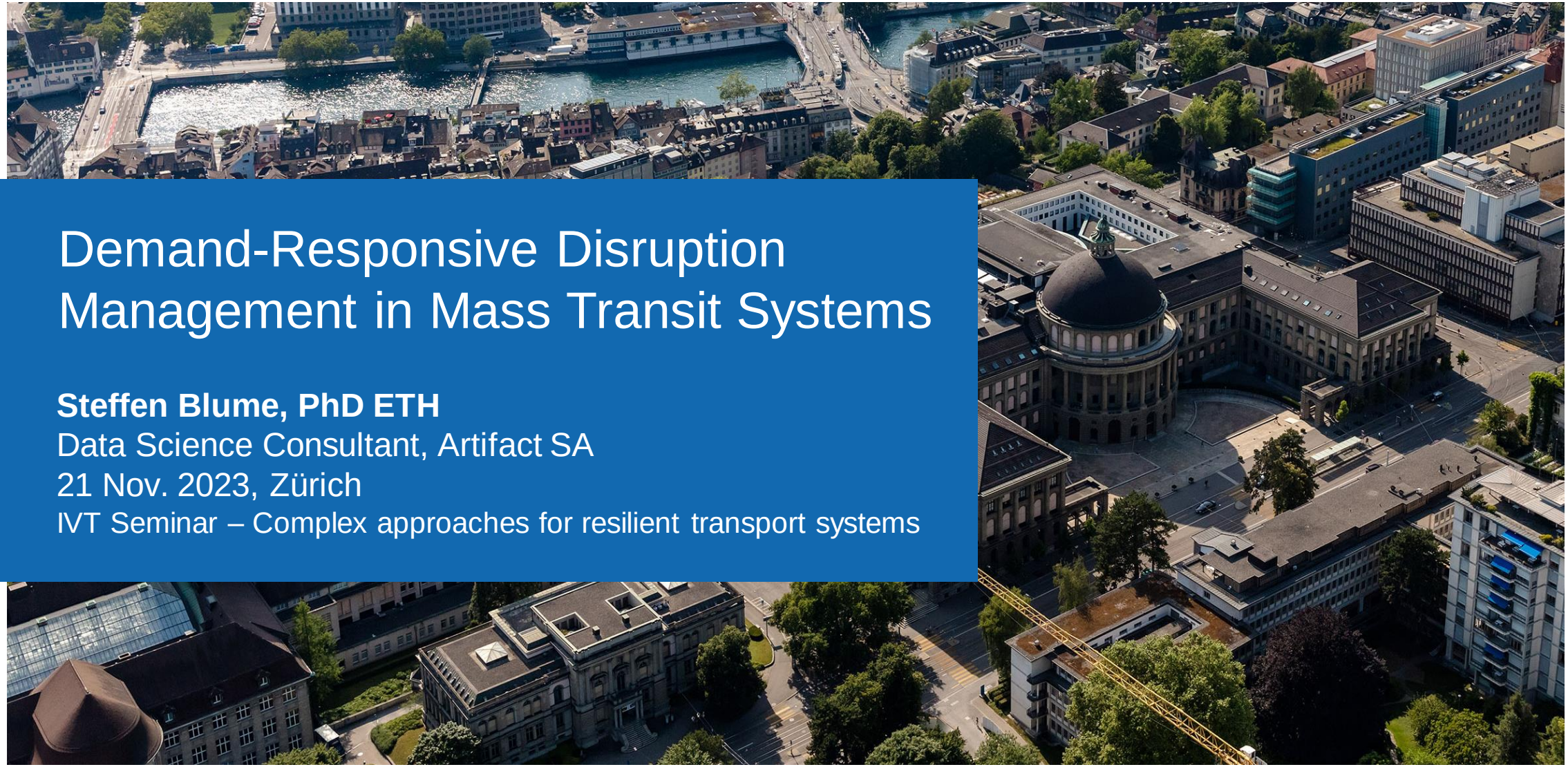
ETH zürich

(FRS) FUTURE RESILIENT SYSTEMS 未来韧性系统

CREATE

RRE
Reliability and Risk Engineering



Demand-Responsive Disruption Management in Mass Transit Systems

Steffen Blume, PhD ETH
Data Science Consultant, Artifact SA

21 Nov. 2023, Zürich

IVT Seminar – Complex approaches for resilient transport systems

About me

Steffen Blume

Data Science Consultant at Artifact


Artifact
accelerating impact with data science

Artifact was founded by 3 hands-on experts to address business challenges with agility & impact through Data Science & AI

Montassar BenMrad
Co-Founder

Accelerating Impactful Digitization

Michael Wegmüller
Co-Founder

Empowering Agile Analytics at Scale

Stefan Ravizza
Co-Founder

Pushing Boundaries with AI

Artifact
accelerating impact with data science

Maximizing your Data Potential with Agile AI Solutions for Transformative Impact

Discovery & Innovation
Assess data and AI possibilities, identify low hanging fruits / blind spots

AI and DS Implementation
Agile use case implementation tailored to the client's needs

Scale the Impact
Develop, run and scale analytics capabilities and increase adoption

Set the Strategy & Excel in the Execution
Supporting actively clients with project management / agile coaching / data advisory & data literacy / data governance including improving data quality and custom-made delivery services

Our Belief

We believe that the impact of data science & AI can be accelerated.

