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Short-Term Traffic and Revenue Forecasting Under Network and Demand Changes

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- Limitations of current forecasting methods
- Proposed methodology
- Training data
- Results
- Future work

- **Limitations of Travel Demand Models**
  - Fail to capture rapid short-term trends.
  - Aggregate inputs and fixed response functions.
- **Limitations of Time-Series Deep Learning Models**
  - Work only when the network is stationary.
  - Performance drops when capacity changes.
- **Hybrid Framework**
  - Combine **historical observations (i.e., demand changes) for real temporal patterns** with
  - **CUBE simulations (i.e., network changes) for counterfactual scenarios (e.g., capacity changes)**.
- **Outcome**
  - Link-level volume and revenue forecasts under dynamic network conditions.

Methodology Overview

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Scenario Generation

1. Apply capacity changes at corridor and global network level to perform CUBE simulations
2. Assign corresponding A–B nodes from network with historical transactions/gantries

Feature Preparation

Generate and normalize features across both datasets

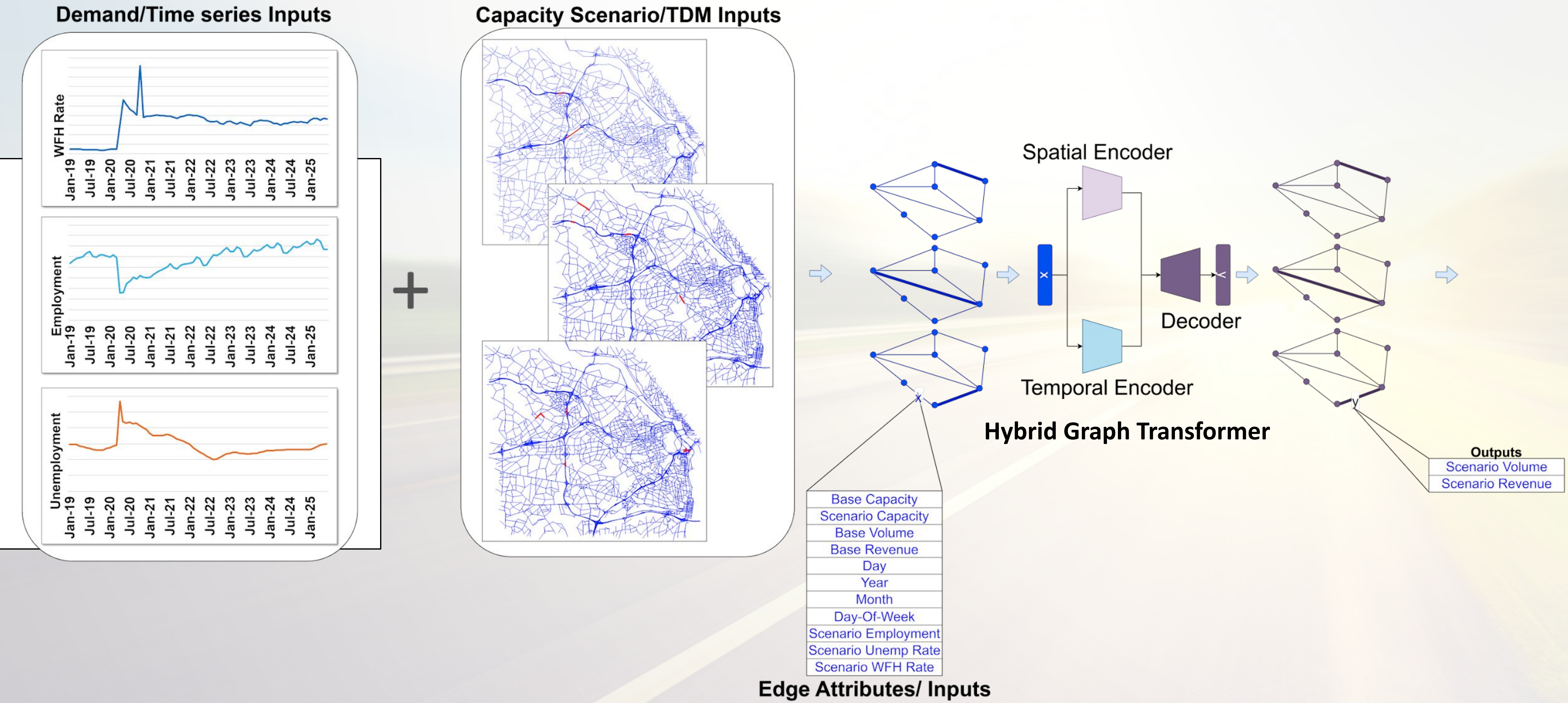
Joint Training

Jointly train temporal and spatial encoders with a single decoder under a unified loss

Evaluation

Evaluate performance using observed data holdout and holdout with unseen capacity changes.

