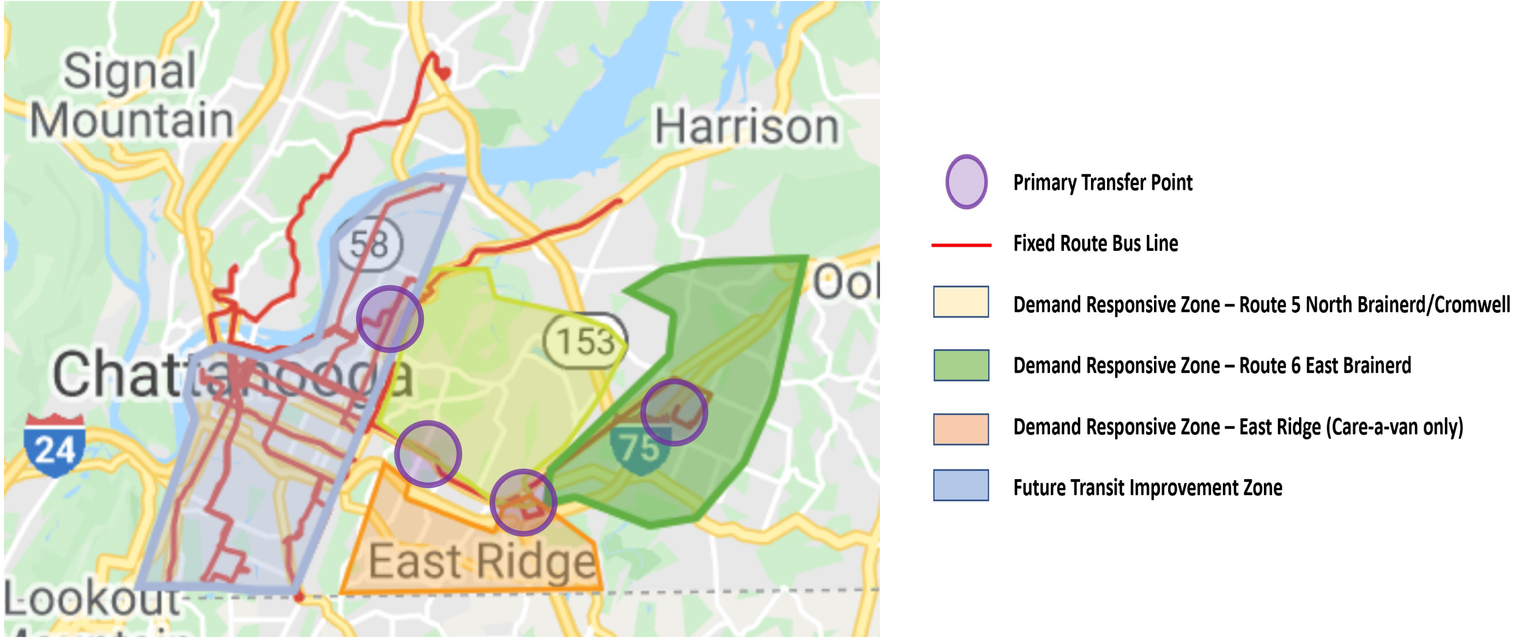
Key challenge : provide good coverage while ensuring the service is economical and efficient

