TRANSIT-GYM: A Simulation and Evaluation Engine for Analysis of Bus Transit Systems

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MOTIVATION

- Public-transit systems face several operational challenges:
  - changing ridership patterns requiring optimization of fixed line services
  - optimizing vehicle-to-trip assignments to reduce maintenance and operation costs
  - ensuring equitable and fair coverage to areas with low ridership
- State-of-the-art methods formulate these problems as variants of the vehicle routing problem and use data-driven heuristics for optimizing the procedures. **However, the evaluation and training of these algorithms require large datasets that provide realistic coverage of various operational uncertainties.**
- *TRANSIT-GYM* can bridge this gap by providing the platform for quickly designing and executing transit scenarios, focusing on variation of demand models, variations of route networks, and variations of vehicle-to-trip assignments.

CHALLENGES

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

- Scenario specification
- Calibration of simulation models

CONTRIBUTIONS

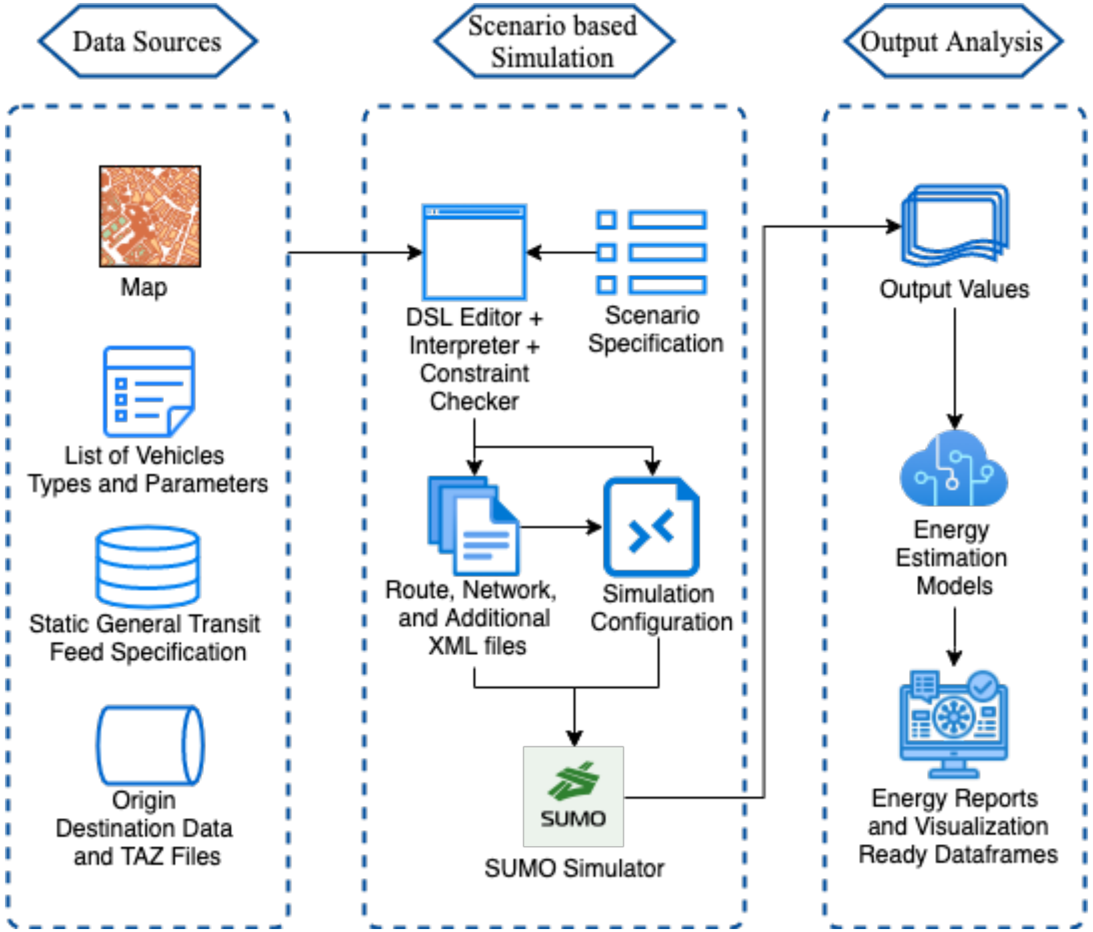
- The central contribution of this work is a **domain-specific language** and associated **experimentation tool-chain** and infrastructure to enable subject-matter experts to intuitively specify, simulate, and analyze **large-scale transit scenarios** and their **parametric variations**.
  - A novel domain-specific language that allows intuitive specification and variation of transit scenarios.
  - A methodology to construct and calibrate street maps that conform to real-world transportation infrastructure.
  - A toolchain that automatically configures simulations from the scenarios specified using the above domain-specific language.
  - A customized general-purpose simulation specifically for transit scenarios.
- An integrated microscopic energy consumption model that also helps to analyze the energy cost of various transit decisions made by the transportation agency of a city.

