(FRS) FUTURE RESILIENT SYSTEMS 未来韧性系统

RRE Reliability and Risk Engineering

Dynamic Disruption Simulation in Large-Scale Urban Rail Transit Systems

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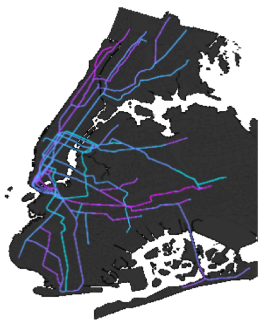
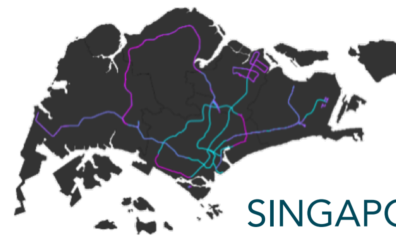
Mass Transport in Megacities



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

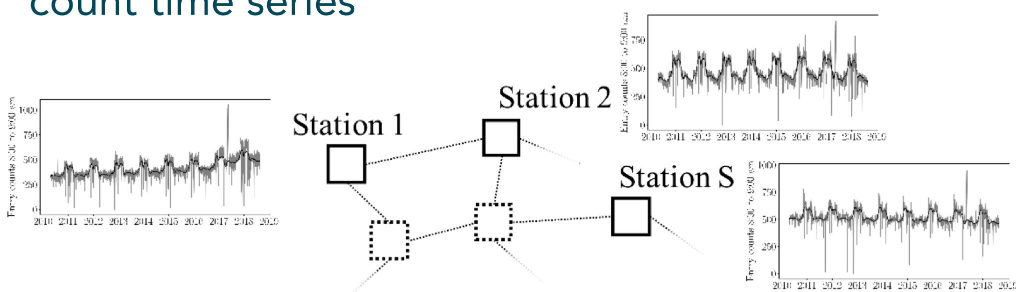
> **Agent-based, Discrete Event Simulation**

- 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**

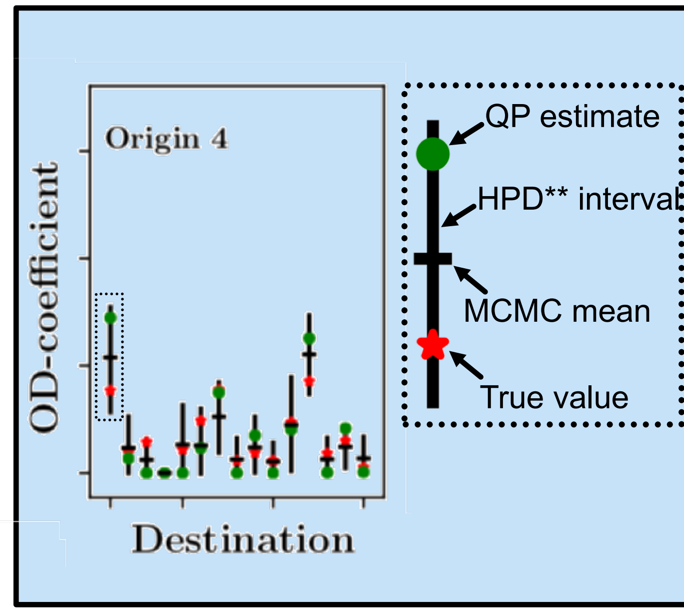
Probabilistic estimates of passenger trip distribution parameters

- 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)***

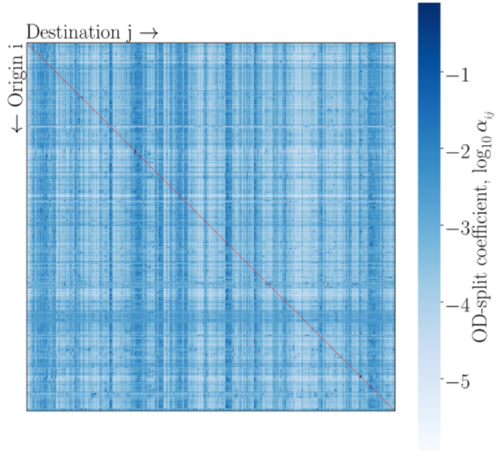


*Carpenter, et al., Stan: A probabilistic programming language. *Journal of Statistical Software* 76(1), 2017