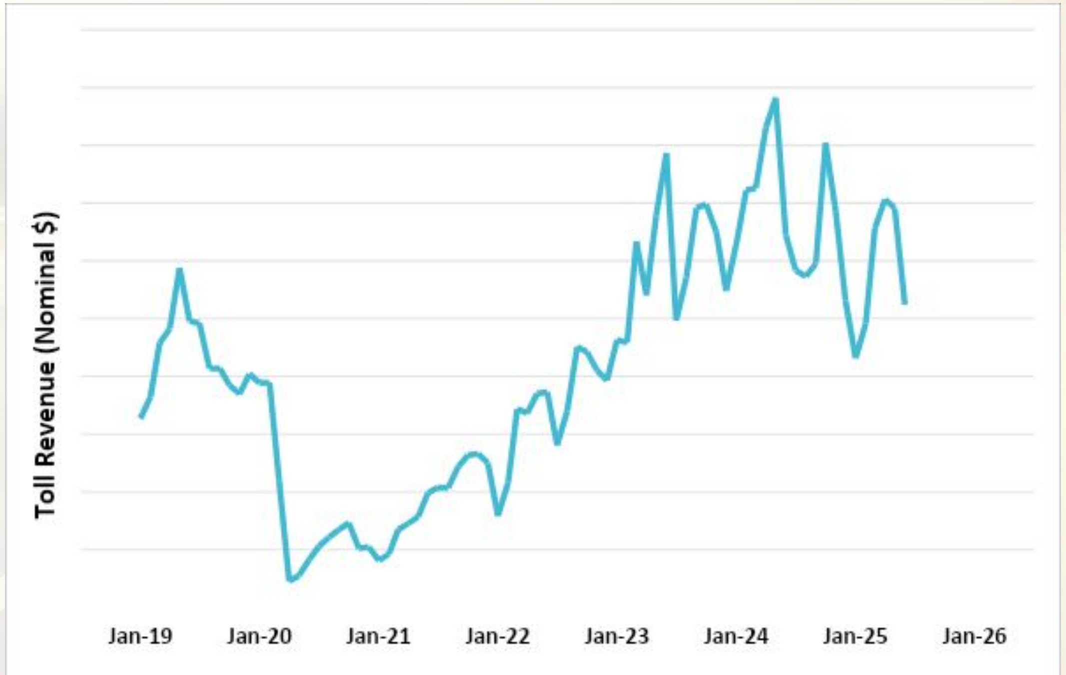
Methodology Overview



- **Existing Literature**
  - DCRNN's graph diffusion + RNN encoder-decoder
  - STGCN's graph conv + gated TCN
  - Graph Transformers
  - Separate space and time modules
- **Cross-domain feature alignment:**
  - We used two transformer blocks (one spatial, one temporal encoder) tied by a shared MLP decoder.
  - Produce a single latent representation for both historical and simulation inputs.
  - This enables weighting of these evidence sources during forecasting.
- **Architectural scalability:**
  - Supports varying network sizes, time resolutions, and forecasting windows without redesign.
  - Makes it practical for corridor-level, region-level, or systemwide applications.