BACKGROUND

- *Model Integrated Computing*
- *Cyber-Physical Systems Wind Tunnel*
- *SUMO*
- *Energy Estimation Models*

METHODOLOGY & SCENARIO CONSTRUCTION

- ***Simulation Platform Setup & Data Sources***
- ***Scenario-Based Simulation***
- ***Energy estimation models (refer to Sun et al. 2021)***
  - ✓ We are developing algorithms using active learning approaches to address three key problems:
    (a) hyperparameter selection,
    (b) model selection,
    (c) performance evaluation.



R. Sun, Y. Chen, A. Dubey, and P. Pugliese, "Hybrid electric buses fuel consumption prediction based on real-world driving data," *Transportation Research Part D: Transport and Environment*, vol. 91, p. 102637, 2021.

METHODOLOGY & SCENARIO CONSTRUCTION

- *Scenario Construction*

```
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 {
        time [0000:1200]
```

Import Section

Configure Section

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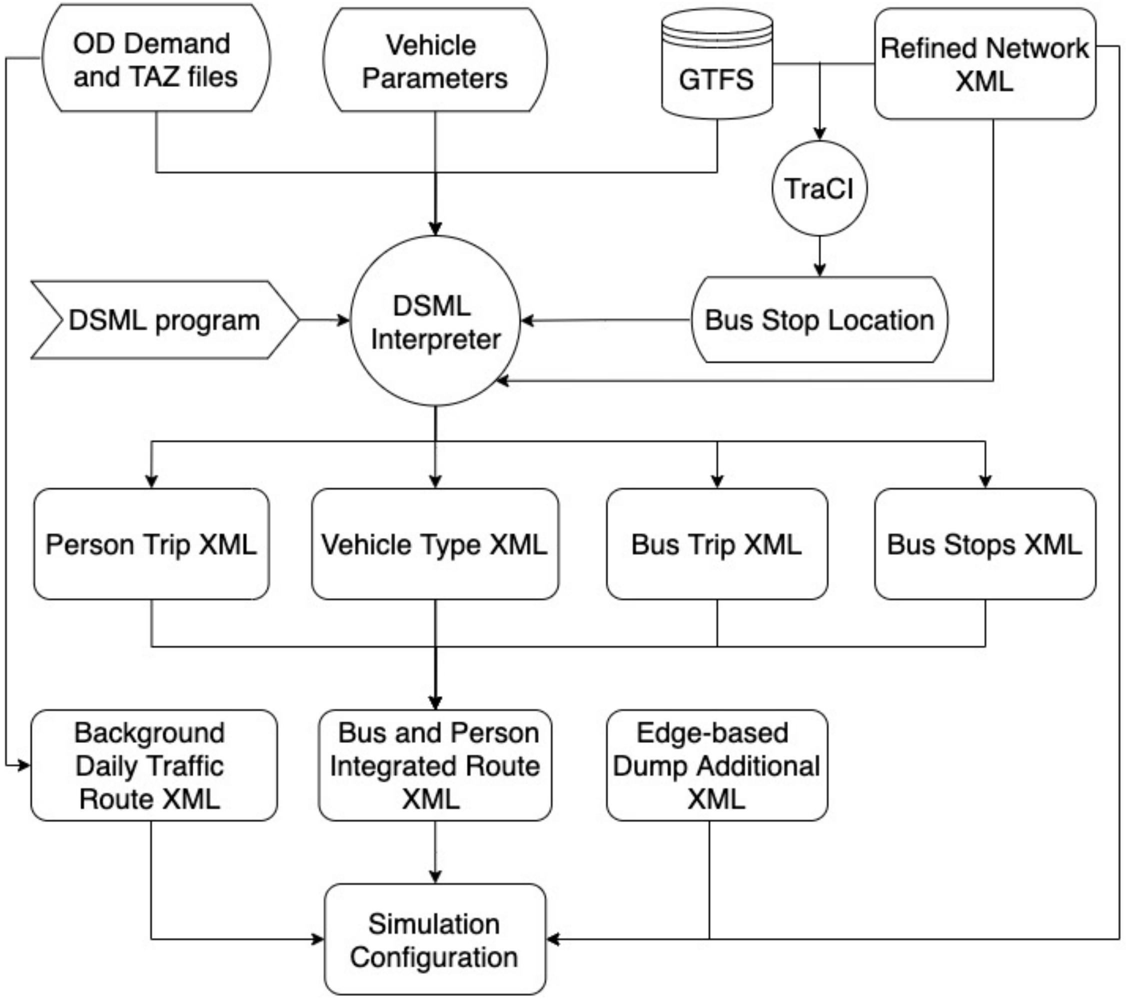
METHODOLOGY & SCENARIO CONSTRUCTION