Great Customer Satisfaction

Net Promoter Score

+84 NPS

Key Differentiator

More pragmatic
More agile
More fun

AI & Data Science Use Cases successfully delivered

70+ Use Cases in >200 projects

Back on topic

Demand-Responsive Disruption Management in Mass Transit Systems

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CREATE

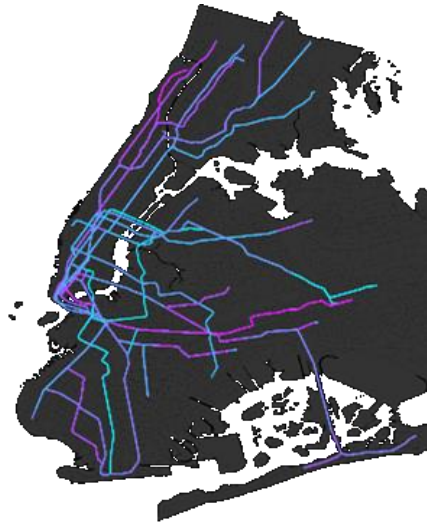
RRE
Reliability and Risk Engineering

Demand-Responsive Disruption Management in Mass Transit Systems

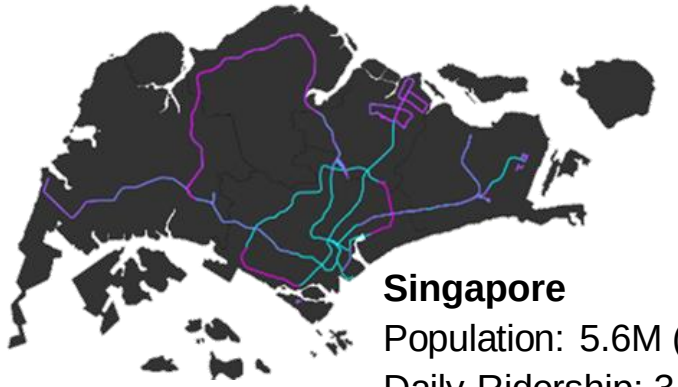
Steffen Blume
Michel-Alexandre Cardin
Francesco Corman
Giovanni Sansavini

Urban Transport Landscape

- **Metro Systems:** Backbone of Urban Mass Transit



New York City
Population: 8.5M (2016)
Daily Ridership: 5.6M (2016)



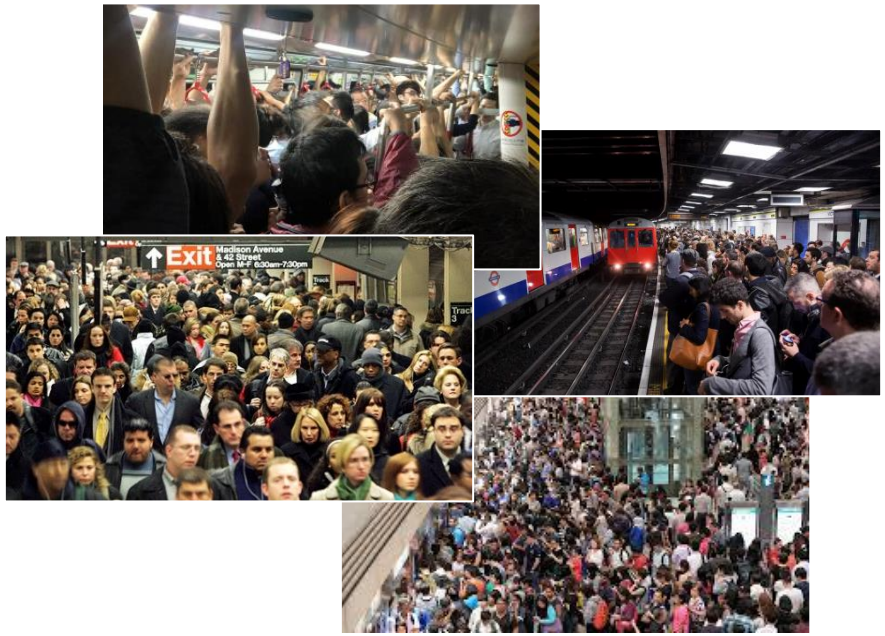
Singapore
Population: 5.6M (2016)
Daily Ridership: 3.1M (2016)

- Modernisation and Expansion (NYC: $40b, SG: $44b): Fallacy of Increased Reliability