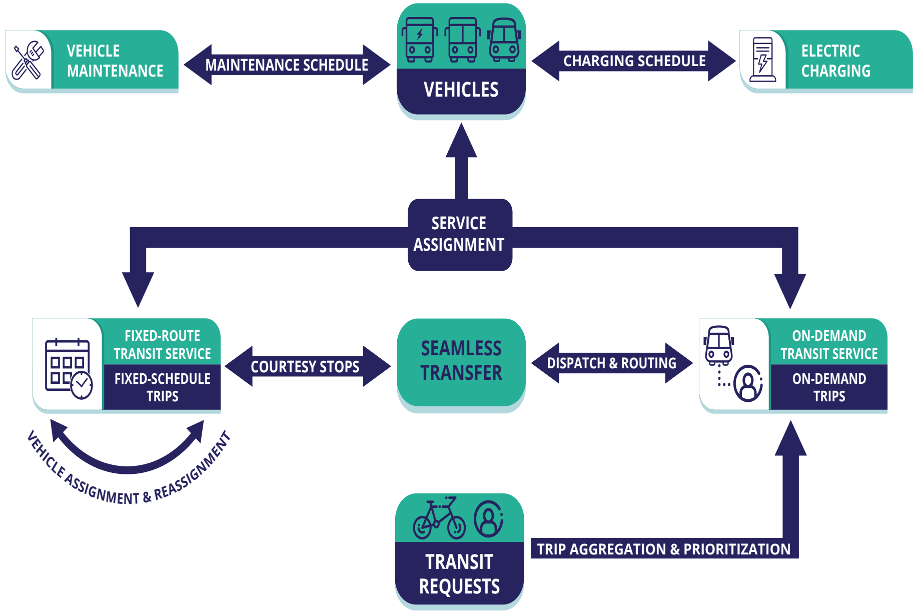


Average ridership per vehicle per route

Our Approach

Approach: Integrating the fixed-line service with on-demand service



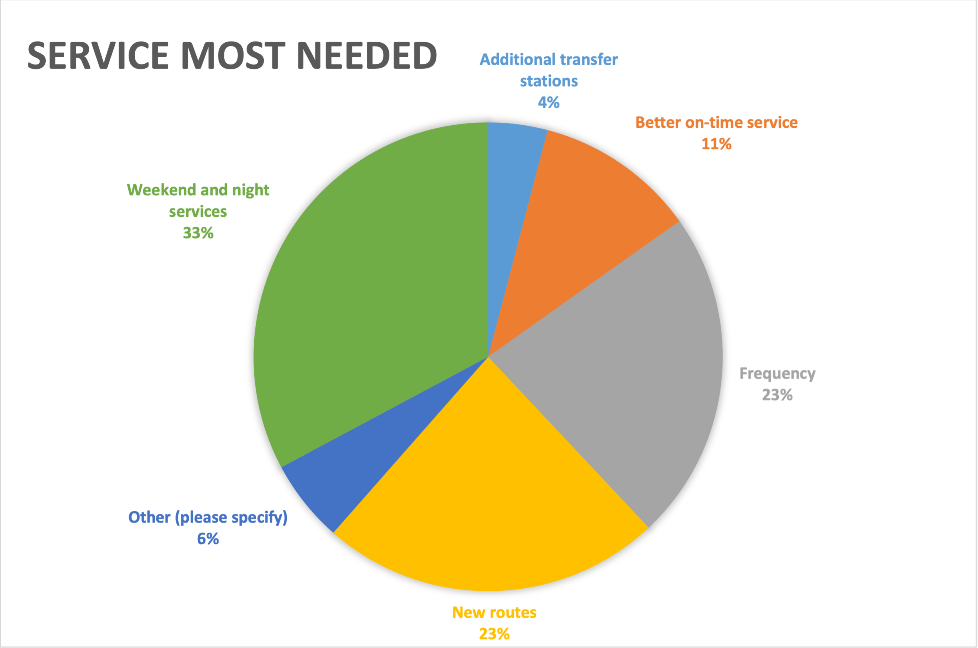


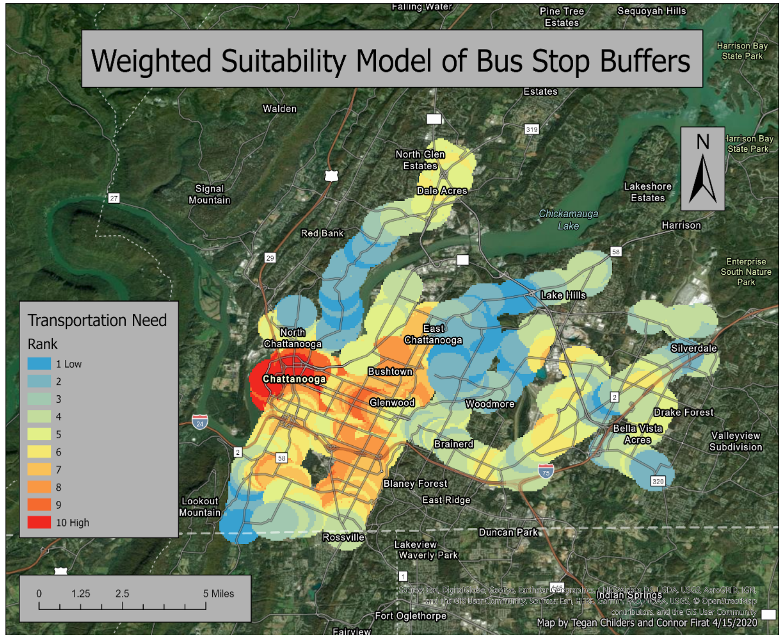
Challenges: System operational efficiency and management