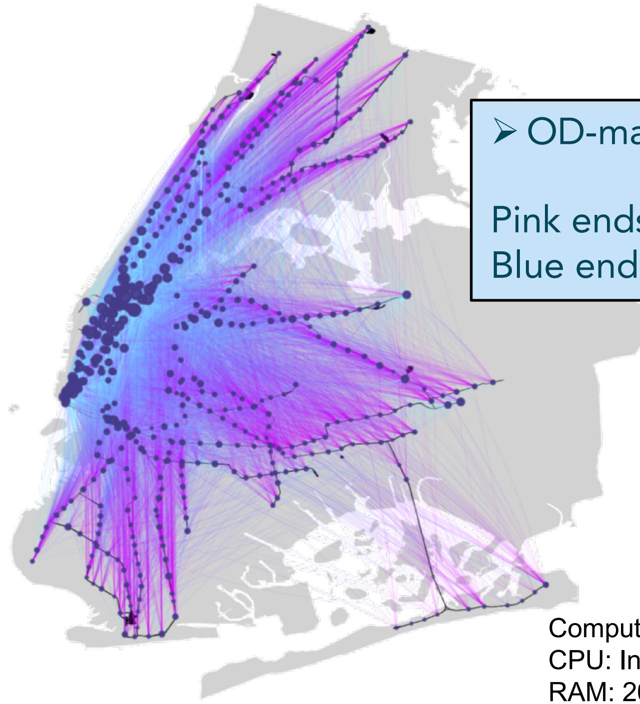
** Highest Posterior Density

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



➢ OD-matrix map representation

Pink ends: Origins
Blue ends: Destinations

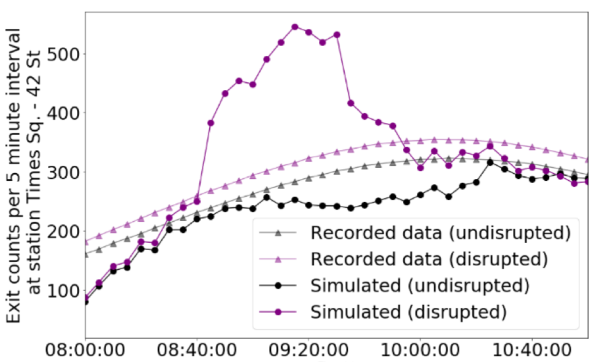
Compute time: ~5 days
CPU: Intel(R) Xeon(R) E5-2699 v3, 2.30GHz
RAM: 200 GB

*Metropolitan Transport Authority, Turnstile Data, http://web.mta.info/developers/turnstile.html

Modelling disruptions – A real-world scenario

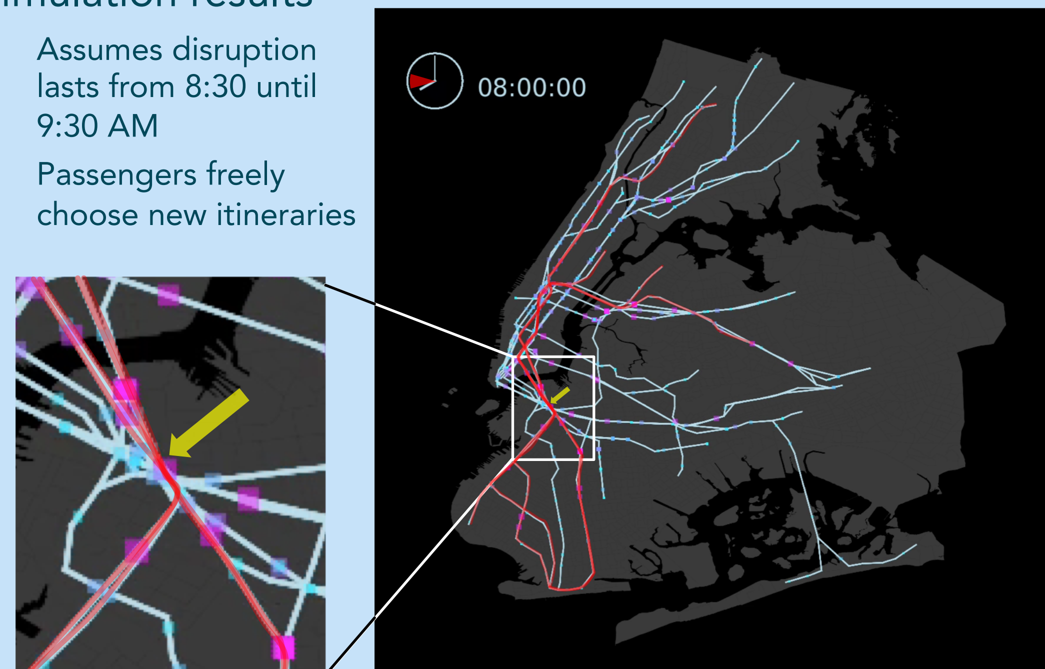
Source: https://twitter.com/NYCTSubway

- ➢ Train capacity [empty … full]
- ➢ Station platform occupancy (relative w.r.t. undisrupted condition) [-15x … 15x]