➢ **Disruptions still persevere**

Urban Mass Transit Disruptions

Irrespective of their age and condition, and despite infrastructure improvements, mass transit systems have recorded **severe system-wide disruptions** with **hundreds of thousands of affected passengers.**



The New York Times

Cuomo Declares a State of Emergency for New York City Subways

By Emma G. Fitzsimmons

June 29, 2017

Evening Standard.
WEBSITE OF THE YEAR

News › Transport

TfL Tube delays: Rush hour misery as disruption hits FIVE London Underground lines

KATY CLIFTON | Thursday 15 November 2018

THE STRAITS TIMES

In Pictures: The massive breakdown that affected more than 250,000 commuters

Service on the North-South and East-West lines was disrupted for more than two hours on Tuesday night, in what is possibly the worst MRT breakdown Singapore has experienced. It is estimated that more than 250,000 commuters may have been affected.

South China Morning Post

Transport

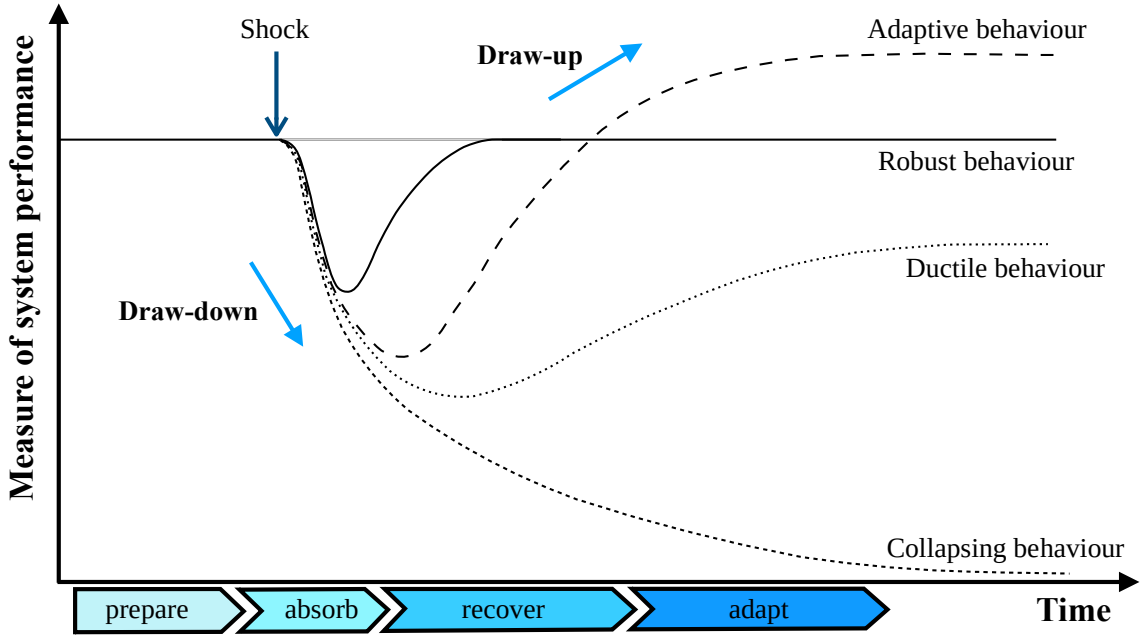
Hong Kong MTR signal fault finally fixed after six hours of commuter chaos

Tseung Kwan O, Island, Tsuen Wan and Kwun Tong lines hit by severe delays, with knock-on effect on road traffic

A Resilience Perspective to Handling Disruptions

"The ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" (United States National Research Council, 2012)

- **Aim:** Augment the Draw-down-Draw-up Cycle through resourceful use of available transit system infrastructure and rolling stock

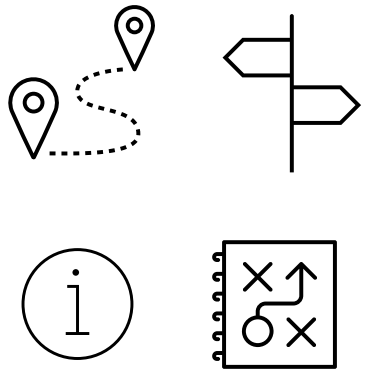


Singapore-ETH Centre (2015)

Key Research Questions

1

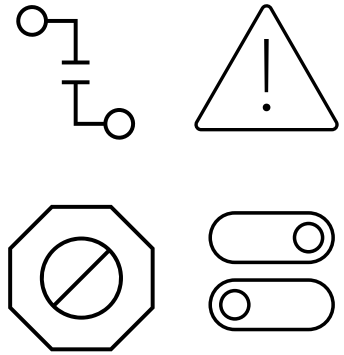
How do passengers (re-)distribute in a transit system?