Community-Driven Design

Approach: Relational models of change that assume people are complex, democratic citizens as opposed to rational consumers may help address existing microtransit challenges

We plan to conduct surveys leveraging the relational network - understand the attitudes, behaviors, barriers to taking public transportation, and alternative modes of transit, in order to distinguish between regular public transit users and dedicated private vehicle users.



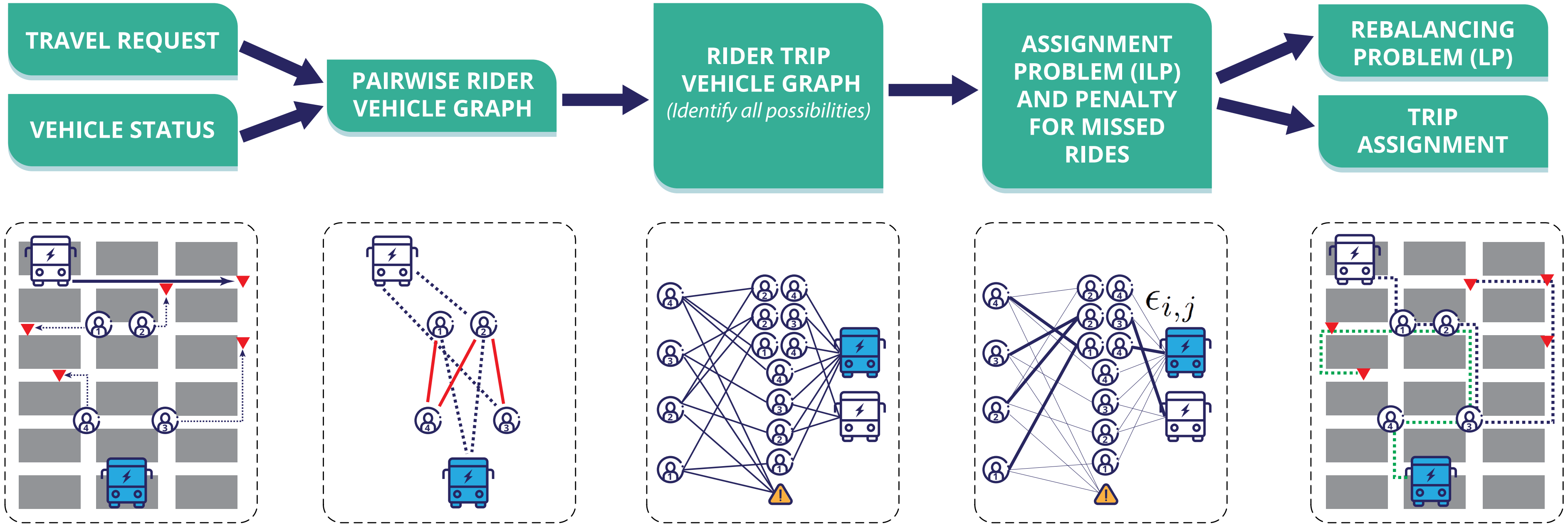


Initial Analysis

Challenges: community outreach, lack of success in prior microtransit efforts, non-rational behavior

Integrated On-demand Transit and Fixed Line Scheduling

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.



- Extend scalable new Dynamic Dial-A-Ride Problem (DARP) formulations to advanced bookings and integration of traditional bus service.
- Design new solution methods and anytime algorithms

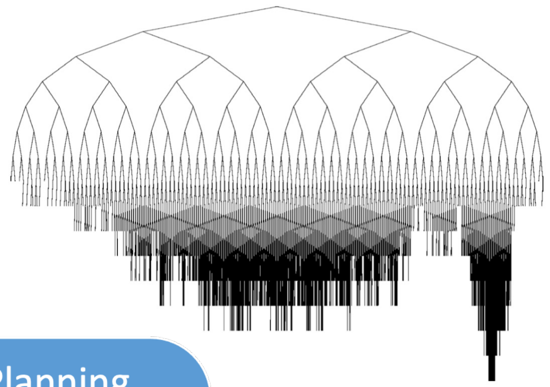
Challenges: computation complexity, operational uncertainty and real-time requests.

