Dynamic Traffic Assignment and Simulation for the SCAG Region

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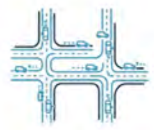

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TraffiQure

(A CMU spinoff firm specializing transportation data and AI,   Caltrans certified DBE)

Outline

1. Project Introduction
   - Scope, Goals, and Schedule
2. Methodology: MAC-POSTS & DTA
   - Core Simulation Framework and Platform Updates
3. Network Conversion
   - Statistics and Technical Enhancements
4. OD Demand Conversion
   - Modeling Traveler Demand
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   - Run Time, Memory, and Data Generation
6. Visualization of Results
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7. Potential Applications
8. Future Work & Next Steps
   - Calibration, Validation, and Case Studies

1. Project Introduction

- **Core objective:**

  To develop a Dynamic Traffic Assignment (DTA) tool as a new, advanced module for SCAG regional travel demand model.

- **Main Goals:**
  - Generate Granular & Enriched Outputs
  - Model Multi-Class Transportation
  - Enable Advanced Policy Analysis
  - Maintain Computational Efficiency

1. Project Introduction

- This is a two-year project, and we divided it into four strategic phases.

Phase 1: Setup, Planning & Data Conversion

- Project Kick-off, Introduction Seminar & Model Development Plan
- Develop tools to convert SCAG network and demand data

Phase 2: Model Implementation & Initial Outputs

- Implement the DTA model for the full SCAG network
- Develop scripts for summarizing key performance metrics

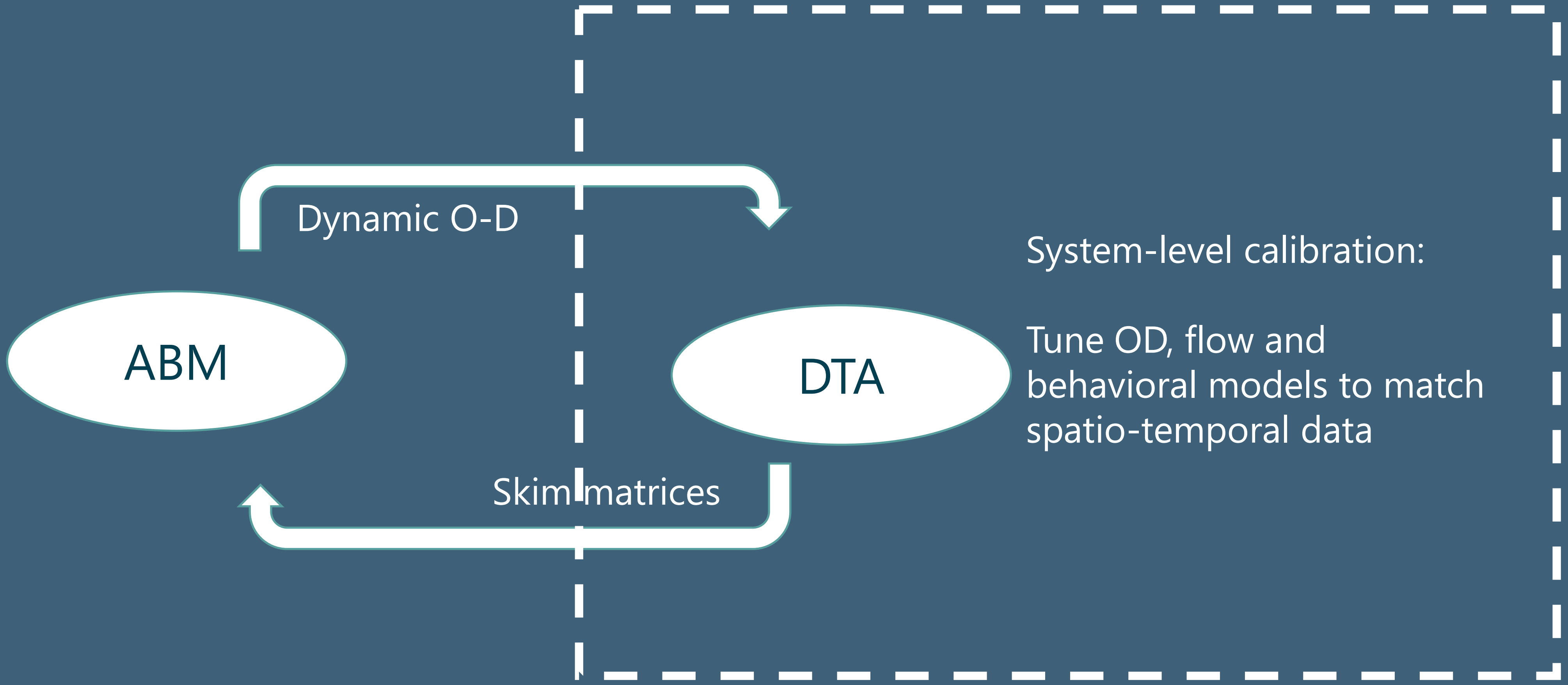
Phase 3: Calibration & Validation

- Calibrate the model against multi-source data (PeMS, NPMRDS, etc.)
- Validate model accuracy and performance

Phase 4: Case Study & Final Reporting

- Conduct a case study on dynamic tolling
- Deliver final report, source codes, and presentation

2. Methodology: ABM <> DTA



System-level calibration:

Tune OD, flow and behavioral models to match spatio-temporal data

Open Source

https://github.com/maccmu/macposts

2. Methodology: MAC-POSTS & DTA

- **Mobility data Analytics Center - Prediction, Optimization, and Simulation toolkit for Transportation Systems (MAC-POSTS)**
  - Data-driven, ML-powered: ability to match high-res multi-source data
  - Multi-class (car, truck, bus, EV, CAV, etc.)
  - Multi-modal (solo-driving, carpool, metro, bus, walk, parking, etc.)
  - State-of-the-art travelers’ behavior model (inferred from data)
  - Computationally efficient for large-scale networks, while being high granular
  - Web-based UI; Minimal workforce training

Use MAC-POSTS

- Dynamic traffic assignment
- Estimate dynamic O-D demand and behavioral models
- Assess traffic congestion, fuel consumption, and emissions
- Evaluate the effectiveness of traffic management plans
- Answer "what-if" questions
  - Tolling, road closures, new infrastructure, TDM, TIM, bus fare change, new metro routes, disasters, ...

How to calibrate? Data and ML

- Roadway infrastructure
  - Regional planning models
  - Transportation improvement plans
- Individual vehicles
  - State vehicle registration records (VIN)
- Aggregated vehicles
  - Traffic speeds and travel times, by car and trucks
  - Vehicle counts, by car and trucks
  - Satellite imagery data
- Parking and Curb usage
  - On-street parking transactions
  - Curb pickup, dropoff, by vehicle class
- Public transit and passengers
  - GTFS, APC, AVL