Simulation results

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

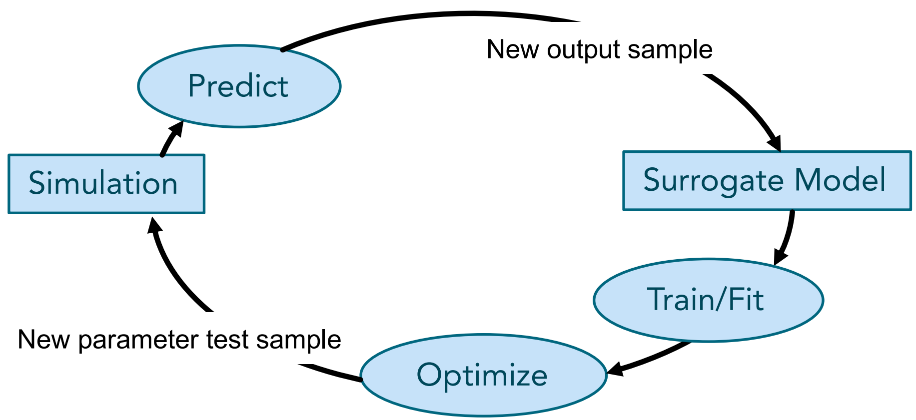


Compute time: ~4 hrs
CPU: Intel(R) Xeon(R) E5-2699 v3, 2.30GHz
RAM: 200 GB

Mitigating Disruptions – Optimization under Uncertainty

- Test
  - Passenger behavior changes
  - Different controller behavior
- Optimize
  - Operational recovery actions
- While subject to
  - Variable passenger demand

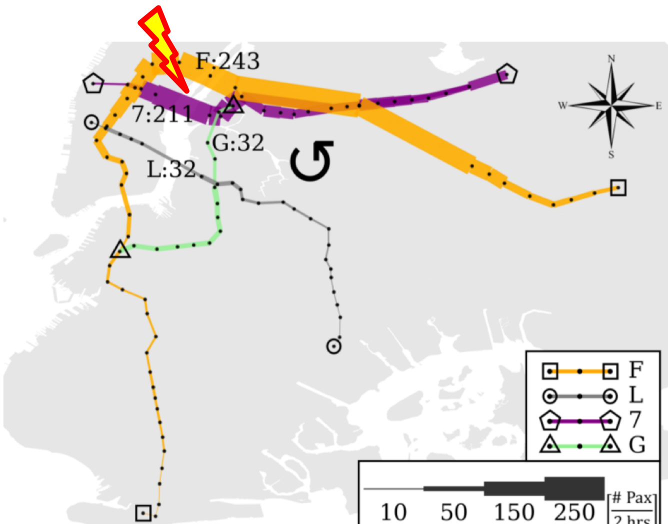
- Bayesian Optimization with Gaussian Processes
  - **Iterative** updating of the Gaussian Process surrogate model with simulation output
  - Surrogate model optimization based on acquisition function
  - Acquisition function: **Expected Improvement**



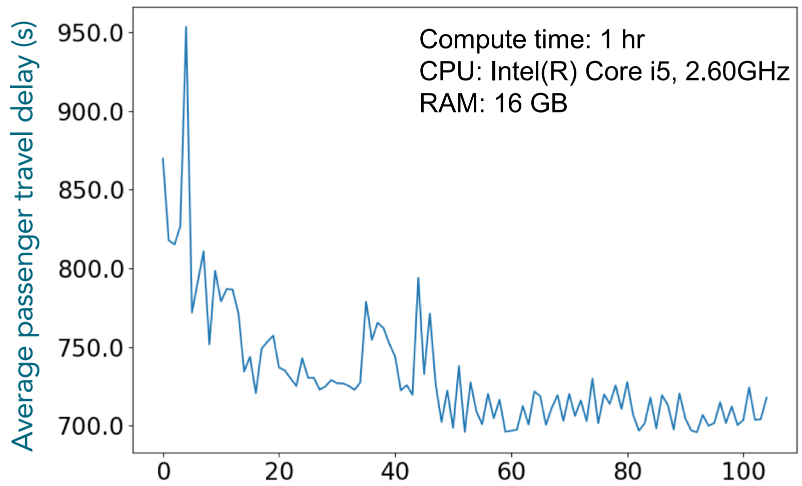
Mitigating Disruptions – Optimization under Uncertainty