UNDERSTAND

2

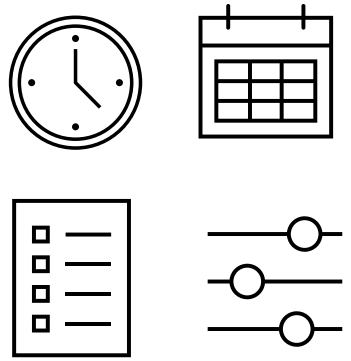
How do different disruption scenarios affect passenger flows?



ASSESS

3

What are the possible measures to improve system resilience?



DESIGN

Agenda

UNDERSTAND

- Origin-Destination Estimation and Transit System Simulation

ASSESS

- Predicting the Effects of a Real-World Disruption Scenario

DESIGN

- Testing an Alternative Rescheduling Measure

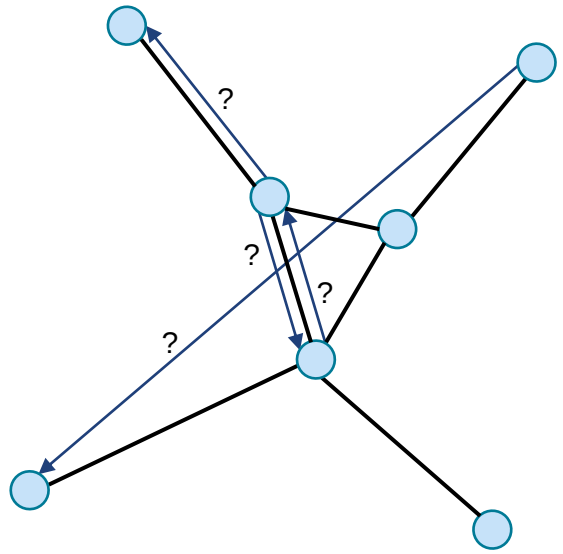
UNDERSTAND

Origin-Destination Estimation

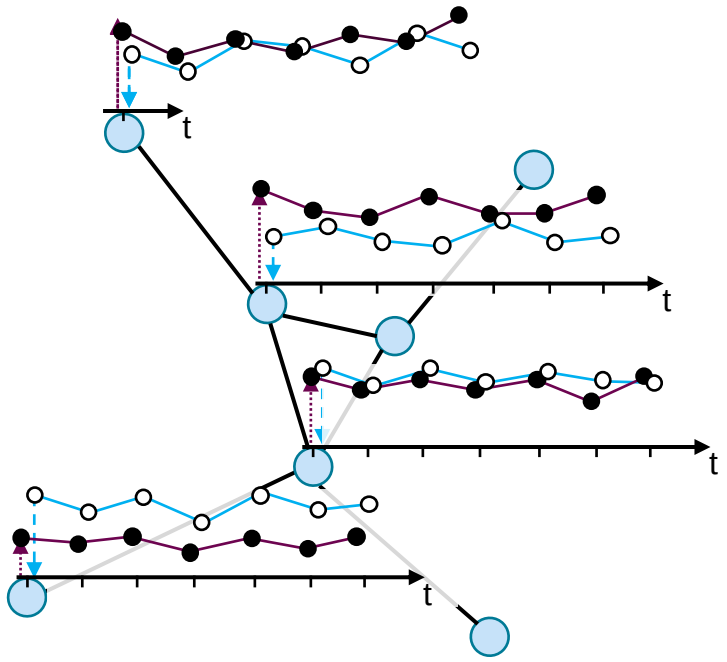
Context

Origin-Destination (OD)-Estimation: Why? How? What?

Purpose
Determine the travel demand rates between the stations of a transit network



Approach
Infer OD-demand from time series measurements of in- and outflow counts



Intended Result
OD-matrix estimate consisting of the normalized travel demand rates

Destinations →
↓ Origins

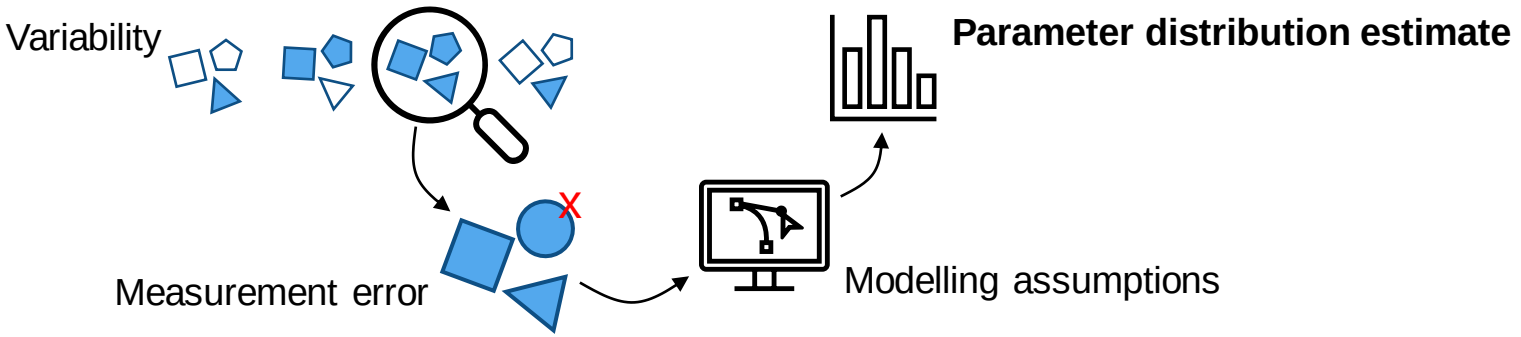
$$\mathbf{A} = \begin{bmatrix} & & \\ & & \\ & & \end{bmatrix}_{S \times S}$$