Generic system-level or individual-level data

Examples

- Bridge tolling impact for DVRPC
- Decarbonization strategies in for SPC

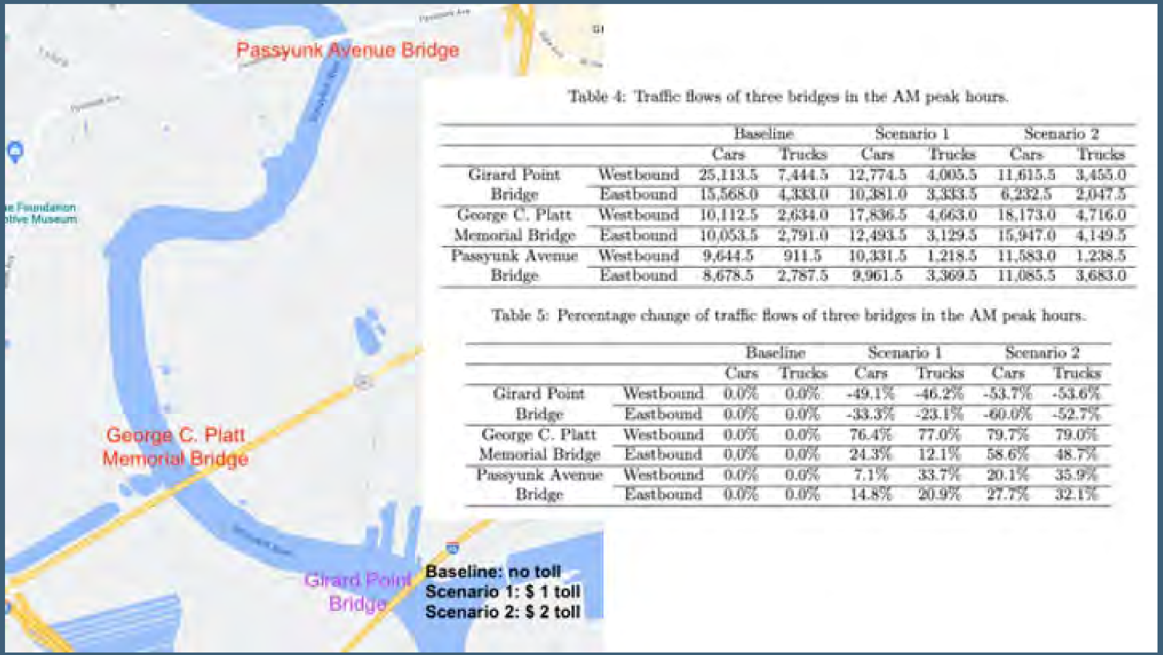
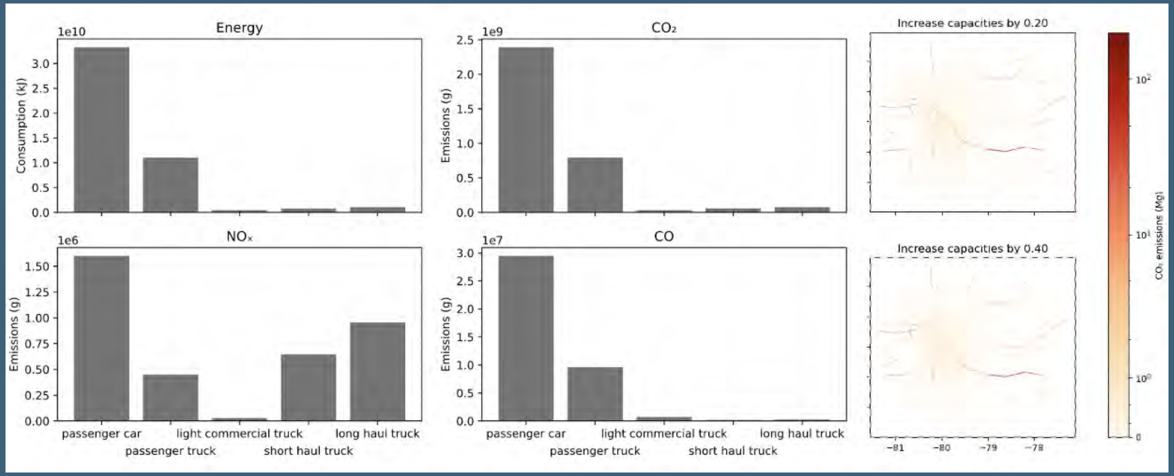


Table 4: Traffic flows of three bridges in the AM peak hours.

		Baseline		Scenario 1		Scenario 2	
		Cars	Trucks	Cars	Trucks	Cars	Trucks
Girard Point Bridge	Westbound	25,113.5	7,444.5	12,774.5	4,005.5	11,615.5	3,455.0
	Eastbound	15,568.0	4,333.0	10,381.0	3,333.5	6,232.5	2,047.5
George C. Platt Memorial Bridge	Westbound	10,112.5	2,634.0	17,836.5	4,663.0	18,173.0	4,716.0
	Eastbound	10,053.5	2,791.0	12,493.5	3,129.5	15,947.0	4,149.5
Passyunk Avenue Bridge	Westbound	9,644.5	911.5	10,331.5	1,218.5	11,583.0	1,238.5
	Eastbound	8,678.5	2,787.5	9,961.5	3,369.5	11,085.5	3,683.0

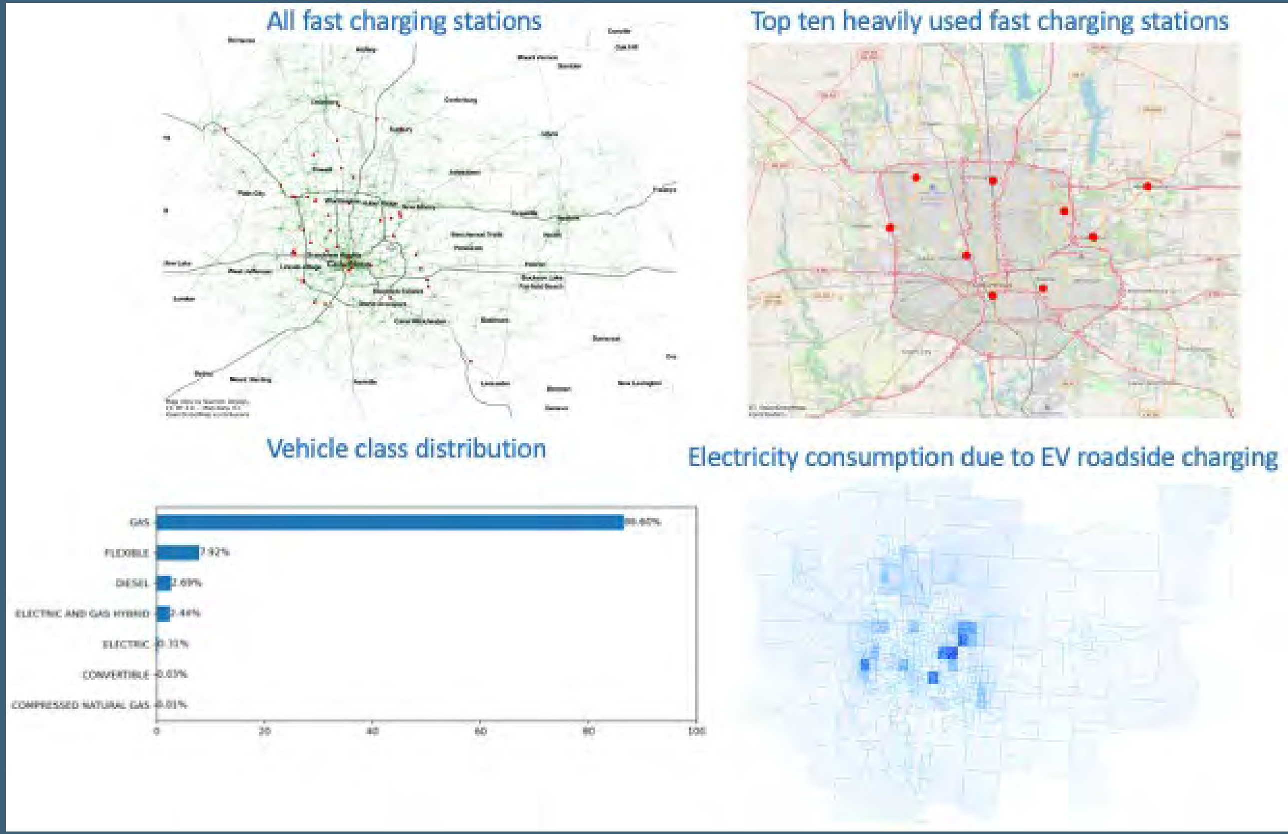
Table 5: Percentage change of traffic flows of three bridges in the AM peak hours.