Related paper: Alonso Mora et al. High-capacity vehicle pooling and ride assignment. PNAS 2017

Addressing Online Requests through Anytime Algorithms

Approach: Introduce new resources only when necessary. Restrict search space. Separate allocation from dispatch – dynamically reallocate periodically. We plan to use Monte-Carlo based anytime algorithms. Grow tree asymmetrically and Use fast (online), simulated playouts to estimate value of node

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 Planning

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

Challenges: computation complexity, operational uncertainty and real-time requests.

Related paper: Pettet et al. Hierarchical Planning for Resource Allocation in Emergency Response Systems. ICCPS 2021 smarttransit.ai

Demand Estimation (boarding events, origin-destination events)

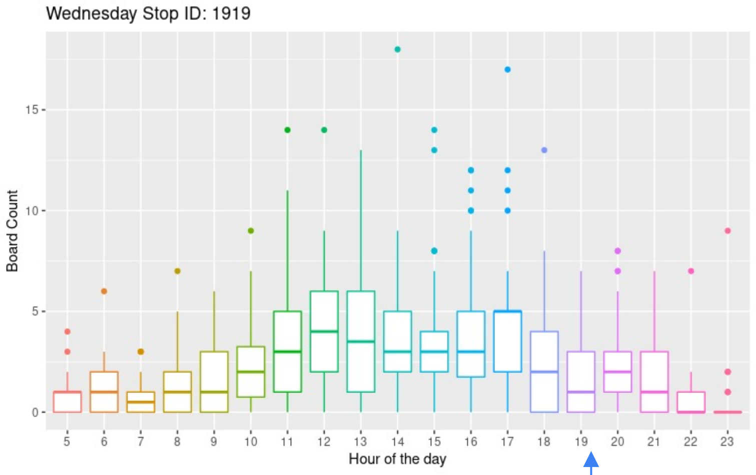
Approach: Use the automated passenger counter data, fare box data and camera data to create models for learning the distribution of commuters across bus stops and develop statistical models for prediction the future demand

Occupancy is a composition of two random processes: **boarding** and **alighting**.

- **Board counts:** $\gamma_t(s_i) \sim Po(\lambda_b^{(t)})$
- **Alight counts:** $\alpha_t(s_i) \sim Po(\lambda_a^{(t)})$

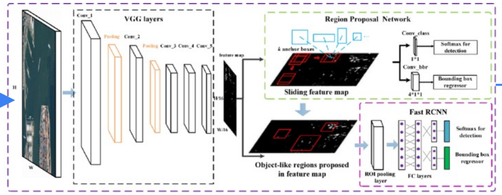
We need to learn distributions: $F_b(\gamma_t(s_i)|w)$ and $F_a(\alpha_t(s_i)|w)$. These can be used to seed a generative model that can be used to predict the likely demand at any bus stop at any time in the future given the nearby events, weather and information about that day.

Models for predicting demand per route, per stop



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

- Correction Factor



Challenges: privacy, robustness of prediction, understanding and responding to distribution shifts

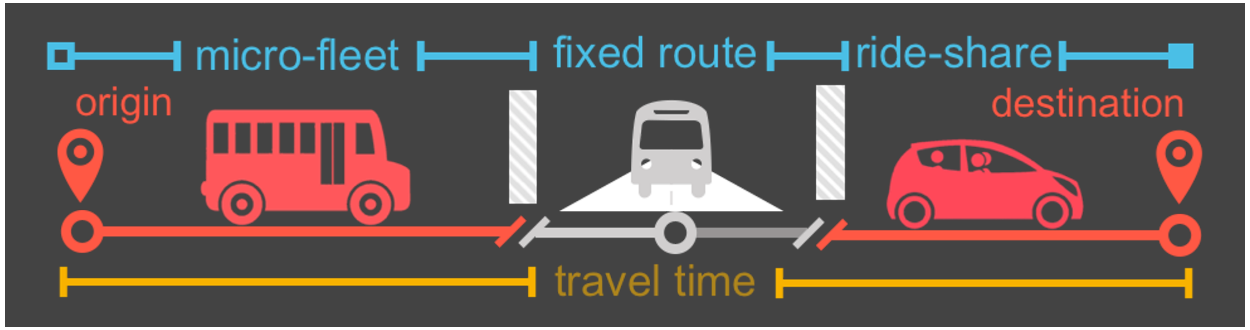
Related Paper : Juan et al. Occupancy Estimation for Bus Transit Systems. (submitted) SmartComp 2021

