UNIVERSITY OF TORONTO

TAL TRANSIT ANALYTICS LAB

Developing a Modular, Data-Driven Mesoscopic Simulator for Stochastic Railway Networks

***Spur:** Simulation for Planning and Understanding Railways*

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Background

- Rail networks are crucial for the **movement of people and goods** within and between cities
- Rail networks are **growing in complexity and scale**, and they often experience significant service **disruptions** which are **costly**
- **High-fidelity modelling tools** for simulating train and passenger flows are needed for effective planning, scheduling and management of rail networks

Railway Simulation Approaches

Microscopic
- Highly detailed and realistic
- Long computation time and complex to set up, not suited for network-level analysis

Macroscopic
- Fast computation
- Only high-level, aggregate statistics about network-level performance

Mesoscopic
- Useful results with minimal investment and fast computation
- Detailed where relevant, flexible in scale

Existing Literature

Work	Scope	Application	Stochasticity	Availability
[1] Saidi et al. (2019)	Line	Control strategy evaluation	✗	Proprietary
[2] Marinov and Viegas (2011)	Line + yards	Freight traffic	✓	Proprietary
[3] Zhong et al. (2018)	Passenger stations	Capacity analysis	✓	Proprietary
[4] Quaglietta et al. (2011)	Line + yards	Design and decision support	✓	Proprietary
[5] Diviš and Kavička (2015)	Nodes	Capacity analysis	✓	Proprietary
[6] Fabris et al. (2014)	Network	Timetable generation	✓	Proprietary
[7] Kavička and Krýže (2021)	Network	Route planning	✗	Proprietary

Research Objectives

1. **Develop** a flexible, **mesoscopic** railway simulation platform
*(for **rapid** prototyping, simulation, and analysis of railway networks of **all** sizes)*

2. **Validate** Spur's performance
*(**Accuracy, flexibility, speed** as applied to a real-world railway network)*

Spur

Software Architecture

Model
- Oversees entire simulation
- Holds network structure

Jitter
- Injects stochasticity (randomness)

Trains (Agents)
- Follow prescribed routes and schedules

Request Use →
← Set occupancy time

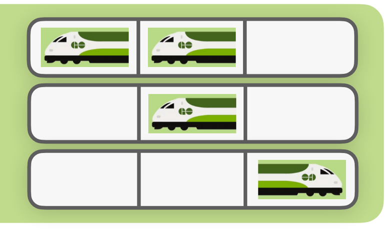
Components (Resources)
- Handle agent requests
- Determine traversal behaviour

Key Design Outcomes

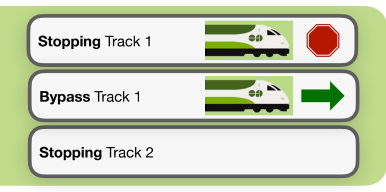
Core Attributes

Modular | **Agent- & event-based** | **Stochastic** | **Data-driven** | **Open source**

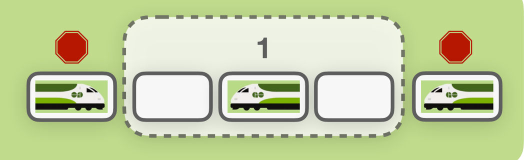
Multi-Block Parallel Track Component
- Parallel tracks with multiple signal blocks
- Cellular automata model
- Train acceptance evaluation logic



Multi-Track Station Component
- Stopping and bypass tracks
- Stochastic dwell time using Burr distribution



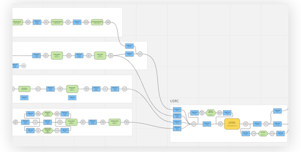
Block Exclusive Zone
- Single-occupancy block with multiple components
- Logic for managing queuing



Network Construction

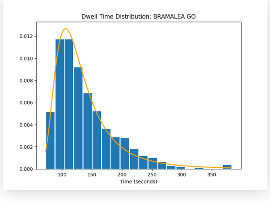
Guiding Principles: **Abstraction** | **Simplification**

Track Diagrams
Tracks, Switches, Signals, Platforms



Conceptual Diagram

ATLS
Train Schedule & Location Data
(Planned + Actual)