- *Workflow of the Public Transit Simulation*



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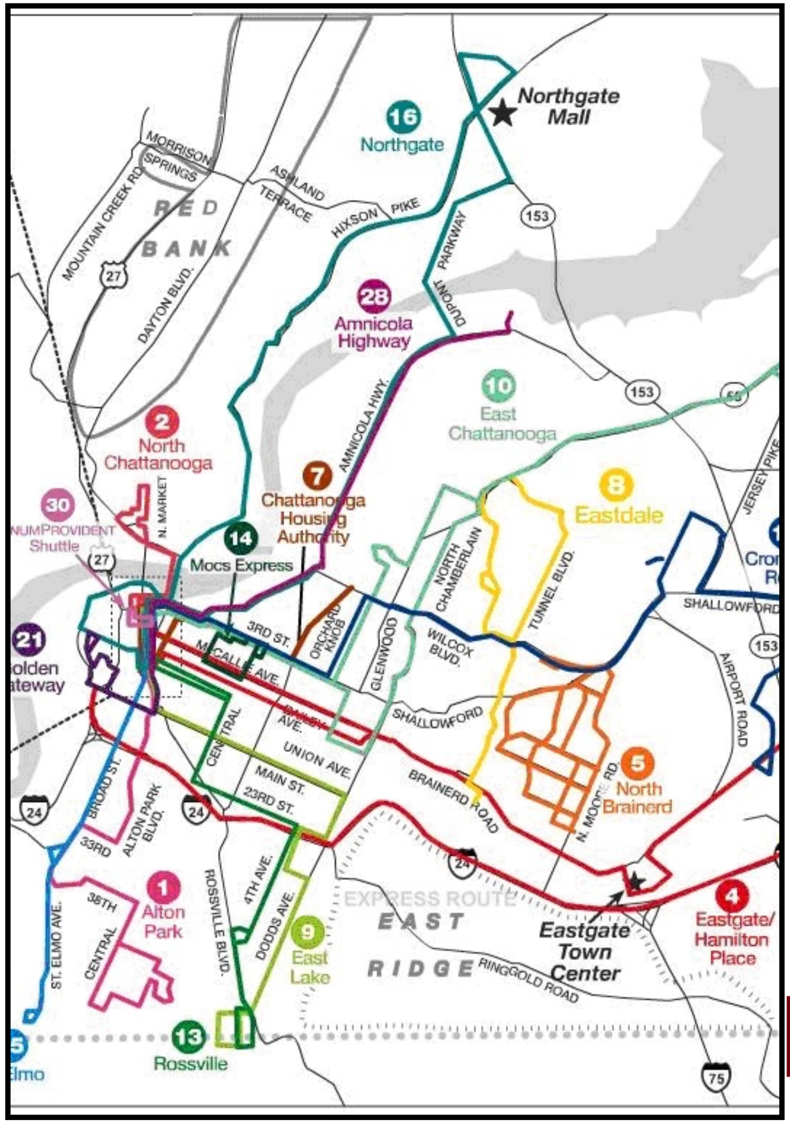
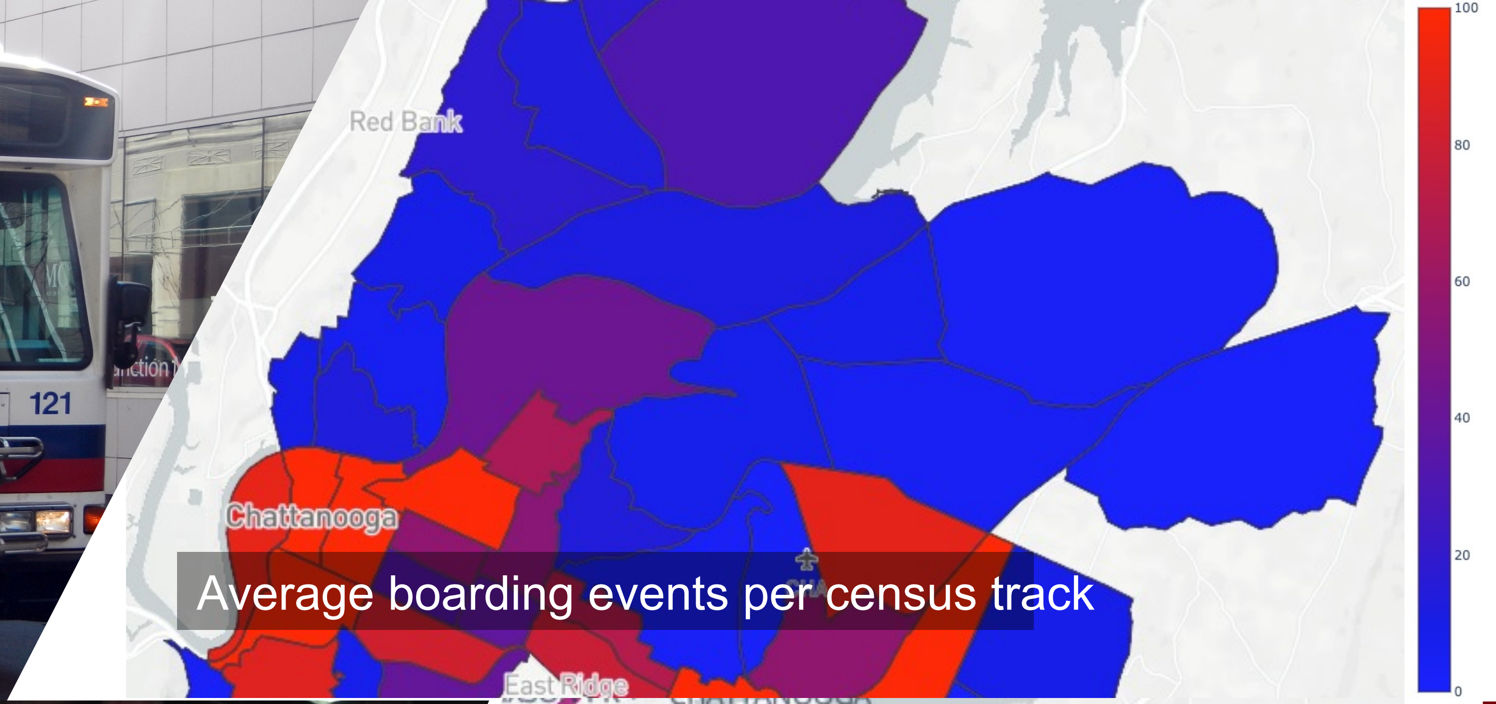