Performance Evaluation and Hyper-Parameter Selection

Approach: design active learning algorithms using tools from multi-armed bandits, where contextual side information is available to address three key problems:

Hyperparameter Selection: explore a suite of parameter configurations (e.g., fleet size, vehicle capacity, risk tolerances) for a class of algorithms (e.g., routing algorithms) in a principled manner

Model Estimation: determining the most informative ground truth samples for improving model accuracy (e.g., origin-destination pairs)



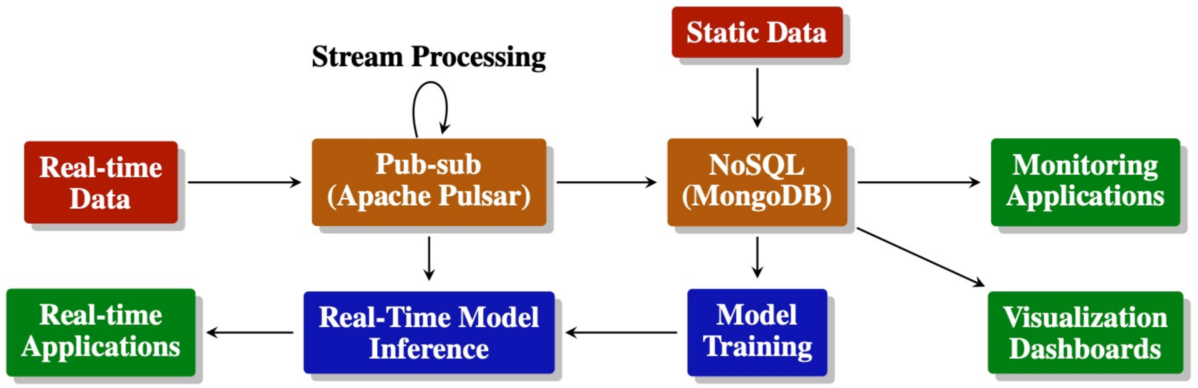
Performance Evaluation: determining if an implemented policy (e.g., routing policy) is failing to meet its desired local behavior target (e.g., travel time)

Challenges: sparse and biased data; partial view of system operations; non-stationary environment

Related paper: Fiez et al. Sequential Experimental Design for Transductive Linear Bandits. NeurIPS 2019

Addressing Computational, Privacy, and Data Challenges

Approach: Use custom data architecture with parallel view and structures to optimize both graph-based and time-based queries. We are also investigating **distributing outsourced computation** to provide cheaper and sustainable alternative to cloud computing.



Data Pipeline

Data	Source	Frequency	Scope	Features	Schema/Format
Diesel vehicles	ViriCiti and Clever Devices	1 Hz	50 vehicles	GPS, fuel-level, fuel rate, odometer, trip ID, driver ID	Viriciti SDK and Clever API
Electric vehicles	ViriCiti and Clever Devices	1 Hz	3 vehicles	GPS, charging status, battery current, voltage, state of charge, odometer	Viriciti SDK and Clever API
Hybrid vehicles	Viriciti and Clever Devices	1 Hz	7 vehicles	GPS, fuel-level, fuel rate, odometer, trip ID, driver ID	Viriciti SDK and Clever API
Traffic	HERE and INRIX	1 Hz	Chattanooga and Nashville region	TMC ID, free-flow speed, current speed, jam factor, confidence	Traffic Message Channel (TMC)
Road network	OpenStreetMap	Static	Chattanooga and Nashville region	Road network map, network graph	OpenStreetMap (OSM)
Weather	DarkSky	0.1 Hz	Chattanooga and Nashville region	Temperature, wind speed, precipitation, humidity, visibility	Darksky API
Elevation	Tennessee GIC	Static	Chattanooga region	Location, elevation	GIS - Digital Elevation Models
Fixed-line transit schedules	CARTA, WeGO	Static	Chattanooga and Nashville region	Scheduled trips and trip times, routes, stops	General Transit Feed Specification (GTFS)
Video Feeds	CARTA	30 Frames/Second	All fixed-line vehicles	Video frames	Image
APC Ridership	CARTA , Wego	Every Stop	All fixed-line vehicles	Passenger boarding count per stop	Transit authority specific