$$\sum_{j=1}^{S} \alpha_{ij} = 1; \quad \alpha_{ij} \geq 0; \quad \alpha_{ij} = 0 \; \forall \; i = j$$

Inference-Based Origin-Destination Estimation

Estimating Model Parameters from Observations

- **Key requirement**
  Account for estimation uncertainty

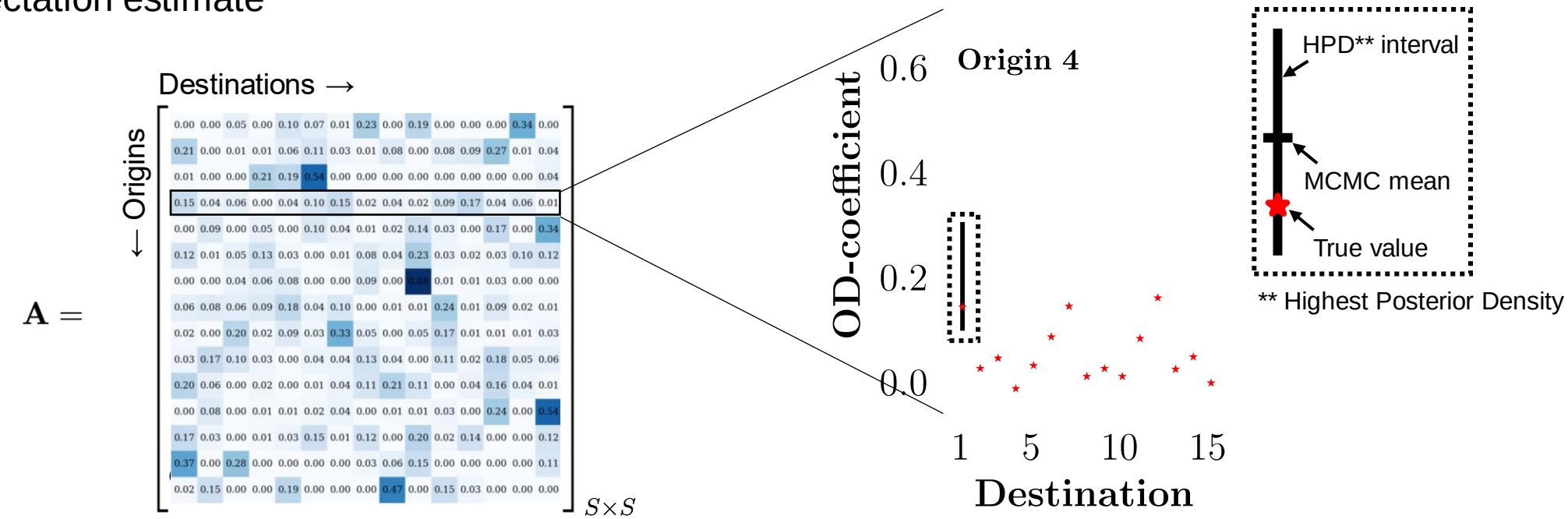


- **Transit network specificities**
  - Large number of stations: High-dimensional OD-estimation problem
  - Fewer observations than unknowns: Underdetermined problem

Markov-Chain Monte Carlo Sampling (MCMC)

Testing the Inverse Problem

- Test network: $S = 15$ (210 OD-coefficients), $N = 30$
- MCMC sampling estimates of OD-coefficient posterior distributions
  - Confidence interval
  - Expectation estimate