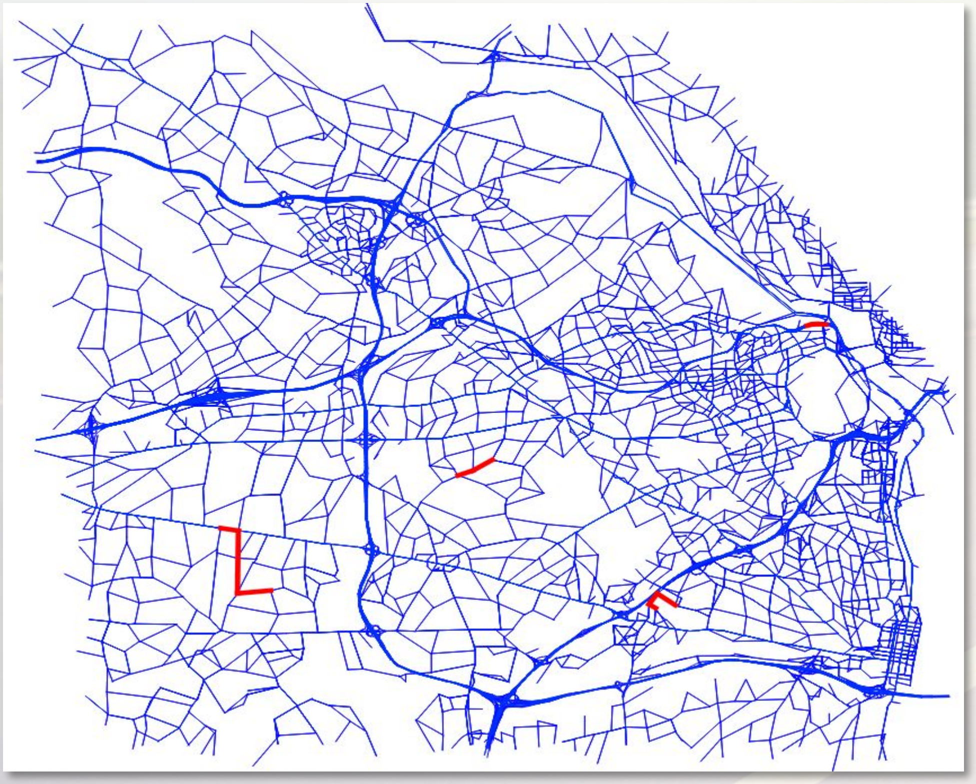
- Detailed 1-minute transaction and toll revenue data for gantries along major express lane corridors in the Northern Virginia Area, from Jan 2019 to Jun 2025.

Tolled Transactions

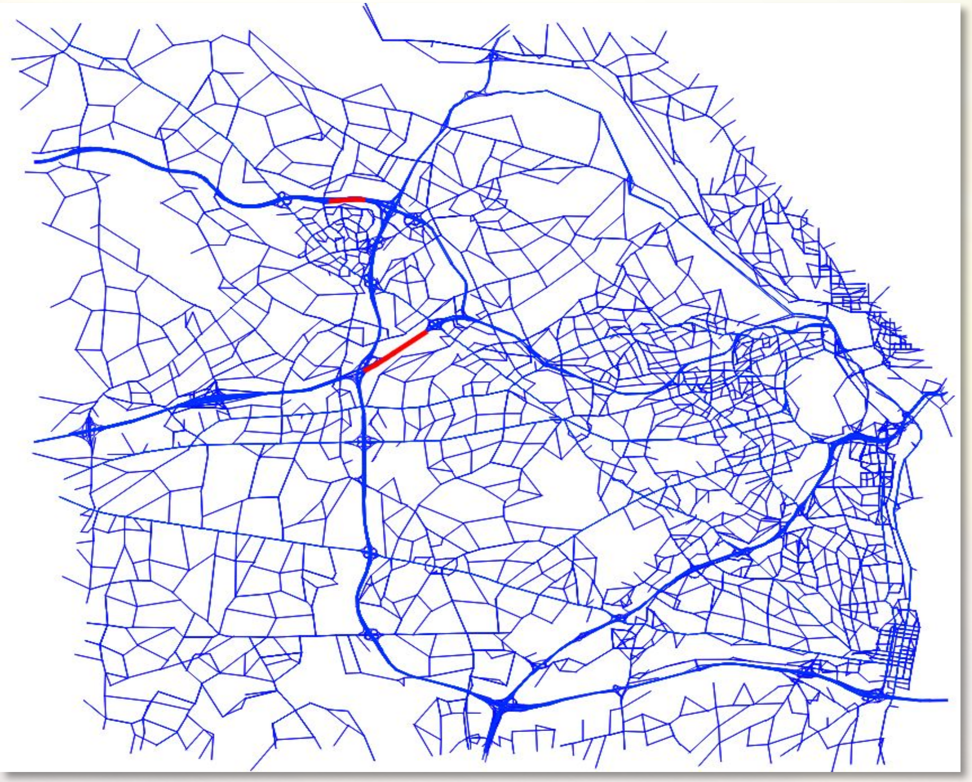


Toll Revenue

- 500 random capacity change scenario runs over a subarea of 2019 year calibrated travel demand model's subarea network:
  - 11,704 edges and 5,973 nodes
  - Corridor-level changes
  - Global changes