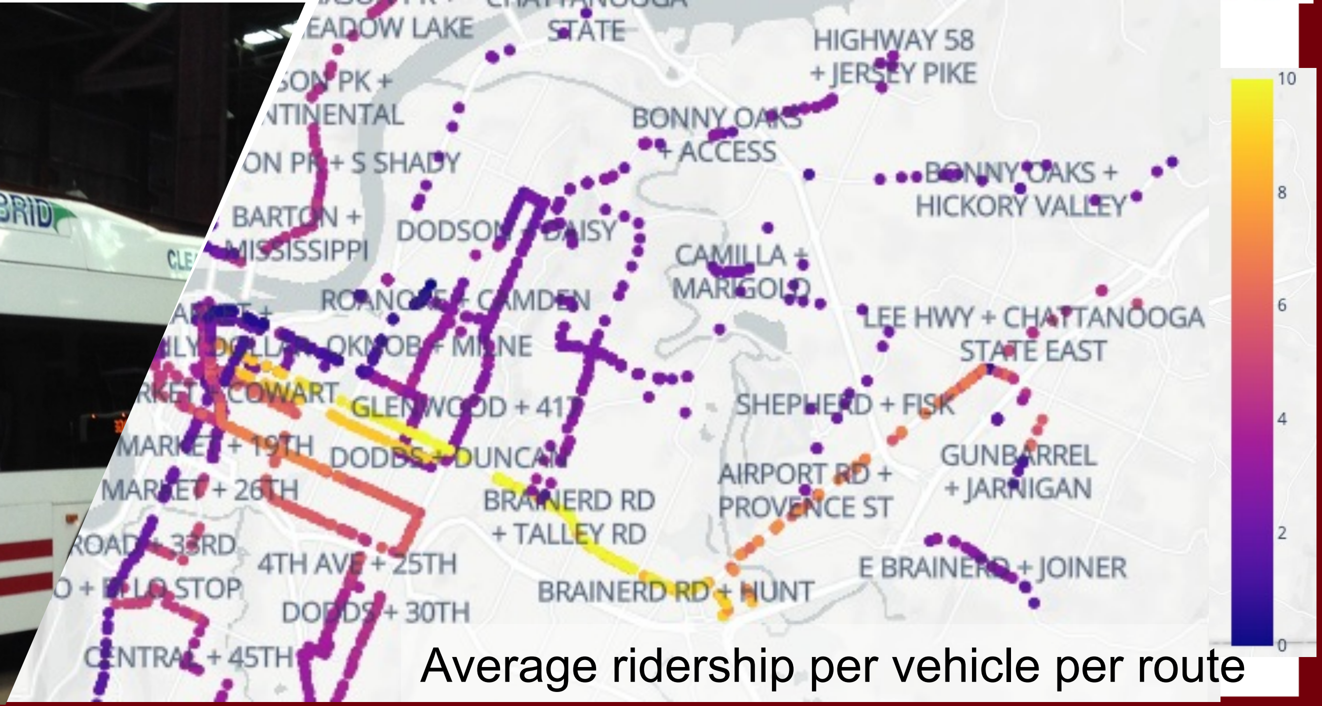
RESULTS AND DISCUSSION

The illustration of the results is based on the investigation of Chattanooga, TN, a mid size city.