		Baseline		Scenario 1		Scenario 2	
		Cars	Trucks	Cars	Trucks	Cars	Trucks
Girard Point Bridge	Westbound	0.0%	0.0%	-49.1%	-46.2%	-53.7%	-53.6%
	Eastbound	0.0%	0.0%	-33.3%	-23.1%	-60.0%	-52.7%
George C. Platt Memorial Bridge	Westbound	0.0%	0.0%	76.4%	77.0%	79.7%	79.0%
	Eastbound	0.0%	0.0%	24.3%	12.1%	58.6%	48.7%
Passyunk Avenue Bridge	Westbound	0.0%	0.0%	7.1%	33.7%	20.1%	35.9%
	Eastbound	0.0%	0.0%	14.8%	20.9%	27.7%	32.1%



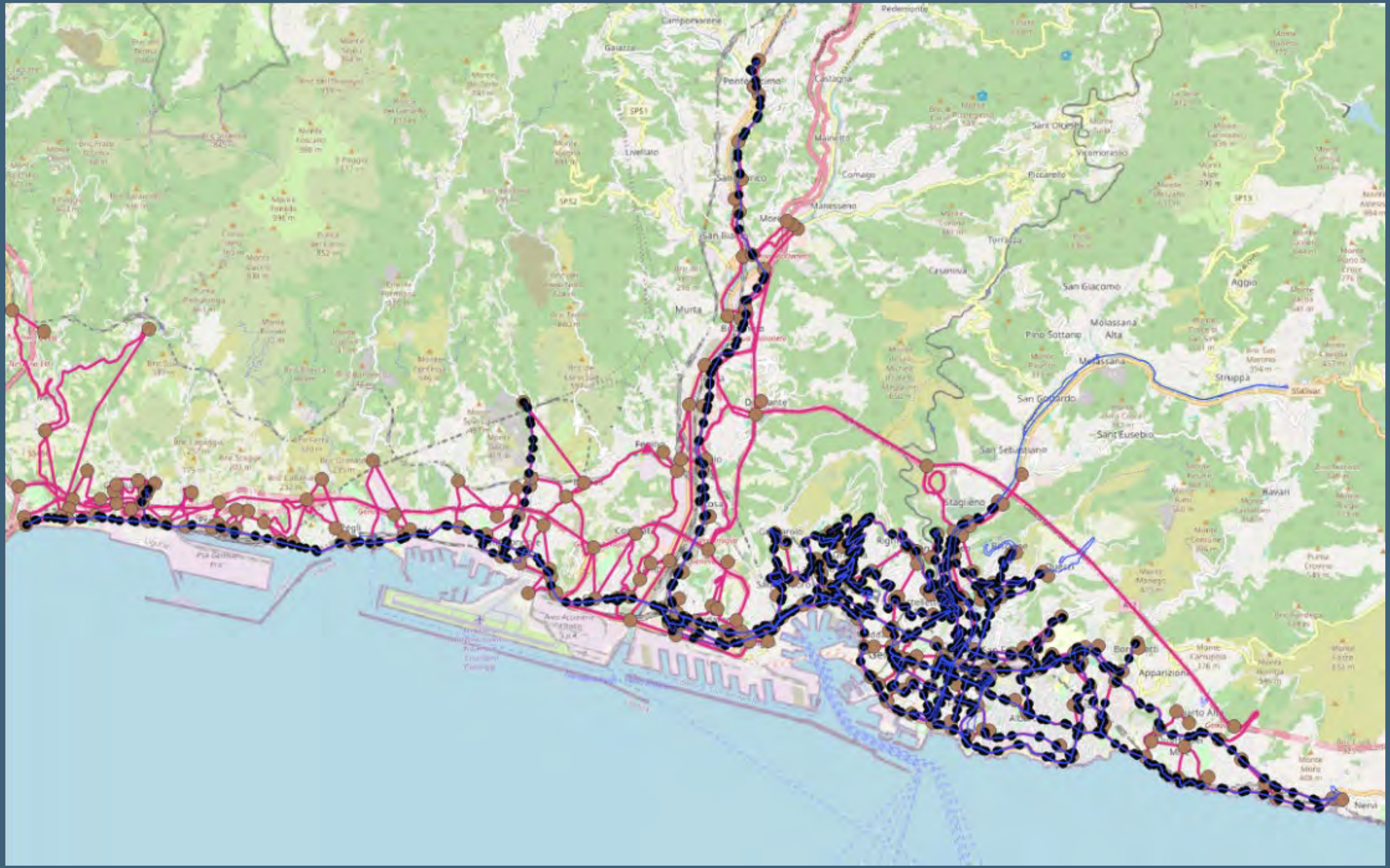
Examples

- EV usage estimation and optimizing siting of charging stations for MORPC

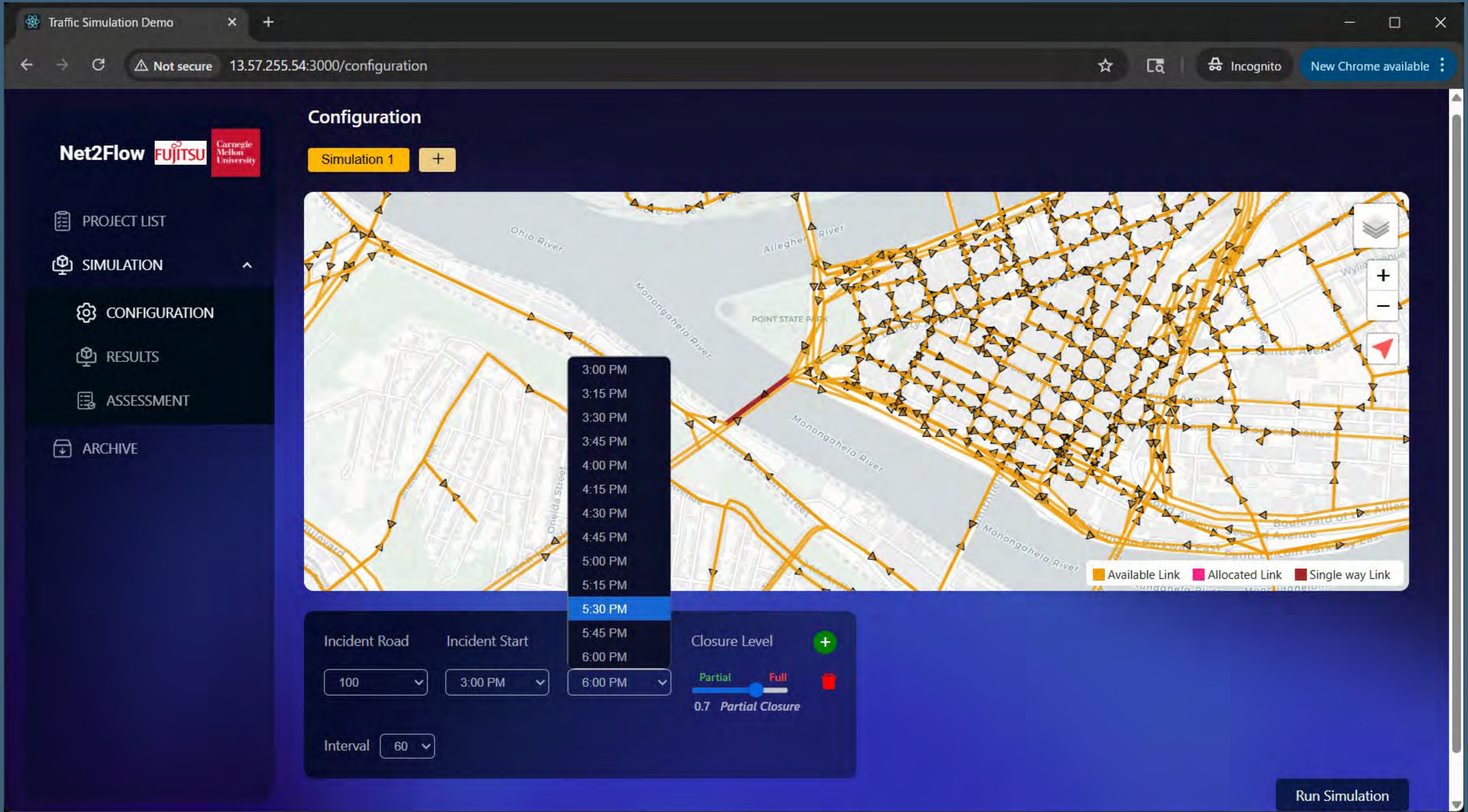


Genova, Italy

- Driving, P&R, Metro, Bus – how to optimize Metro usage



A pilot in Pittsburgh (with Fujitsu America)