Global Group



Corridor Group

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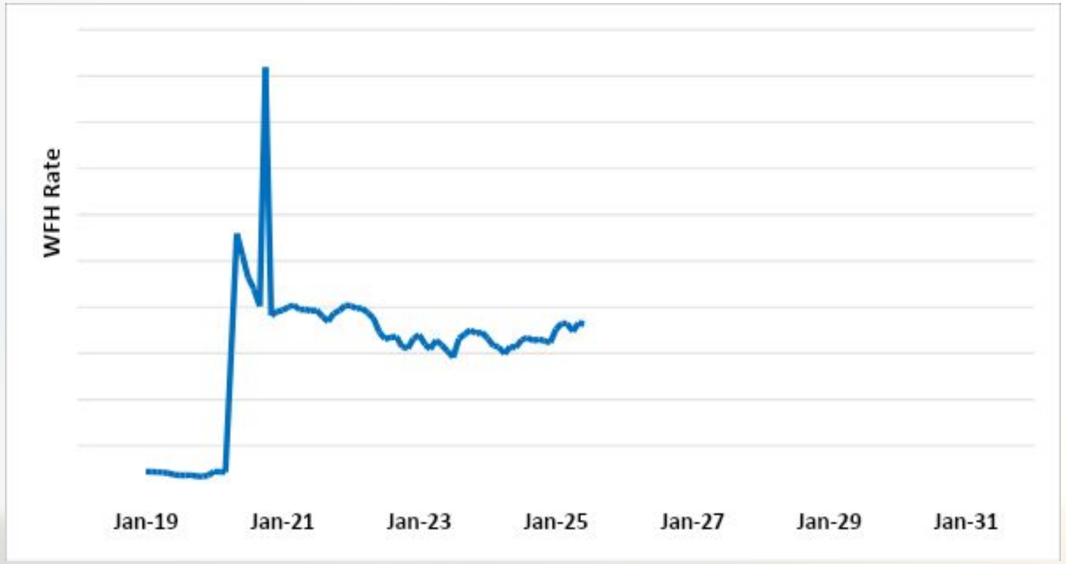
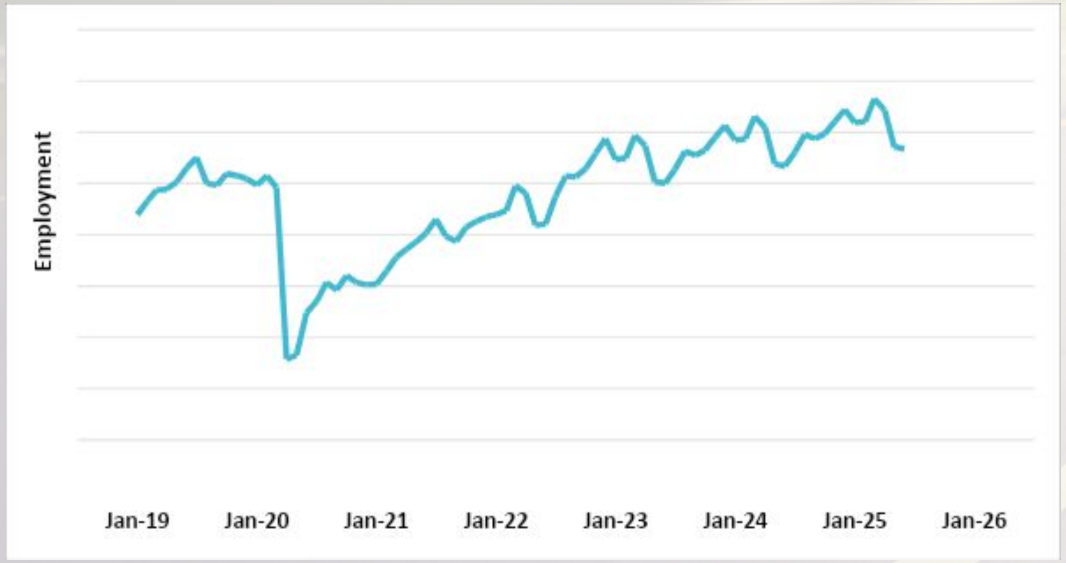
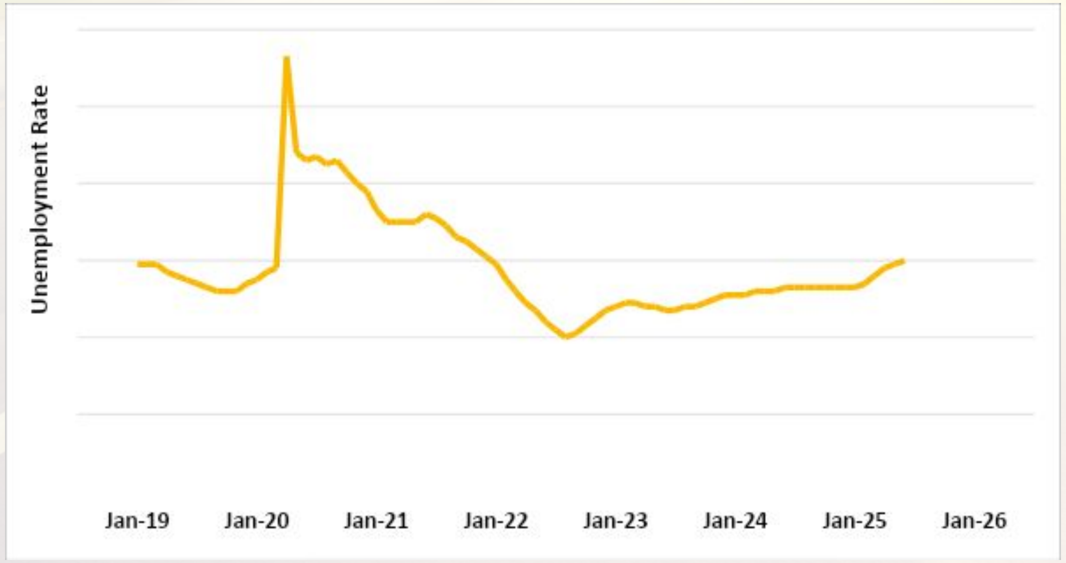
** All data corresponds to the project area*