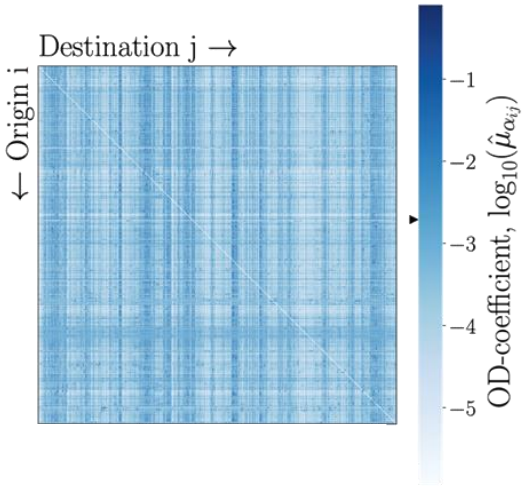
Real-World OD-Estimation

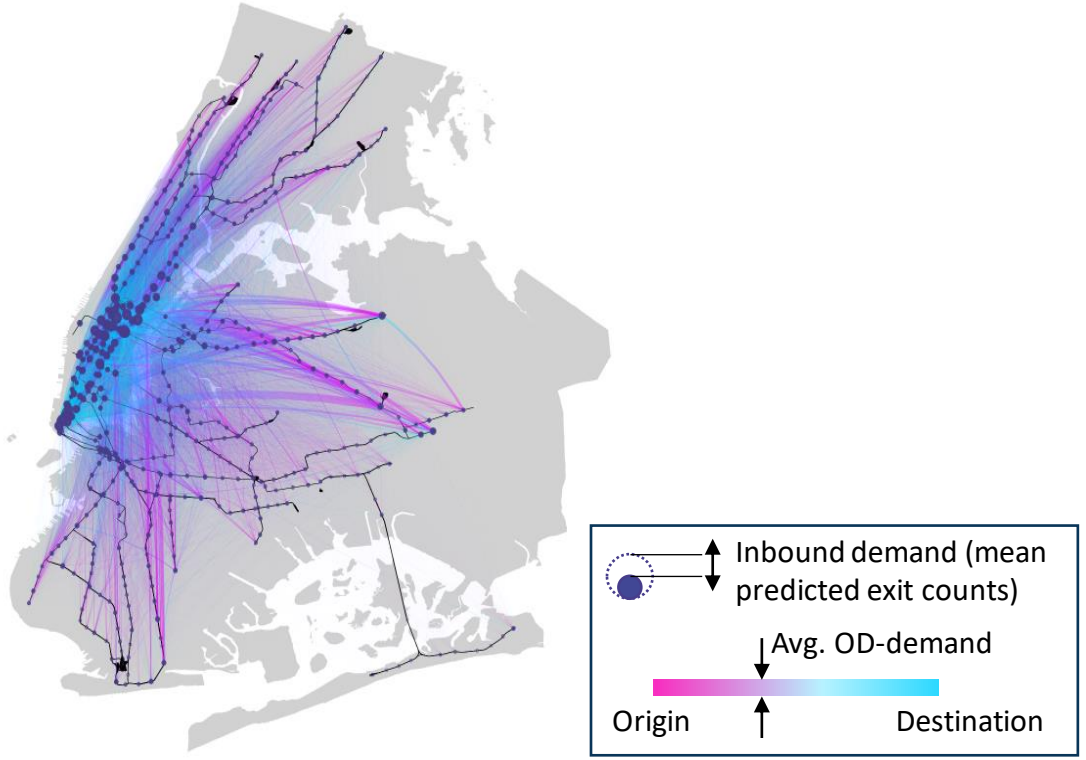
Applying the MCMC sampling approach to the NYC subway

- 471 stations: 221,370 OD-coefficients
- Publicly available turnstile counts: $N = 1315$ observations of passenger in- and outflows

➢ OD-coefficient posterior means and absolute average OD-demand estimates

Morning peak (8 AM to 9 AM)