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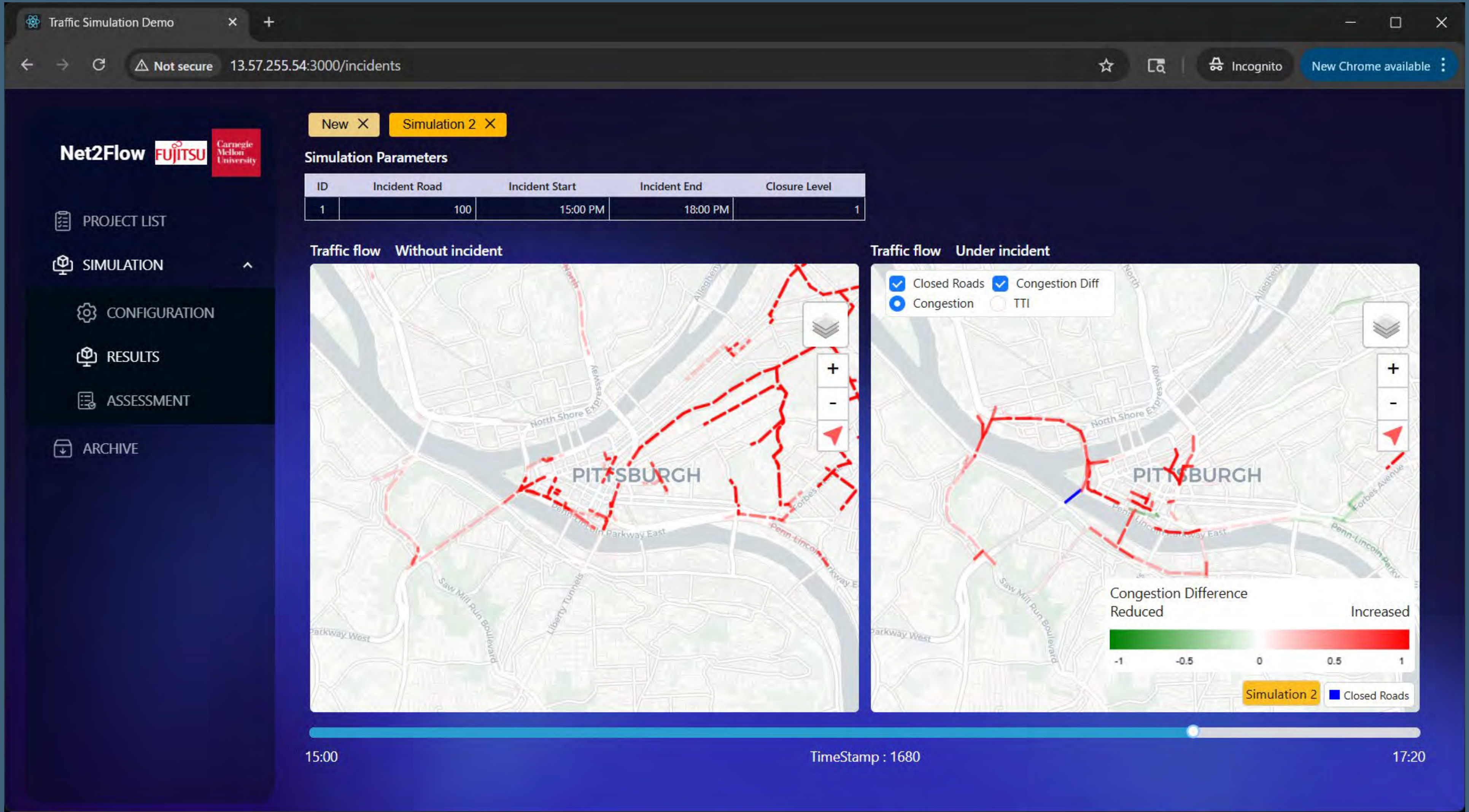


2. Methodology: Simulation Framework

This project utilizes MAC-POSTS with significant enhancements for SCAG

1 Modeling Heterogeneous Traffic Flow

- The model explicitly simulates multiple vehicle classes (passenger cars, light/medium/heavy-duty trucks) and their unique interactions in mixed traffic
- This is critical for accurately capturing congestion and emissions

2 Simulating Realistic Driver Behavior

- Travelers are modeled as two distinct types:
- **Habitual Drivers:** Follow pre-determined, typical routes
- **Adaptive Drivers:** Can change their route choices "on the fly" based on real-time traffic conditions
- This dual approach is essential for modeling traffic diversion between general-purpose lanes, HOV lanes, and express/toll lanes

3 Capturing Complex Infrastructure

- The network model encodes key infrastructure features, including:
- HOV lanes
- Truck-only lanes
- Dynamic toll lanes
- Allowing the simulation to capture their specific operational characteristics

MAC-POSTS Hybrid Routing for SCAG

Multiple vehicle classes with different characteristics

Different networks for different vehicle types based on link prohibitions

Mix of habitual and adaptive routing behaviors

2. Methodology: MAC -POSTS Windows Migration

Key Project Enhancement

Successfully migrated MAC -POSTS from Linux-only to native Windows platform, making the tool more accessible for SCAG staff and consultants.

Environment Setup

- Install necessary software (VSCode, CMake, Python, MSVC)
- Configure environment variables and paths

CMake Configuration

- Update CMakeLists.txt for Windows compatibility
- Handle platform-specific configurations

Key Challenges Overcome

- DLL load failures
- CMake generator issues
- Segmentation faults
- Float number comparison

Code Modifications

- Modify platform-specific code (file paths, system calls)
- Handle differences in compilers and libraries

Dependency Management

- Identify and install necessary dependencies on Windows
- Update code to link and use dependencies correctly

Python Integration

- Ensure scripts work with Windows paths
- Modify Linux-specific features

Testing

- Test partial SCAG network
- Fix platform-specific bugs

3. Network Conversion

Main Task

Building a multiclass DTA model that considers the routing constraints for various vehicle types under specific link traversal prohibitions.