Work-From-Home Rate

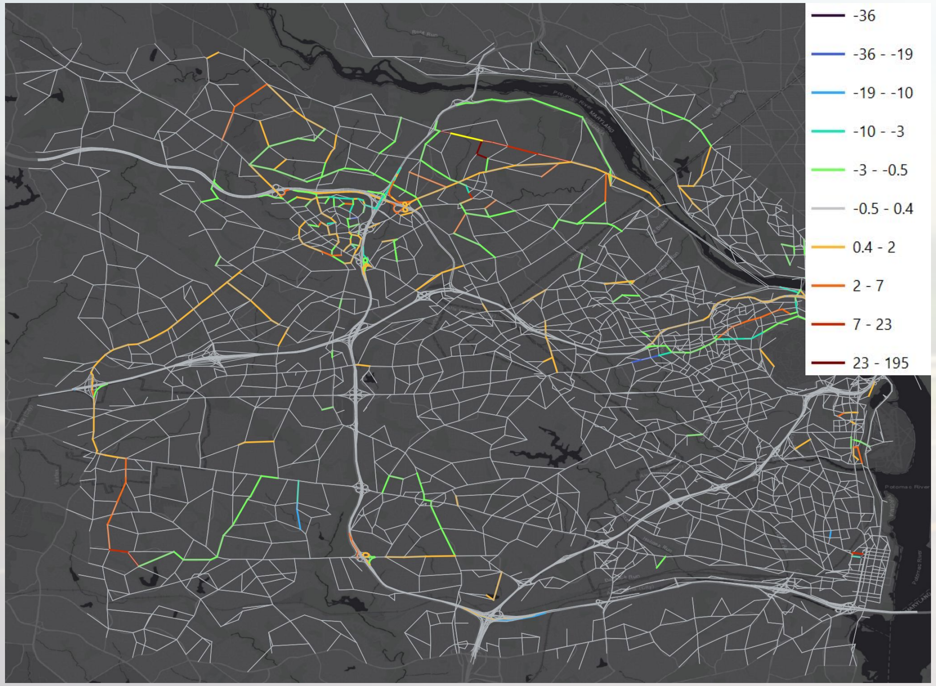


Employment



Unemployment Rate

Comparison of percentage change in volume compared to Base Scenario under capacity change



CUBE

Hybrid Graph Transformer

- Validated on 64 capacity change scenarios
- Av. Diff. between model predicted and CUBE predicted scenarios not used during training was 3.4% MAPE, indicating strong robustness to network perturbations
- Highest error for a link observed at 10.03% MAPE.