Average boarding events per census track



Average ridership per vehicle per route

RESULTS AND DISCUSSION

- ***Simulation Output Analysis***

❑ Passenger occupancy status:

✓ Passenger occupancy of each bus along the bus stops across 24 hours

✓ Maximum passenger occupancy of each bus along the bus stops across 24 hours

✓ The total boarding and alighting passengers of each bus across 24 hours

✓ Distributions of bus occupancy over specific hours on specific route

❑ Vehicle trajectory:

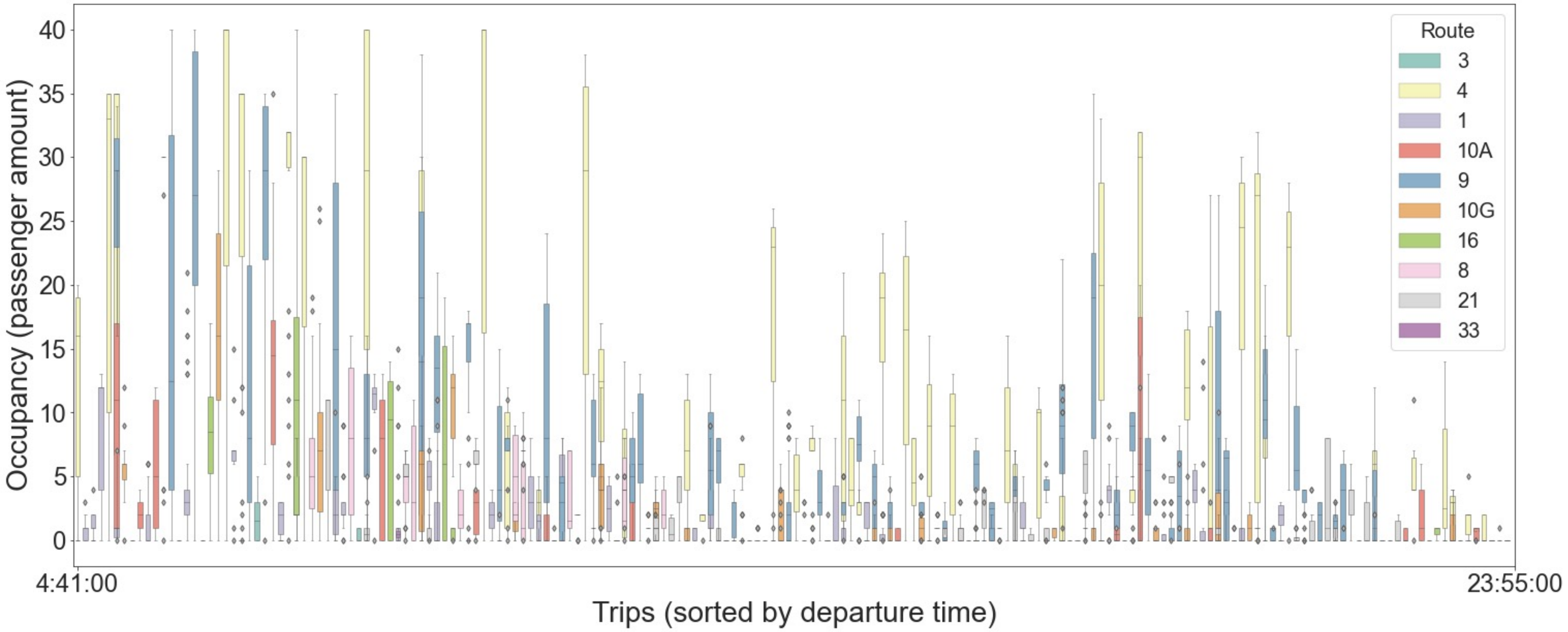
✓ Distributions of bus speed

✓ Average speed of buses on specific route during specific hours

RESULTS AND DISCUSSION