Vehicle Types & Link Prohibitions

Vehicle Type	Links Prohibited
SOV	1. Truck only links (facility types 89 and 90) 2. HOV 2 link (facility type 20) 3. HOV 3+ link (facility type 21)
HOV 2	1. Truck only links (facility types 89 and 90) 2. HOV 3+ link (facility type 21)
HOV 3+	1. Truck only links (facility types 89 and 90)
LHDT/MHDT/HHDT	1. Links with Truck_Prohibit_Flag 2. HOV 2 link (facility type 20) 3. HOV 3+ link (facility type 21)

Conversion Process

1. Determine necessary fields for DTA (Link ID, endpoint nodes, lanes, capacity, free-flow speed)
2. Convert two-way links to two separate one-way links
3. Delete Tier-2 TAZs and related OD connectors
4. Add separate nodes to represent origins and destinations (Tier-1 TAZs)
5. Create different networks routable only for a class of vehicles

Network Statistics

Original Shapefiles

Tier-1 TAZs:	4,192
Nodes:	66,765
Links:	120,003
OD connectors:	36,143

After Conversion

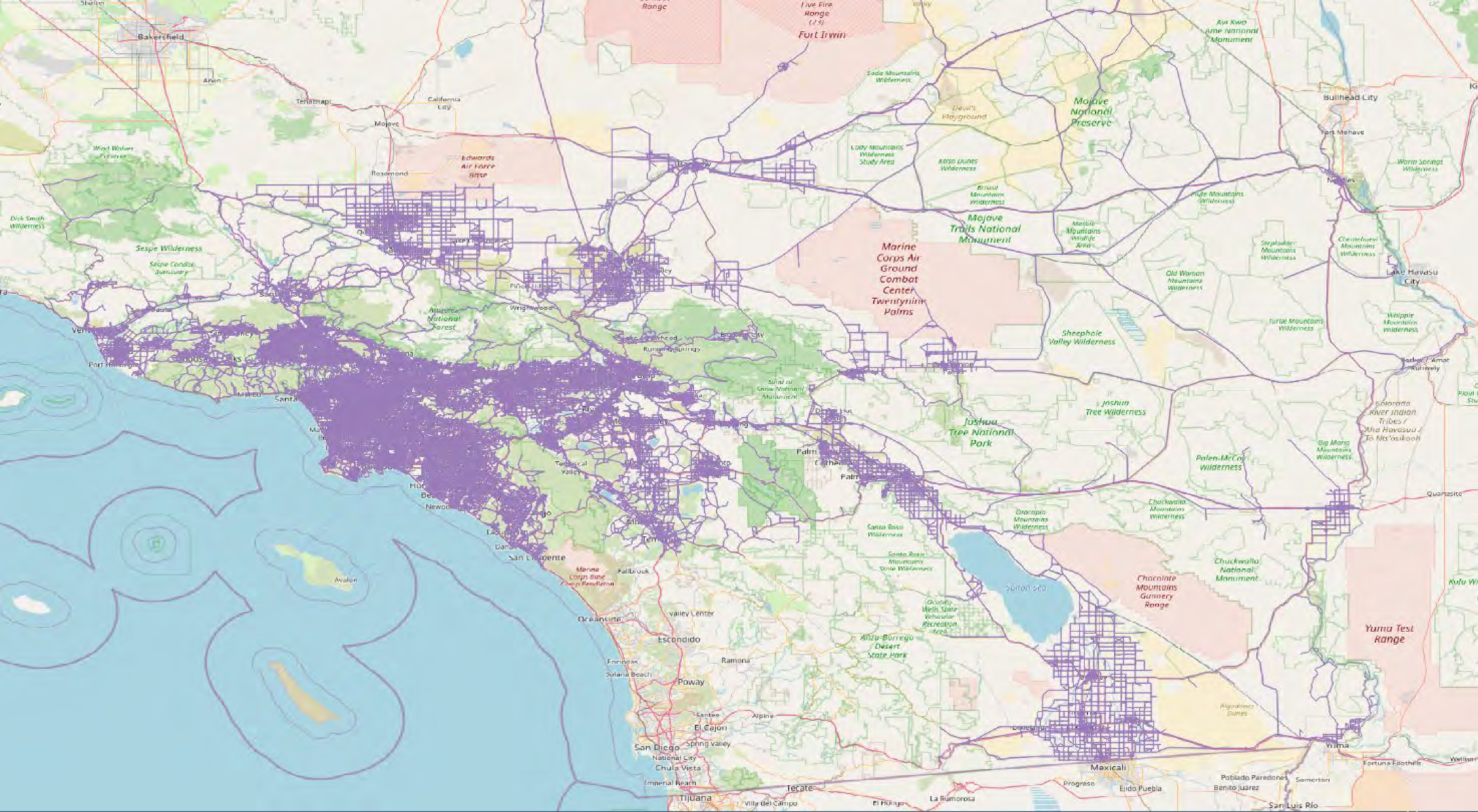
Origins/Destinations :	4,192
Nodes:	65,693
Links:	168,527
OD connectors:	25,150

Subgraphs Created

Subgraph 1: for Car DA, 167,184 links
Subgraph 2: for Car SR2, 168,472 links
Subgraph 3: for Car SR3, 168,473 links
Subgraph 4: for Trucks, 166,547 links

Key Link Parameters

Length
Free-flow speed by car and truck
Jam density by car and truck
Flow capacity by car and truck
OD connectors has sufficiently large capacity



Bakersfield
Arvin
Tehachapi
California City
Mojave
Rosamond
Edwards Air Force Base
Fort Irwin
Soda Mountains Wilderness
Devil's Playground
Mojave National Preserve
Bullhead City
Fort Mohave
Needles
Warm Springs Wilderness
Cady Mountains Wilderness Study Area
Kelso Dunes Wilderness
Bristol Mountains Wilderness
Piute Mountains Wilderness
Mojave Trails National Monument
Marble Mountains Wildlife Area
Marine Corps Air Ground Combat Center Twentynine Palms
Wind Wolves Preserve
Dick Smith Wilderness
Sespe Wilderness
Sespe Condor Sanctuary
Wrightwood
Angeles National Forest
Running Springs
Sand to Snow National Monument
Sheephole Valley Wilderness
Stepladder Mountains Wilderness
Chemehuevi Mountains Wilderness
Old Woman Mountains Wilderness
Lake Havasu City
Turtle Mountains Wilderness
Whipple Mountains Wilderness
Joshua Tree Wilderness
Joshua Tree National Park
Port Hueneme
Temescal Valley
Palen-McCoy Wilderness
Big Maria Mountains Wilderness
Quartzsite
Chuckwalla Mountains Wilderness
Orocopia Mountains Wilderness
Santa Rosa Wilderness
Santa Rosa Mountains State Wilderness
Salton Sea
Chuckwalla National Monument
Chocolate Mountains Gunnery Range
Yuma Test Range
Avalon
San Clemente
Marine Corps Base Camp Pendleton
Fallbrook
Oceanside
Valley Center
Escondido
Ramona
Encinitas
Solana Beach
Poway
Ocotillo Wells State Vehicular Recreation Area
Anza-Borrego Desert State Park
Algodones Dunes
Santee
Alpine
El Cajon
Spring Valley
San Diego
National City
Chula Vista
Imperial Beach
Tijuana
Tecate
Villa del Campo
El Hongo
La Rumorosa
Mexicali
Progreso
Ejido Puebla
Poblado Paredones
Benito Juárez
Somerton
Yuma
Fortuna Foothills
San Luis Rio

3. Network Conversion: MAC-POSTS Enhancements

MAC-POSTS Enhancements

Extending MAC-POSTS library's functionality to accommodate more car/truck subclasses and more flexible routing scenarios.

1. Enhanced Shortest Path Algorithm

- Multiple graphs considering different link traversal prohibitions
- Graph mapping for different vehicle classes:

2. Hybrid Routing

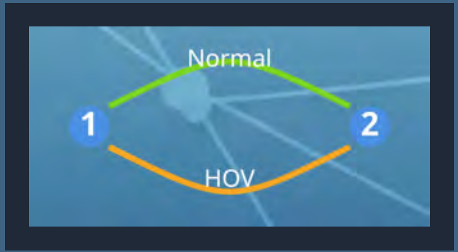
- Hybrid routing for each subclass using corresponding routing graph
  - **Habitual users:** using fixed routes
  - **Adaptive users:** updating routes enroute at a given time interval based on the current network condition
- Each vehicle subclass has proportions of habitual and adaptive users

3. Routing Constraints

- Each vehicle subclass may correspond to different link traversal prohibition
- Use different network topologies for routing different vehicle subclasses

