Dynamic Disruption Simulation in Large-Scale Urban Rail Transit Systems

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Mass Transport in Megacities

NEW YORK CITY
- Population: 8.5M (2016)
- Daily Ridership: 5.6M (2016)

SINGAPORE
- Population: 5.6M (2016)
- Daily Ridership: 3.1M (2016)

Objectives

- **Understand** the effects of (unseen) disruptions on system operations and passenger flow
- Aid decision making: **planning** and **design** of resilient mass transport systems
Understand, Plan & Design Resilient Mass Transport Systems

- A real-world system model of an urban rail mass transport system
  - Train operations based on real-world schedules
  - Dynamic passenger assignment
  - Disruption generator that can mimic real-world scenarios

➢ Agent-based, Discrete Event Simulation

- Necessary to have appropriate data sources
- System Uncertainties are ubiquitous
  - (Aleatory) Variability of real-world system
  - (Epistemic) Uncertainty about modelling error and propagation of measurement uncertainty into parameter estimation

➢ Parameter inference models
Probabilistic estimates of passenger trip distribution parameters

- Origin-Destination estimation from station in- and outflow count time series

- Desired result: OD-split coefficient estimates for the proportions of passenger trips between every OD-pair

- Problem: Quadratic increase in the number of inferred parameters with increase in the number of station

Markov-Chain Monte Carlo Sampling (No U-Turn Sampler)*


**Highest Posterior Density
Probabilistic estimates of passenger trip distribution parameters

- Station-level turnstile counts in the NYC subway network*
- NYC subway system: 471 stations, ~1000 records, ~220,000 parameters

- MCMC OD-coefficient mean estimates for the 7:00 – 9:00 am morning rush-hour window

Modelling disruptions – A real-world scenario

Simulation results
- Assumes disruption lasts from 8:30 until 9:30 AM
- Passengers freely choose new itineraries

Train capacity
- Station platform occupancy (relative w.r.t. undisrupted condition)

Source: [Twitter](https://twitter.com/NYCTSubway)

Compute time: ~4 hrs
CPU: Intel(R) Xeon(R) E5-2699 v3, 2.30GHz
RAM: 200 GB
Mitigating Disruptions – Optimization under Uncertainty

- **Test**
  - Passenger behavior changes
  - Different controller behavior

- **Optimize**
  - Operational recovery actions

- **While subject to**
  - Variable passenger demand

**Bayesian Optimization with Gaussian Processes**
- **Iterative** updating of the Gaussian Process surrogate model with simulation output
- Surrogate model optimization based on acquisition function
- Acquisition function: *Expected Improvement*
Mitigating Disruptions – Optimization under Uncertainty

- Simulation optimization of train dispatch schedule during disruptions

- Preliminary experiments on a test network with an arbitrary disruption
- Optimization objective: Minimize average passenger travel delay
- Control parameters (total: 8): Train dispatch timings, Duration of schedule adjustment

Test network

Average passenger travel delay (s)

Iteration

Compute time: 1 hr
CPU: Intel(R) Core i5, 2.60GHz
RAM: 16 GB
Mitigating Disruptions – Optimization under Uncertainty

- Rescheduled train dispatch on routes not affected by disruption
  - Rescheduling results in: Additional train injections, Dispatch time changes, Headway adjustments
  - Average passenger travel delay overall reduces even under variable passenger demand

Disruption duration

The optimized schedule

*Average passenger travel delay in undisrupted network: 54 s
Recap and Outlook

- Explicitly incorporated system uncertainties into model parameter estimates
- Agent-based, discrete-event simulation of subway network disruptions
- Optimized system schedules for improved disruption recovery
- Future work:
  - Test flexible operational schedule adjustment strategies
  - Test new system layouts
  - Test various disruption scenarios

THANK YOU!