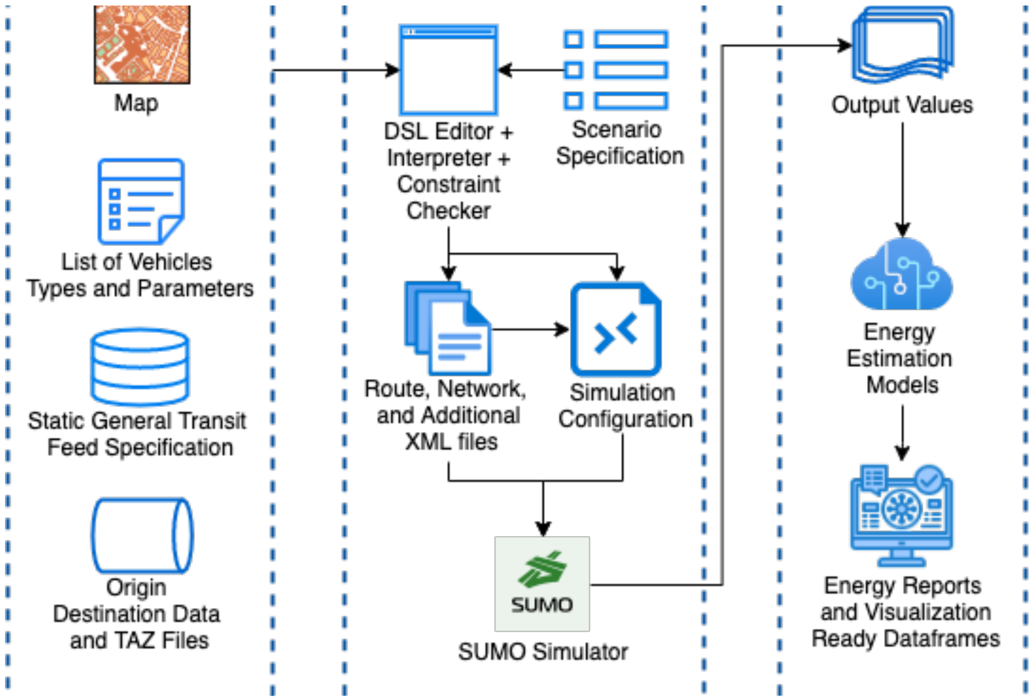
Sample of the data we are ingesting

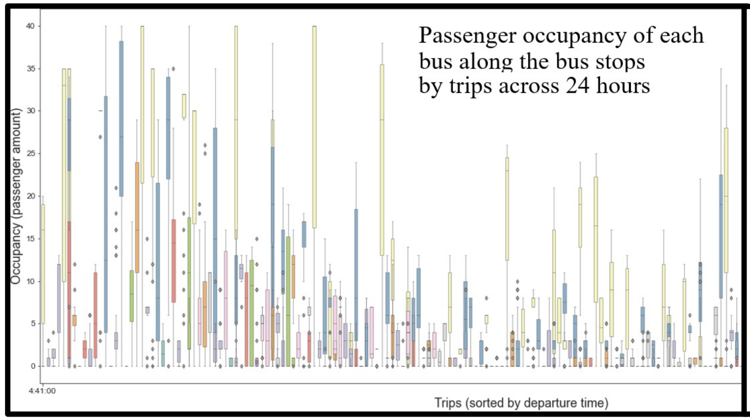
Challenges: privacy of multi-modal data, computation sustainability, fast joins.