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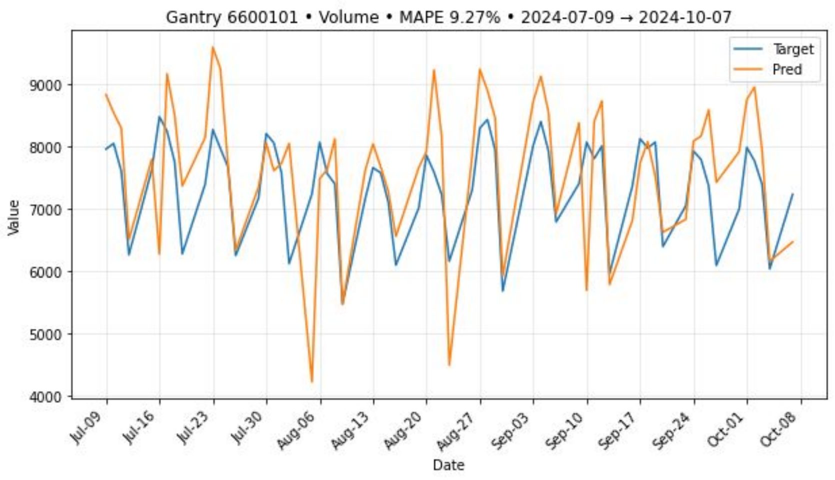
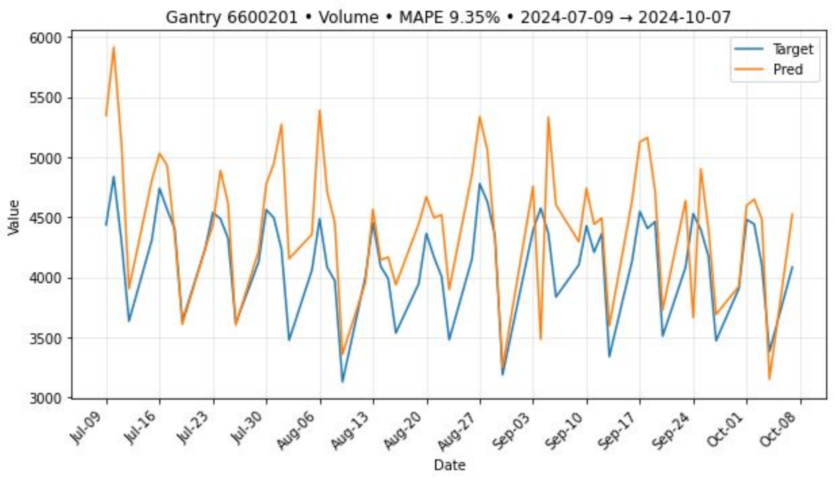
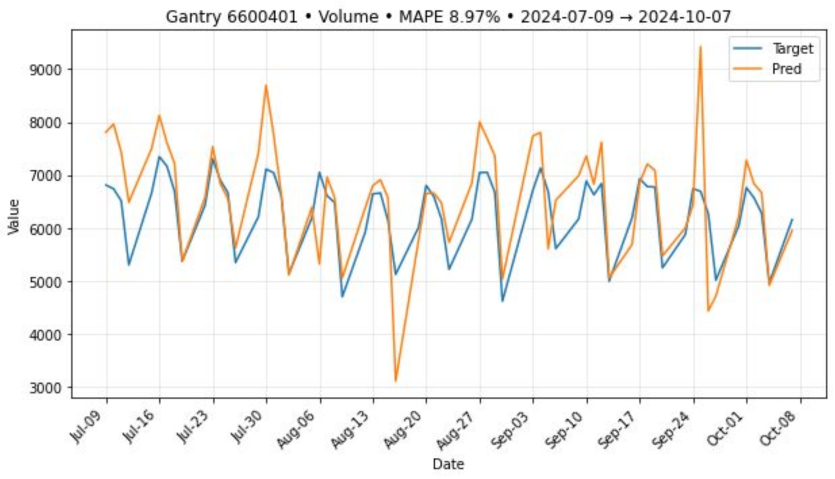
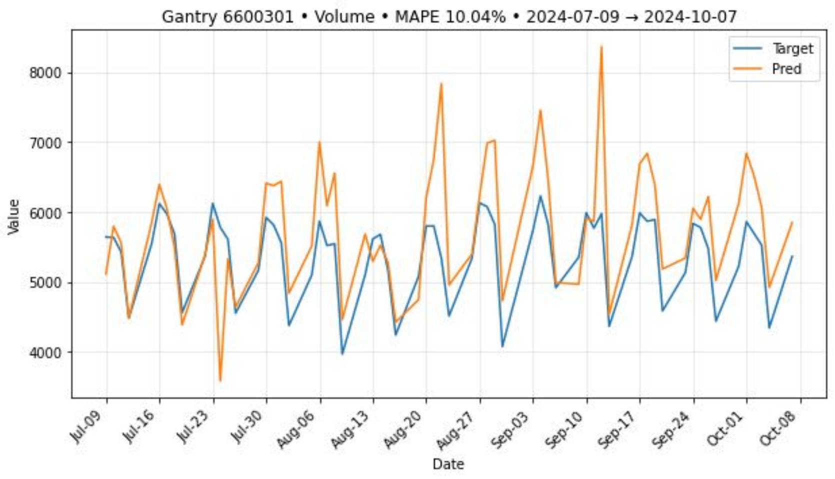
Comparison of Predicted Volume compared to Observed Historical under demand change