- ***Visualization examples***

✓ Passenger occupancy of each bus along the bus stops by trips across 24 hours



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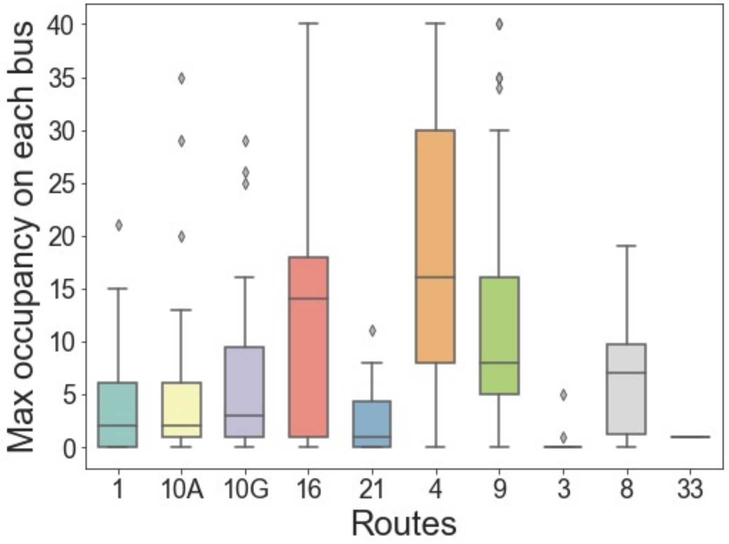
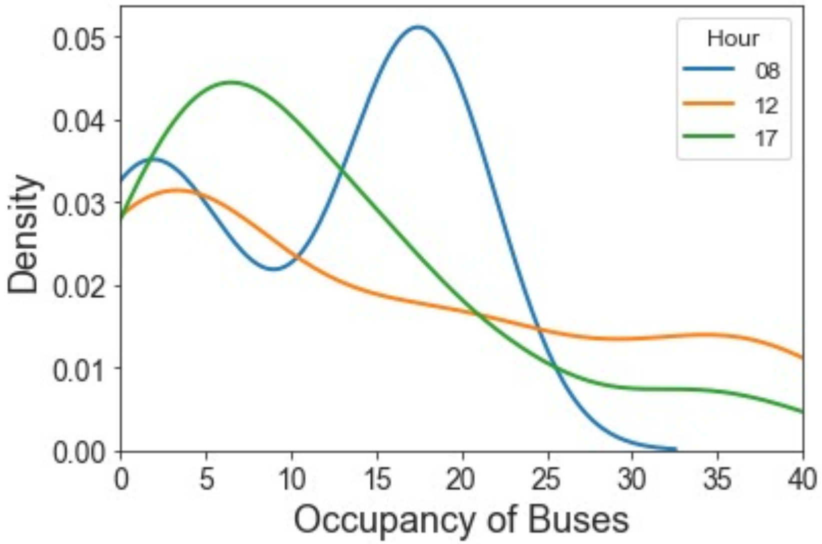
RESULTS AND DISCUSSION

- ***Visualization examples***

✓ Maximum passenger occupancy of each bus along the bus stops by routes across 24 hours (left). Distributions of bus occupancy between specific hours on route 4 (right)





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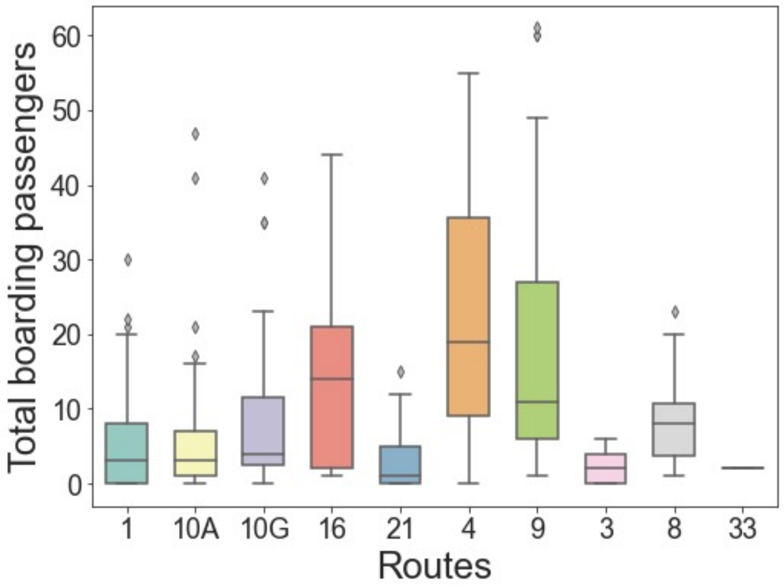
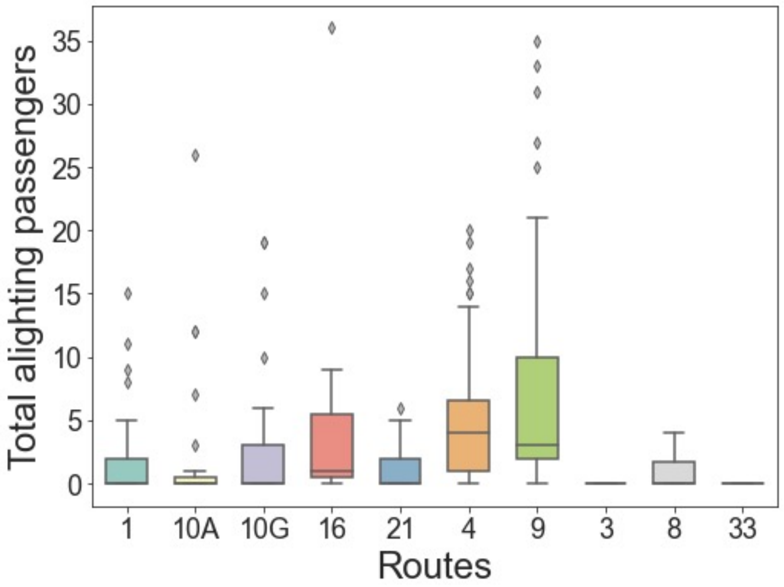
RESULTS AND DISCUSSION