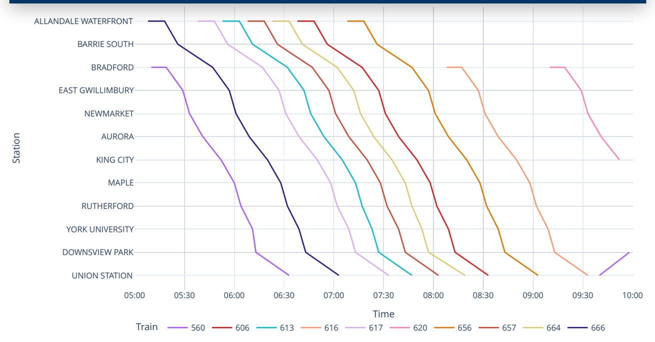
Station Dwell Time Fitting

Jitter → **Components** → **Spur Input Files (JSON)**

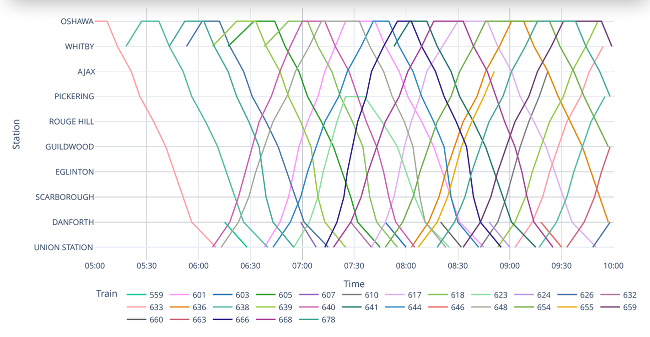
Routes, Tours, Trains

Simulated Train Trips

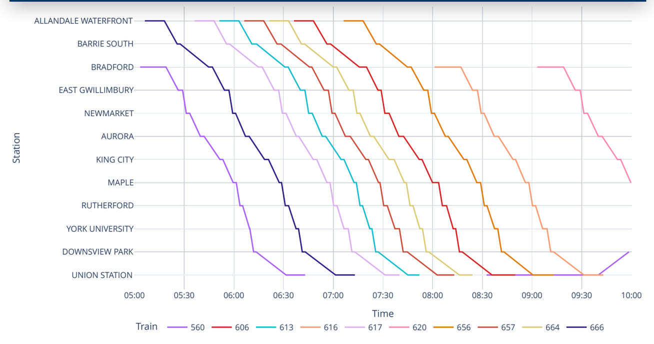
Timetable Trips | Barrie Line



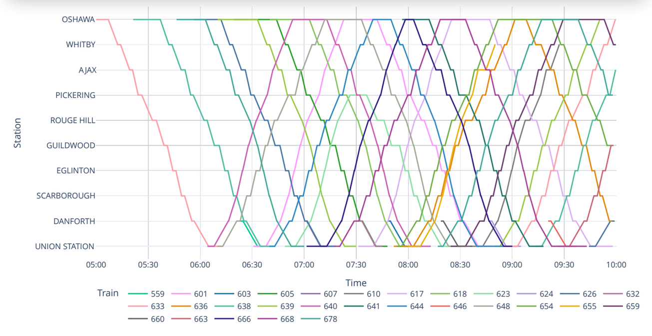
Timetable Trips | Lakeshore East Line



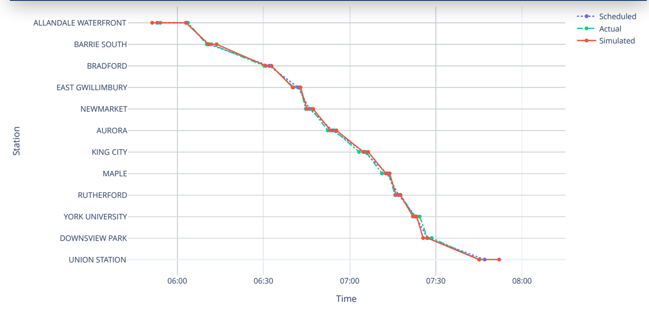
Simulated Trips | Barrie Line



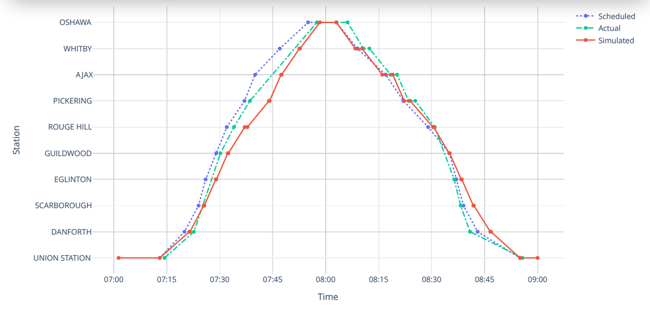
Simulated Trips | Lakeshore East Line



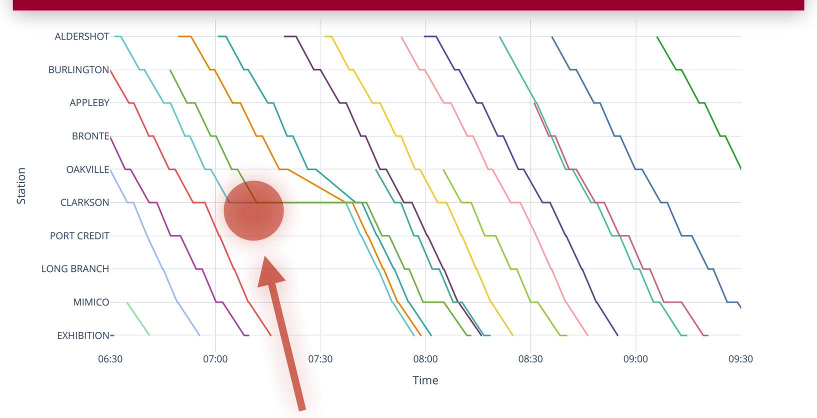
Single Trip Comparison | Barrie Line



Single Trip Comparison | LSE Line



Delay Propagation | Lakeshore West Line



Injected **30-minute delay** at Clarkson Station

Key Results

Successful Replication of GO Train Network
- Close resemblance with schedule and actual train data, including stochastic dwell and travel times, on all corridors (diff. < 1 minute)
- Propagation of delays across the network follows infrastructure and operational constraints

Modular Design
Train movement is controlled directly and only by each component

Fast Running Time
14 seconds to simulate full network for the entire day
(70 trains, 622 trips, 196 components)

Use Cases & Applications

Analyze large networks **(regional / national)**

Quickly test ideas for network and service configurations

Support simulation-based **optimization**

Large-scale network improvements
- Capacity analysis
- Integration with other simulations (pedestrian, surface transit)

Service planning
- Design of new service strategies
- Planning of timetable and route changes

Disruption management
- Scenario-based contingency planning
- Real-time response

Links

Project GitHub:

References & Docs:
bit.ly/spur-trb-ref