- Validated on 64 days of historical data across 4 gantries.
- Av. Diff. between predicted vs actual gantry volumes was 9-10% MAPE, indicating strong robustness to temporal variations

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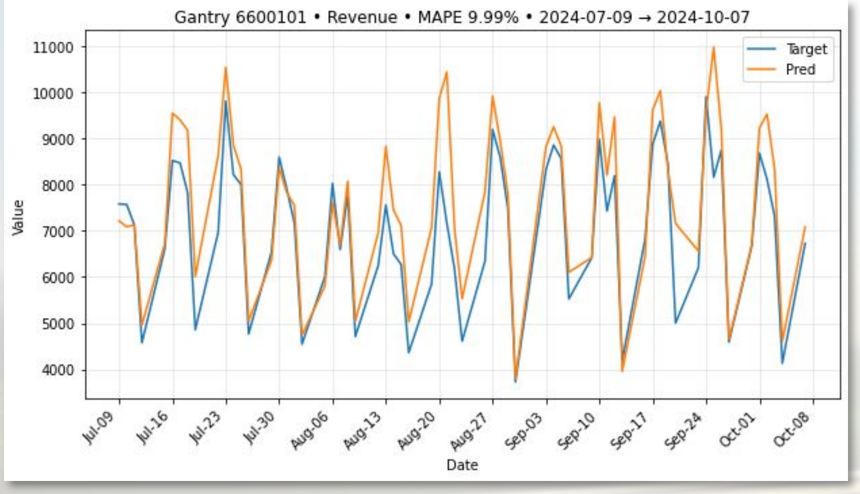
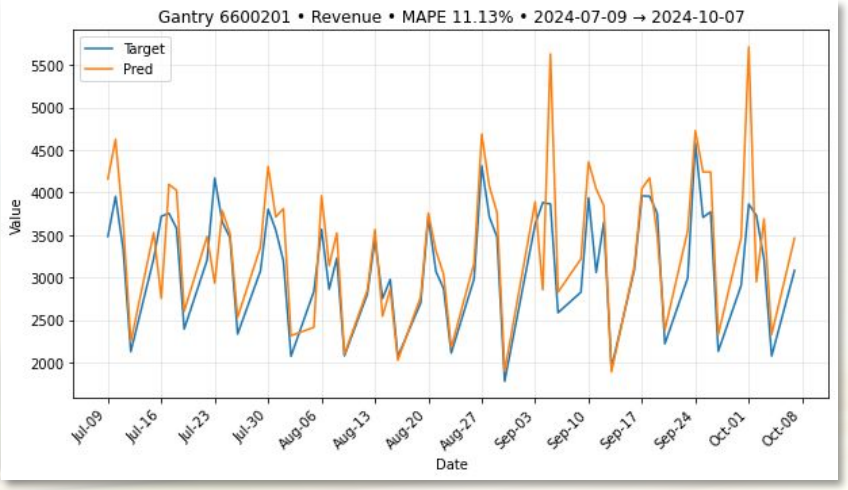
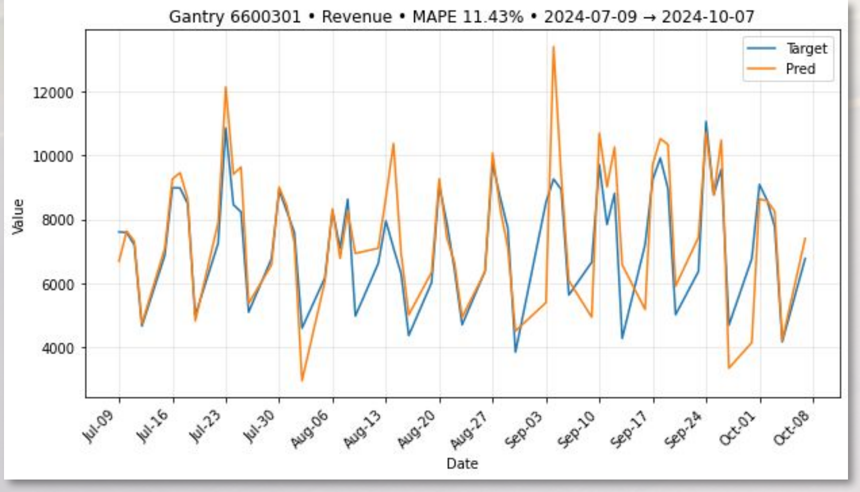
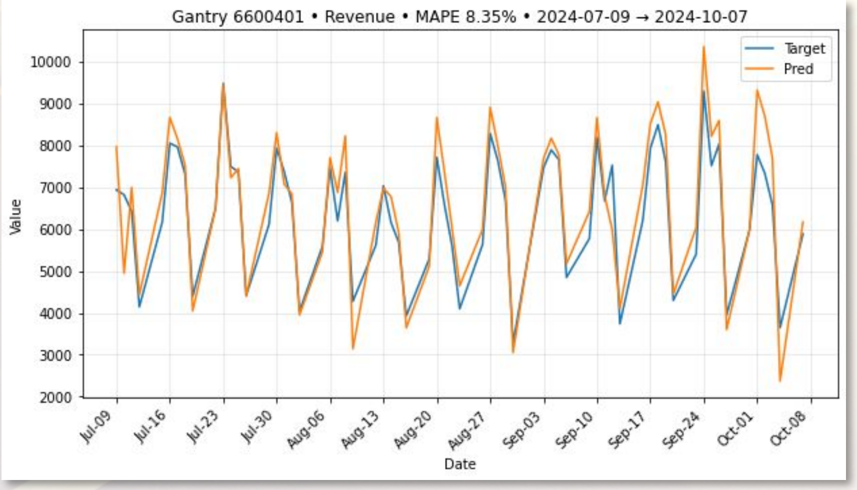
Comparison of Predicted Revenue compared to Observed Historical under demand change









- Validated on unseen 64 days of historical data across 4 gantries
- Av. Diff. between predicted and actual gantry revenues was 8-11% MAPE, indicating strong robustness to temporal variations

- More real-world validation
  - Create capacity-change scenarios reflecting observed impacts: phased lane closures, temporary reversible lanes, ramp detours, and traffic pattern shifts.
- Test performance on other architectures:
  - DCRNN’s graph diffusion + RNN encoder-decoder
  - STGCN’s graph conv + gated TCN
- Support downstream optimization (e.g., maximizing throughput or revenue)
- Mid-term to long-term forecasting

- The proposed framework explicitly handles joint demand and network changes:
  - Robust short-term forecasting
  - Credible what-if analysis under capacity changes

- This method:
  - Scales to larger multi-facility networks
  - Can be fine-tuned using real-world capacity change/network scenarios

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Questions/Comments

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