- ***Visualization examples***

✓ The total boarding passengers (left) and the total alighting passengers of each bus by routes across 24 hours (right)





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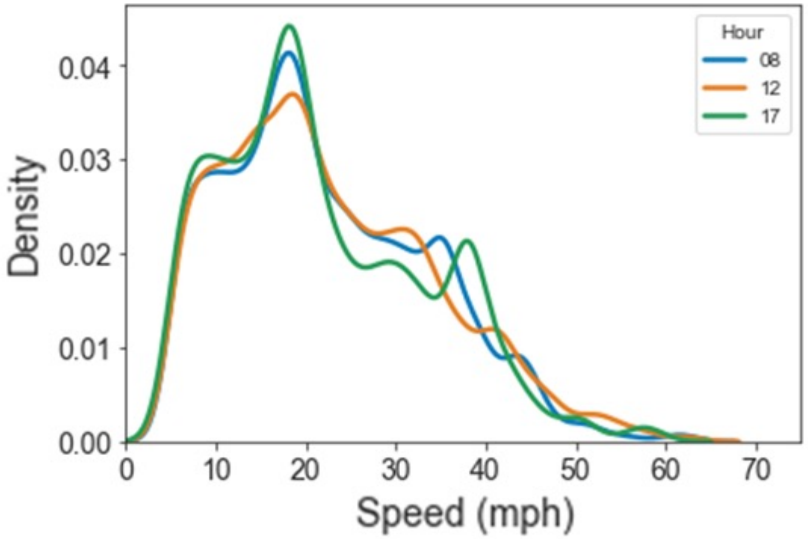
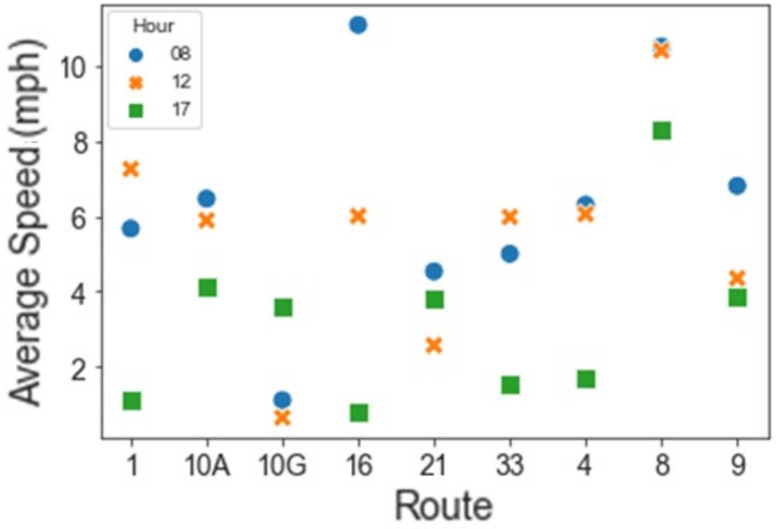
RESULTS AND DISCUSSION

- ***Visualization examples***

✓ Distributions of bus speed (left), average speed of buses on route 4 during three specific hours (right)