4. Handling Multiple Links Between Nodes

- Different types of links may exist between the same pair of nodes



3. Network Conversion: MAC -POSTS Enhancements

MAC-POSTS Enhancements

- dta_input_AM
  - config.conf
  - MNM_input_demand_car
  - MNM_input_demand_truck
  - MNM_input_link
  - MNM_input_node
  - MNM_input_od
  - path_table_0
  - path_table_0_buffer
  - path_table_0_link_seq
  - path_table_1
  - path_table_1_buffer
  - path_table_1_link_seq
  - path_table_2
  - path_table_2_buffer
  - path_table_2_link_seq
  - path_table_3
  - path_table_3_buffer
  - path_table_3_link_seq
  - Snap_graph
  - Snap_graph_1
  - Snap_graph_2
  - Snap_graph_3
  - Snap_graph_4

DTA Input Files

Time-dependent car and truck demands by subclasses

```
#Origin_ID Destination_ID <car subclass 0 demand by interval> <car subclass 1 demand by interval> ...
4117 1000437 0.015436 0.017768 0.020491 0.022632 0.023850 0.023700 0.023621 0.024135 0.022241 0.018237 0.015151 0.
4117 1001627 0.002626 0.003023 0.003486 0.003850 0.004057 0.004032 0.004019 0.004106 0.003784 0.003103 0.002578 0.
4117 1002734 0.002114 0.002433 0.002806 0.003099 0.003266 0.003245 0.003234 0.003305 0.003045 0.002497 0.002075 0.
```

Four path tables corresponding to different link traversal prohibitions

Four graphs corresponding to different link traversal prohibitions

4. OD Demand Conversion: Challenges & Solutions

Full OD pairs 4,192 * 4,192 = 17,572,864.

Observation: 75% of OD pairs have a total daily demand <0.5.

In DTA, a demand resolution is set 0.5

Solution: Demand Pruning & Redistribution

Pruning:

Remove 75% of OD pairs that have a total demand less than 0.5.

Redistribution:

Add the small demands from pruned 75% of OD pairs back to the demand of retained 25% OD pairs to maintain vehicle statistics.

Demand Rounding & Coverage

Number of OD pairs	Demand Car	Demand Truck	Demand Total
Full OD (17,568,672)	40,657,418.42	1,572,340.23	42,229,758.65
OD with total daily car or truck demand >= 0.5 (4,550,842)	40,644,179.09	1,380,154.57	42,024,333.66
Ratio	99.97%	87.78%	99.51%

Rounded Demand Coverage

Vehicle	Demand for full OD	Rounded demand (>= 0.5)	Coverage (>= 0.5)	Rounded demand (>= 5)	Coverage (>= 5)
DA	26,436,546.31	26,436,546.00	100.00%	26,436,546.00	100.00%
SR2	8,621,365.84	8,621,365.50	100.00%	8,621,365.50	100.00%
SR3	5,599,506.27	5,599,506.00	100.00%	5,599,506.00	100.00%
LHDT	849,832.99	849,832.50	100.00%	849,832.50	100.00%
MHDT	320,698.63	320,698.50	100.00%	320,698.50	100.00%
HHDT	401,808.61	401,808.50	100.00%	401,808.50	100.00%

5. Model Performance & Outputs

Run Time and Memory

Full SCAG network (168,527 links) with 5 -hour traffic demand:
Resolution: 5 seconds, 200~500 feet

Run Time

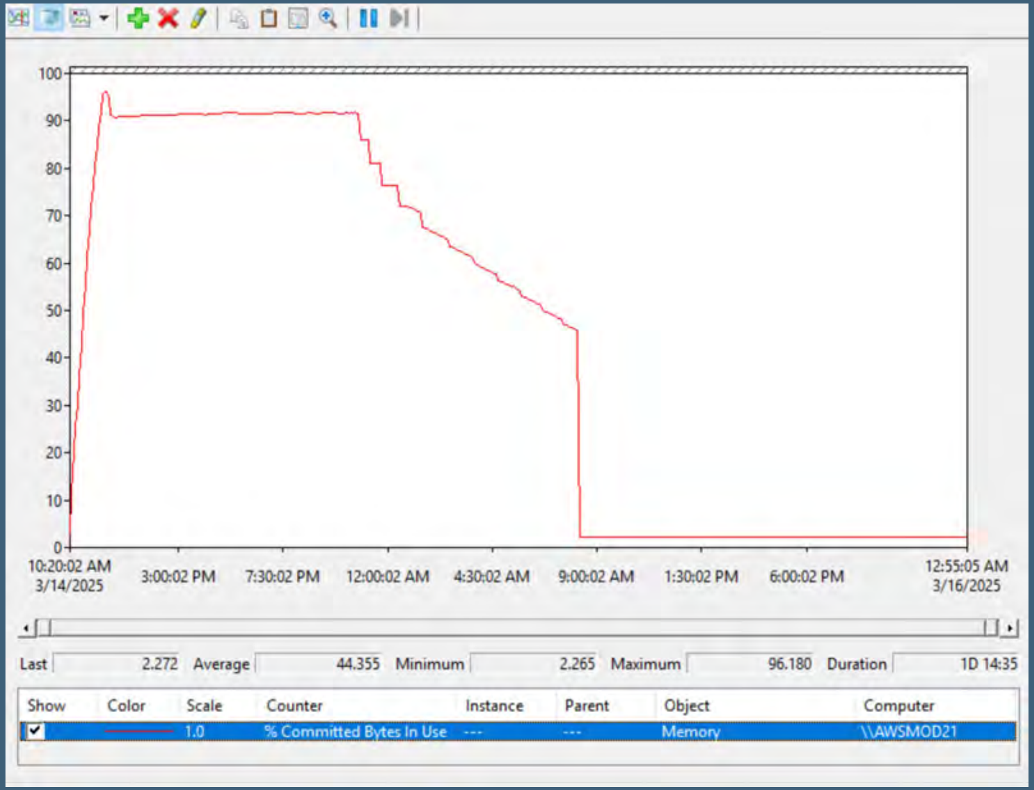
24 hours

on a SCAG AWS server
(380GB RAM)

Memory Usage

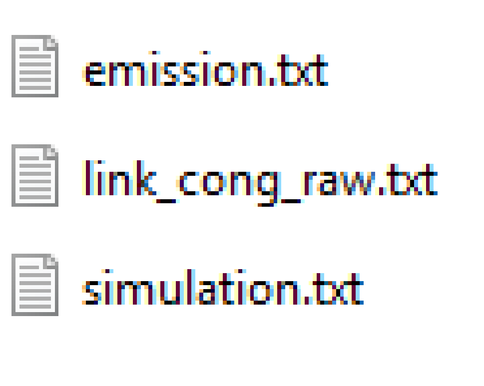
100 GB

peak memory consumption
during simulation



Output Files

The output files are stored in the folder "record" once the simulation is done:



System-level emission, VMT, VHT

Link-level time-dependent vehicle count/speed

System-level vehicle count by subclass

Vehicle-level second-by-second traces are available

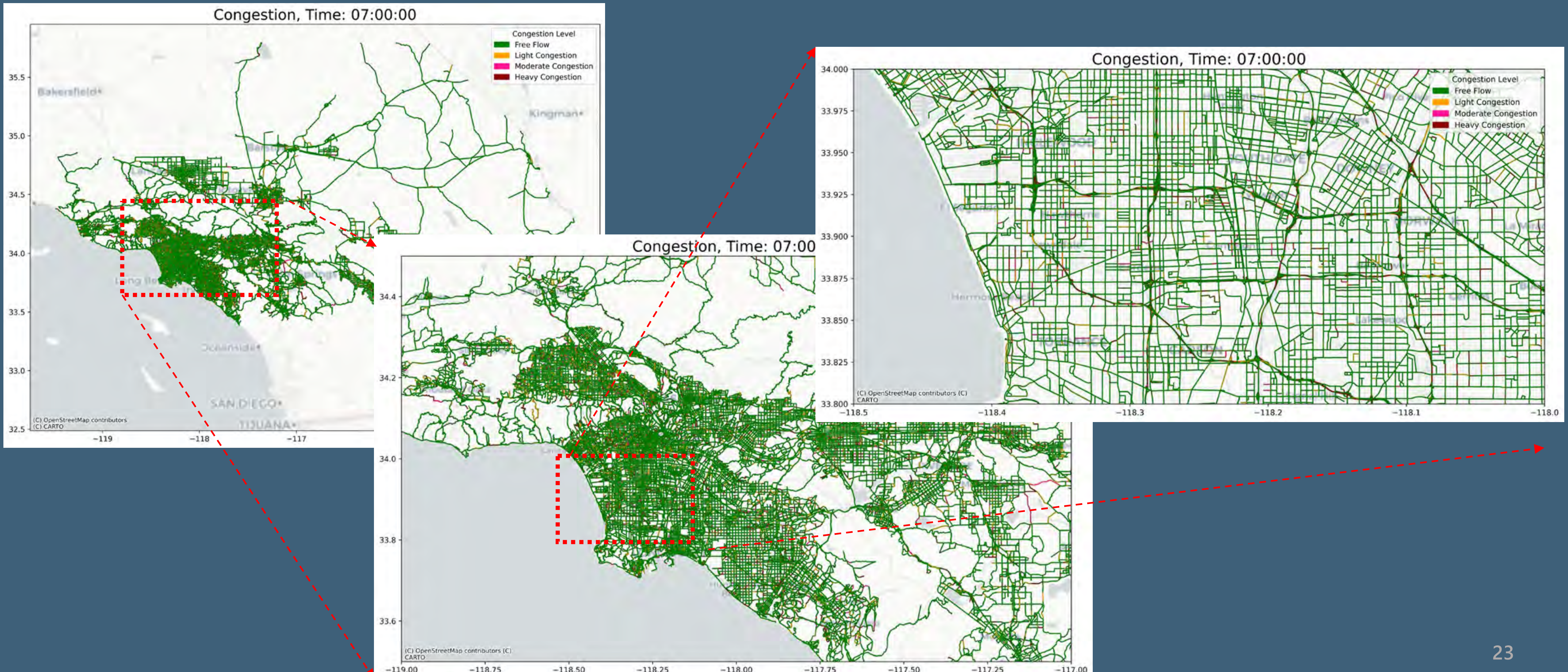
5. Model Performance & Outputs

Category	VMT (miles)	VHT (hours)	Released Vehicle #	Enroute Vehicle #	Finished Vehicle #	Mile per vehicle	Hour per vehicle	Average delay (min)
Total Cars	79,697,629.70	4,616,945.96	8,375,780.50	1,007,624.50	7,368,156.00	9.52	0.55	22.60
Car (DA)	56,989,949.35	3,288,391.38	5,075,442.50	707,372.50	4,368,070.00	11.23	0.65	26.37
Car (SR2)	13,337,622.66	779,018.39	1,810,712.00	177,163.00	1,633,549.00	7.37	0.43	17.95
Car (SR3+)	9,370,057.69	549,536.19	1,489,626.00	123,089.00	1,366,537.00	6.29	0.37	15.42
Total Trucks	3,776,745.84	164,898.37	236,532.00	35,414.00	201,118.00	15.97	0.70	24.21
Truck (LHDT)	1,669,750.62	87,431.64	136,530.00	20,474.00	116,056.00	12.23	0.64	24.51
Truck (MHDT)	689,718.10	28,045.57	50,284.00	5,414.00	44,870.00	13.72	0.56	18.57
Truck (HHDT)	1,417,277.12	49,421.16	49,718.00	9,526.00	40,192.00	28.51	0.99	29.08

LA County avg one-way commute: 26-33 min, 9-17 miles, (indexmundi.com, 2014-2018)
Southern CA one-way trip (all purposes) : 10-17 miles, 27-35min (2021 NextGen NHTS CA OD Addendum)