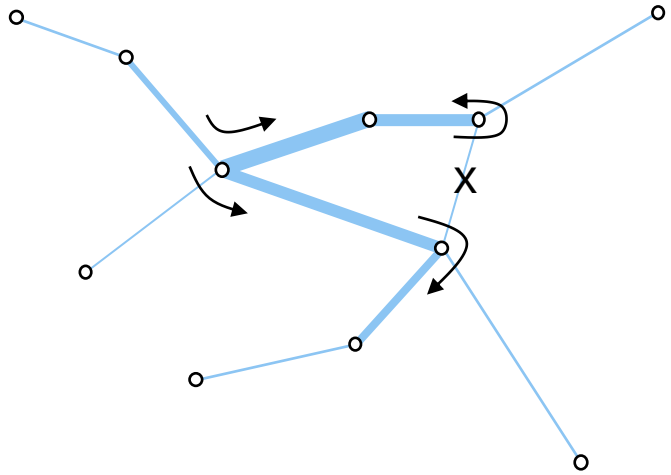
UNDERSTAND

Transit System Simulation

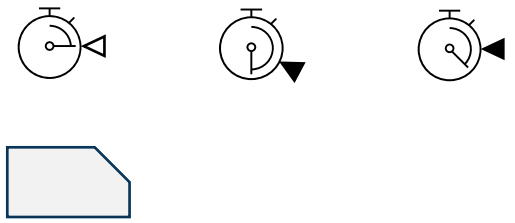
Context

Capturing Transit System Operations

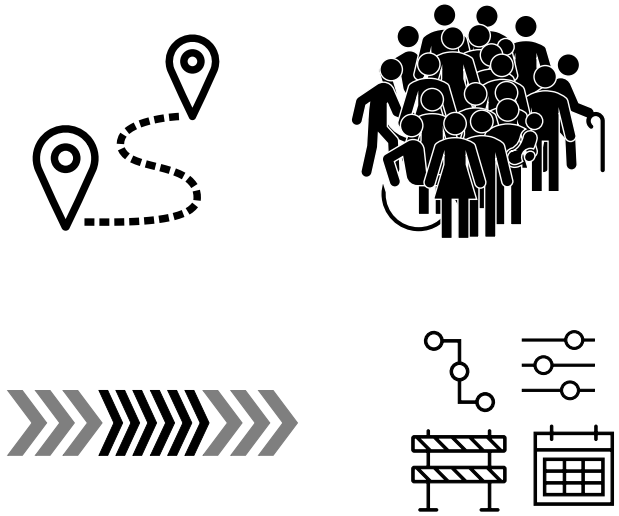
Purpose
Estimate how passengers and operations are affected during major disruptions.



Approach
Capture disaggregate passenger demand and bi-directional supply-demand interaction.



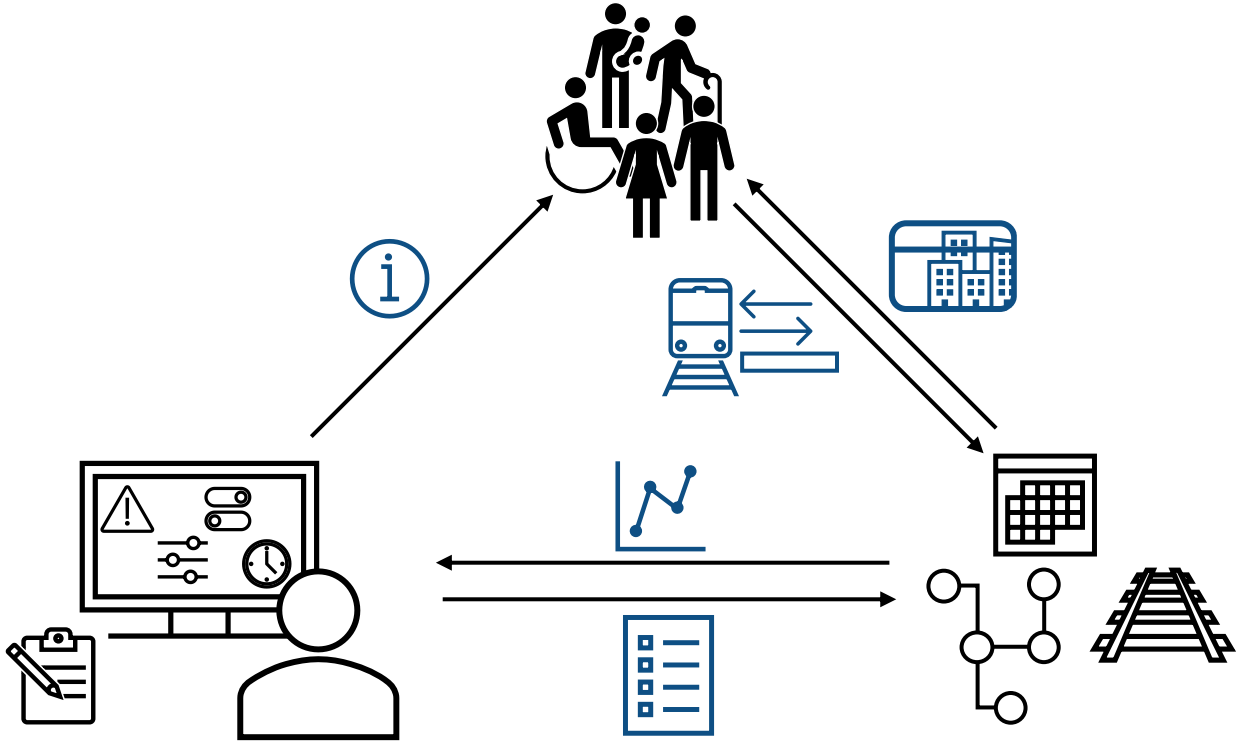
Intended Result
Predict passenger travel journeys, crowding, congestion, and disruption/rescheduling effects.