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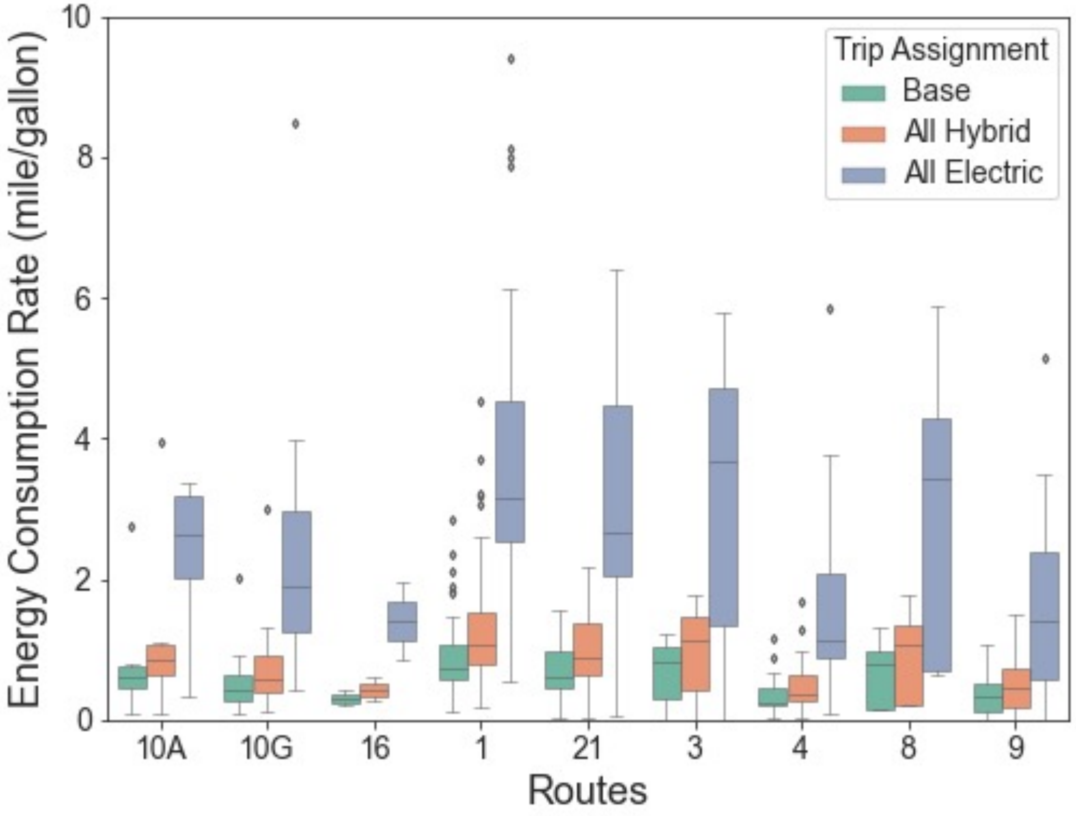
RESULTS AND DISCUSSION

- ***Scenario Analysis of Energy Consumption***

✓ Variations of vehicle trip assignments

- The comparison of energy consumption rate of buses among different trip assignment scenarios, including base scenario, using all hybrid buses and using all electric buses.
- It is obvious that buses in the scenario using all electric trip assignment generally consumes the least energy than that of using the other assignments across all the routes.



RESULTS AND DISCUSSION

- ***Scenario Analysis of Energy Consumption***

✓ Variations of demand models

- To check the impact of background traffic on the energy estimation, two scenarios regarding different background demand models are constructed.
- The estimated energy consumption rates for three bus types under the two scenarios are shown in Table

Route No.	Trip No.	Energy consumption rate (mile/diesel equivalent gallon)					
		Original demand			Reduced demand		
		Diesel	Hybrid	Electric	Diesel	Hybrid	Electric
1	1	1.0	1.3	11.6	1.2	1.8	5.0
	2	2.7	4.3	11.7	2.8	4.7	10.7
	3	2.3	3.3	10.8	2.7	4.6	10.4
	4	1.1	1.5	8.1	1.5	2.7	6.3
3	5	1.6	2.0	14.9	1.9	2.9	9.5
	6	3.7	5.0	15.9	4.2	6.4	16.8
	7	1.2	1.5	11.4	3.3	5.5	14.6
4	8	2.0	2.8	11.4	1.4	2.0	5.0
	9	2.3	3.1	14.0	2.4	3.7	10.2
9	10	2.8	3.8	14.0	2.5	3.9	10.9
	11	2.1	3.4	9.4	2.3	3.7	8.0
10A	12	2.5	3.4	14.2	2.5	4.0	10.7
	13	2.8	4.2	12.8	3.0	4.7	10.7
10G	14	2.4	4.0	9.5	2.8	4.5	9.6
	15	0.9	1.1	8.1	2.3	3.7	8.4

CONCLUSIONS AND FUTURE WORK

- This paper demonstrated the broader applicability of *TRANSIT-GYM* for realistic transit simulations and providing efficient decision-support for transportation planning. *TRANSIT-GYM* is freely available on GitHub: *https://github.com/smarttransit-ai/transit-simulator*.
- Several extensions to *TRANSIT-GYM* we are working on:
  - Integrating transportation planning with transit simulation and energy consumption estimation together as a co-simulation using Vanderbilt's CPSWT framework
  - Developing a richer scenario modeling language to incorporate more specific transit use-cases
  - Increasing performance of our simulation through partitioned traffic simulations,
  - Scaling our simulations for broader cloud integration
  - Enhancing visualization of experiment and analysis results

ACKNOWLEDGEMENT

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THANKS!

GitHub: https://github.com/smarttransit-ai/transit-simulator
Project Website: https://smarttransit.ai/

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