➢ 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

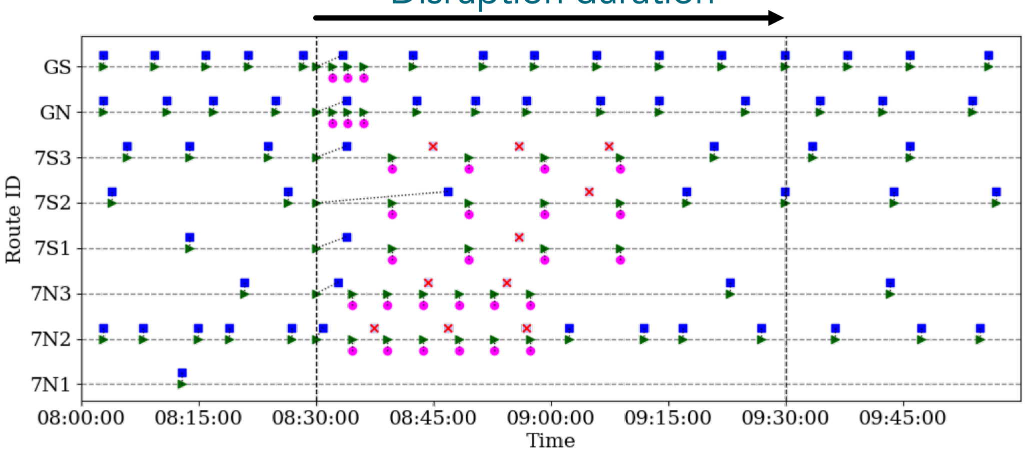


Mitigating Disruptions – Optimization under Uncertainty

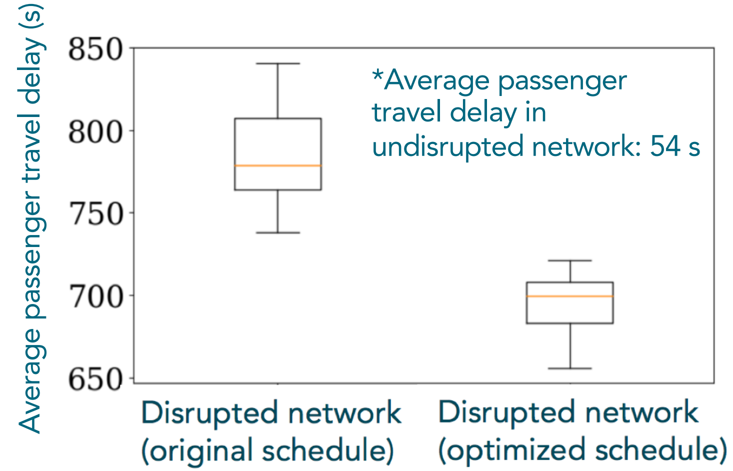
> ➢ Rescheduled train dispatch on routes not affected by disruption

- Rescheduling results in: Additional train injections, Dispatch time changes, Headway adjustments
- Average passenger travel delay overall reduces even under variable passenger demand

Disruption duration

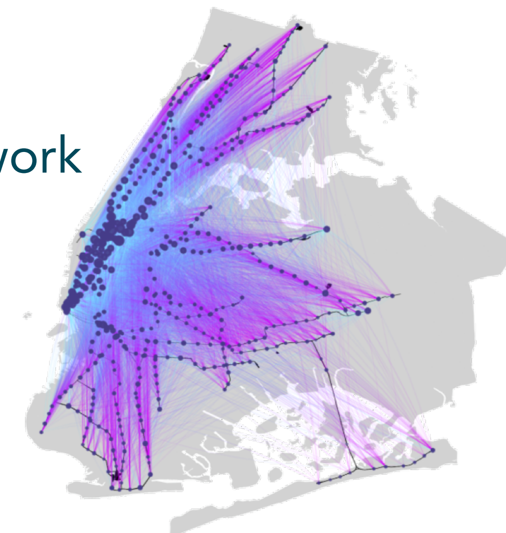


The optimized schedule



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 !