6. Visualization of Current Results

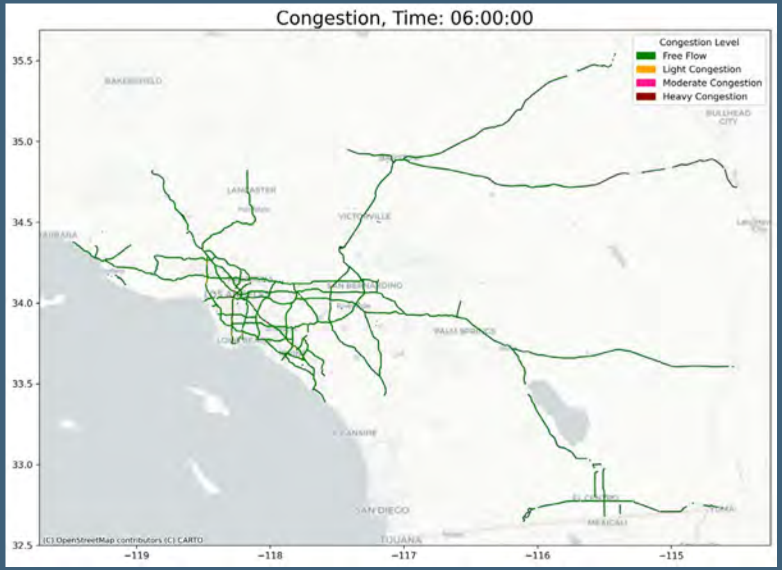
Whole SCAG Network

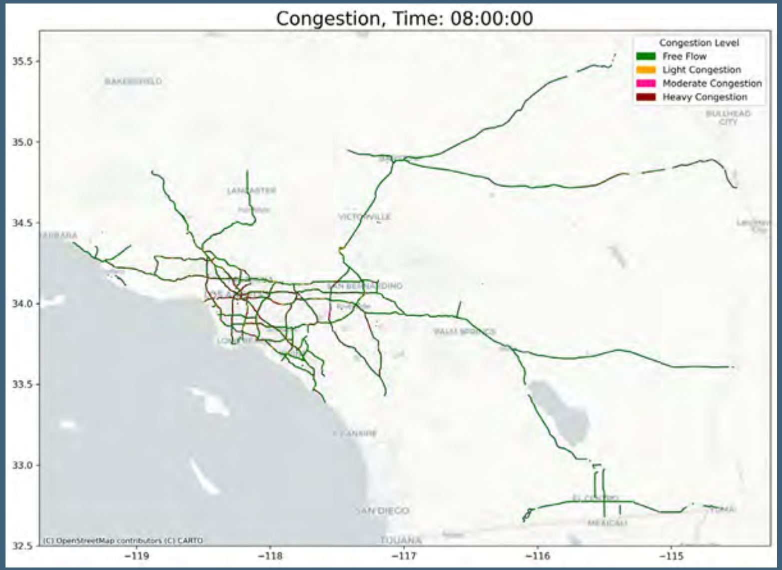


6. Visualization of Current Results

Freeway

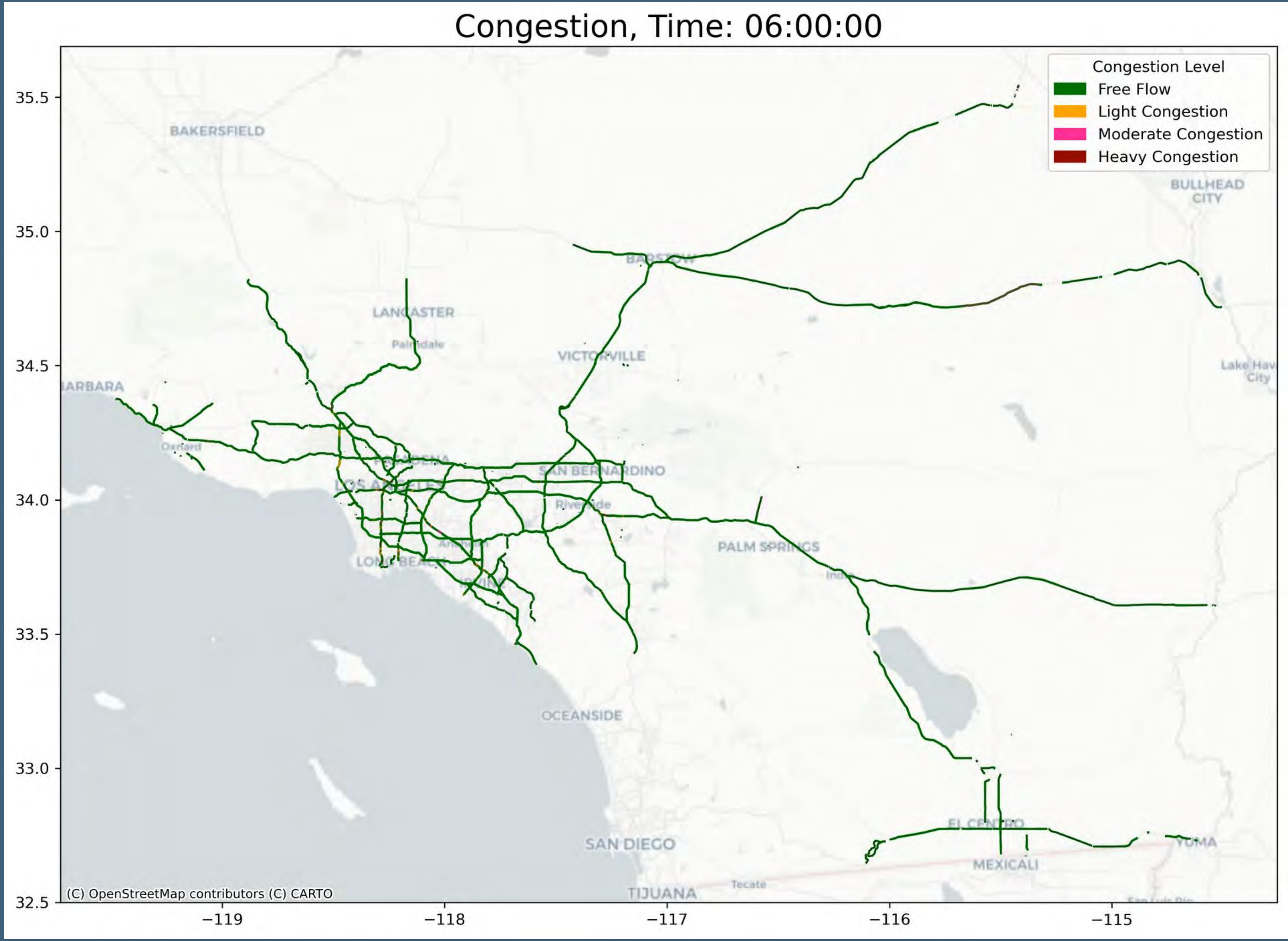
Congestion Level: Free Flow Light Moderate Heavy





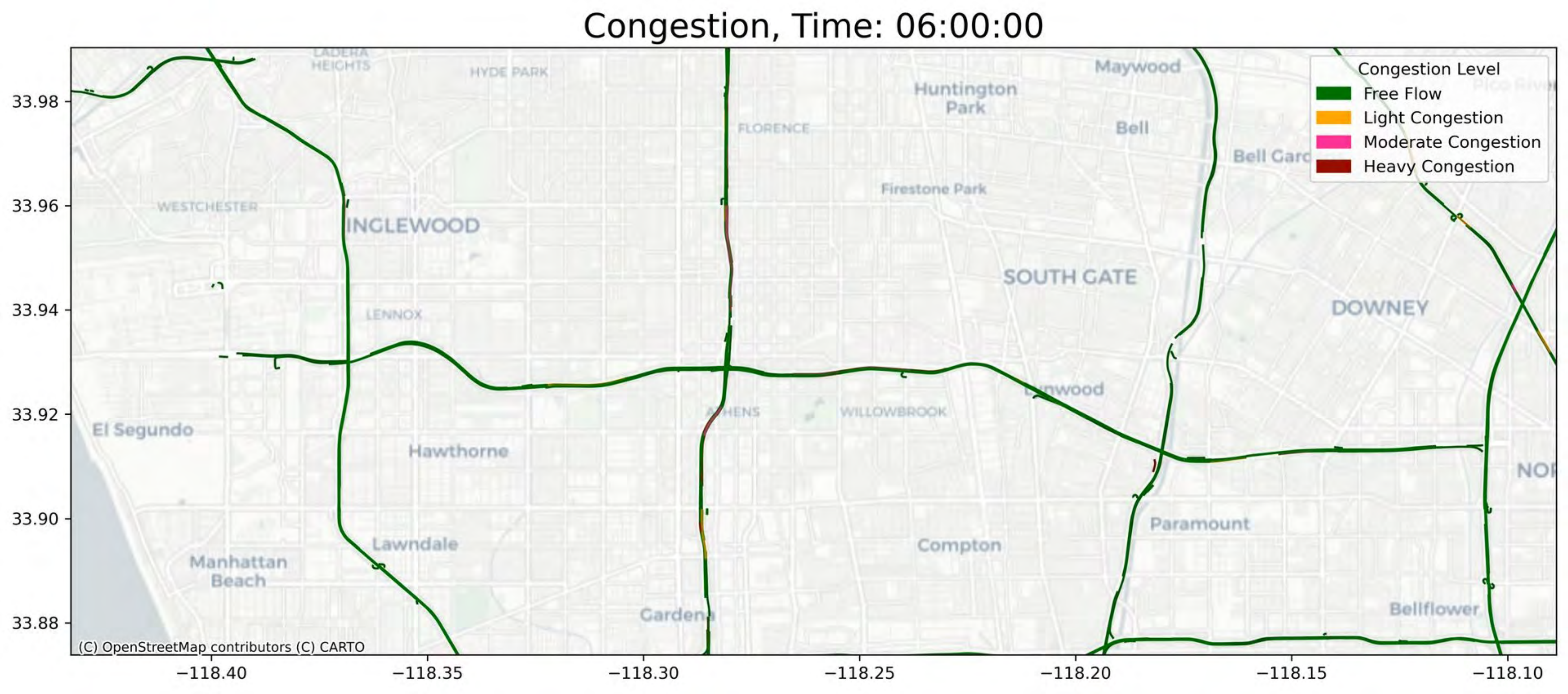
6. Visualization of Current Results

Freeway



6. Visualization of Current Results

I-105 ExpressLanes Project Area



Congestion Level:

Free Flow | Light | Moderate | Heavy

Project website: https://www.metro.net/projects/i105-expresslanes/

7. Potential Applications

Transportation Planning

Evaluate new infrastructure projects
Analyze transportation demand management strategies
Assess impacts of land use changes on transportation
Support long-range transportation planning

Transportation Operations

Evaluate road-closure impacts
Real-time traffic management
Work zone planning

Policy Analysis

Evaluate congestion pricing
Assess HOV/HOT lane policies
Evaluate emission reduction strategies
Analyze equity impacts of transportation policies
EV, CAV impacts

8. Future Work & Next Steps

Model Calibration & Validation for a focus network as a POC

Calibrate the model using multi -source data (PeMS, NPMRDS, etc.) and validate model accuracy and performance against ground truth data.

Case Studies

Conduct a dynamic tolling case study to evaluate the impact of different tolling strategies on traffic flow, travel time, and revenue implications.

Documentation & Training

Create comprehensive documentation and user manuals, and provide training and technical support to SCAG staff.

Conclusion

- Successfully converted SCAG network and demand data to MAC -POSTS format and implemented a full-network DTA simulation.

- Developed a computational framework that can handle the large-scale SCAG network with reasonable run time and memory usage.

- With calibration and validation, the DTA model will become a powerful tool for transportation planning and policy analysis in the SCAG region.

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Thank you for your attention!