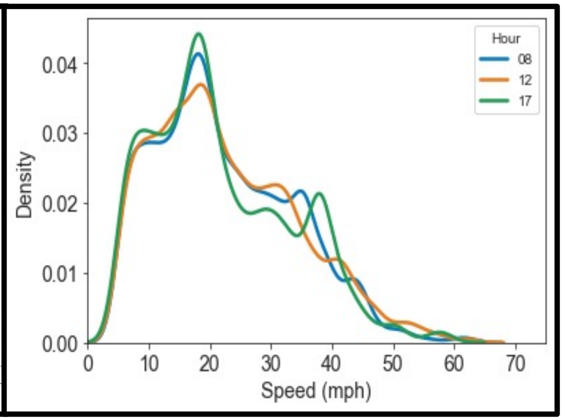
- Wilbur et al. Efficient Data Management for Intelligent Urban Mobility Systems. AAAI Workshop for Urban Mobility 2021
- Eisele et al. Mechanisms for Outsourcing Computation via a Decentralized Market. DEBS 2020

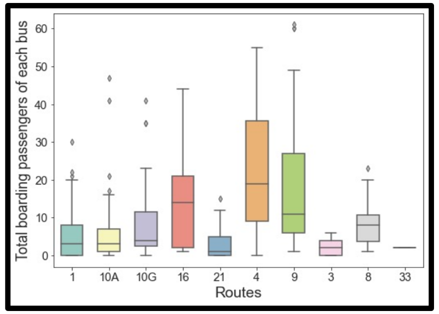
Addressing the Complexity of Developing Algorithms

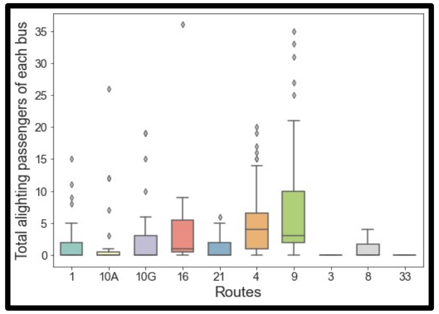
We need the ability to design different demand scenarios and test the algorithms against changing demand and traffic patterns.

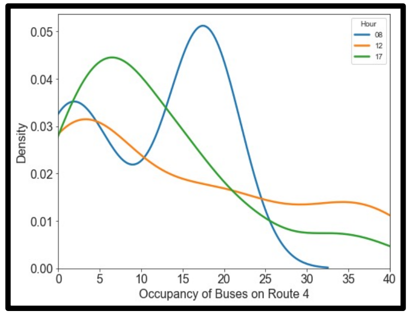












Challenges: multi-scale simulation, scenario specification, calibration of simulation models.

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

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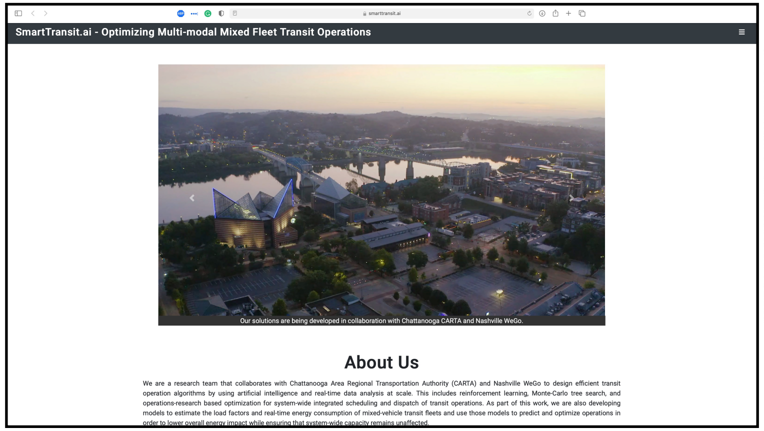

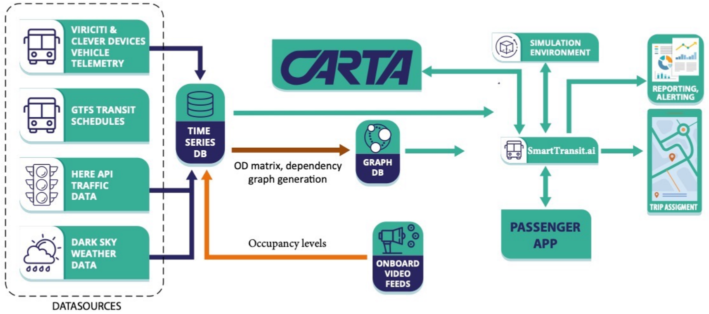

We started this project last year in October and we are working on solving this grand challenge and developing an integrated solution with a two phased test and evaluation plan by 2024.

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