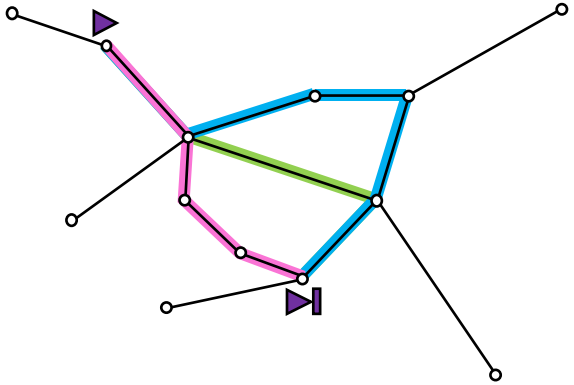
Simulation Components

Agent-Based Modelling

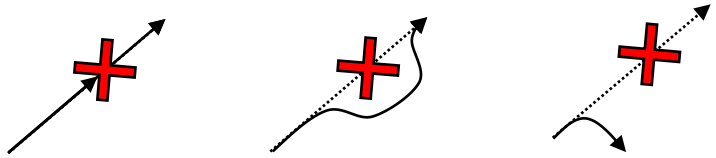
Passenger Agents: Individual entities that can each make their own (re-)routing decisions



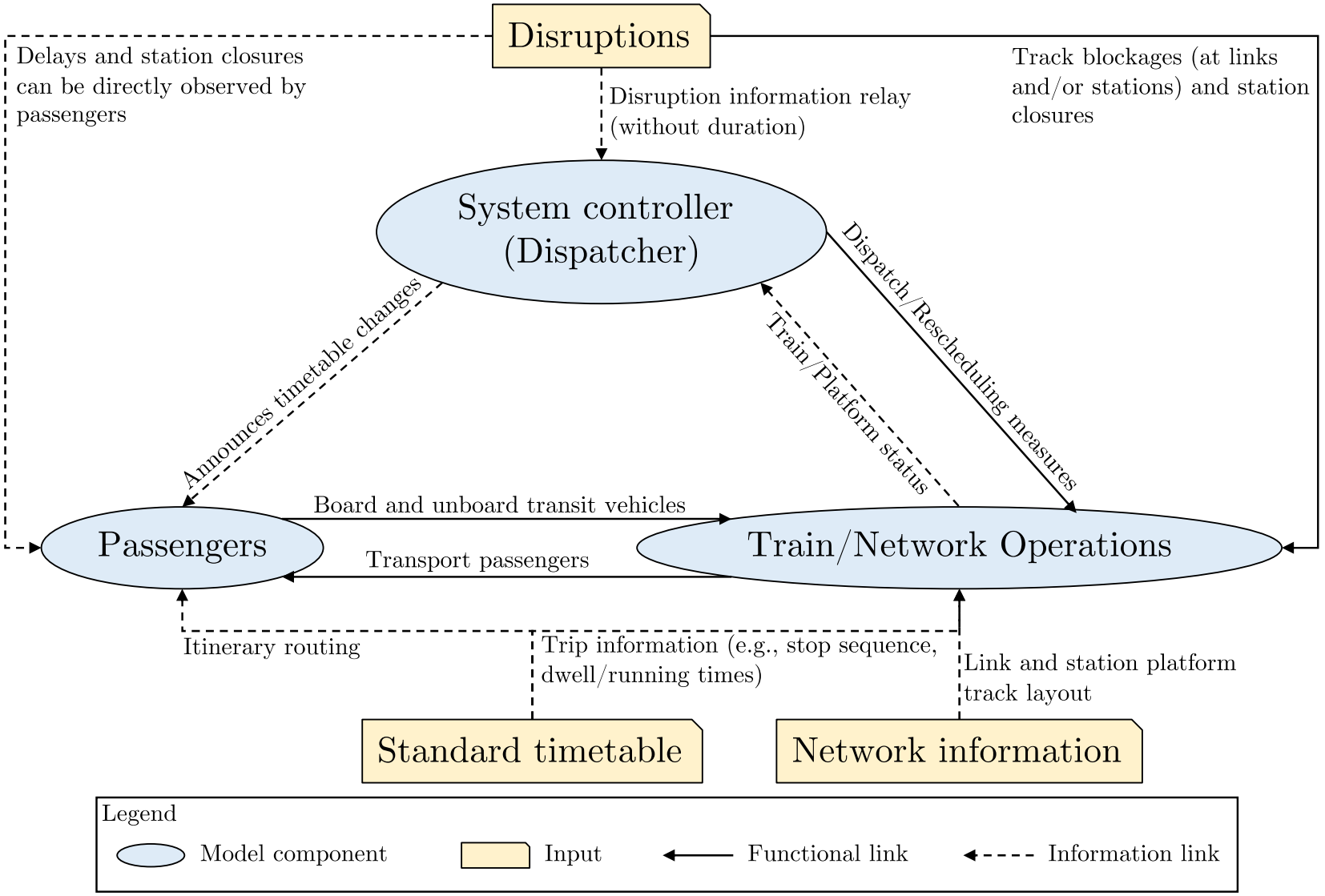
Route Finding and Selection



Re-Routing



Simulation Components

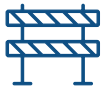


Network and System Controller Model

Capturing Transit System Operations

Train services operate according to a planned timetable

Interfered by (knock-on) delays even without disruptions (e.g., peak demand, track conflicts)



Disruption generator triggers user-specified disruptions: Track blockages, Station Closures

System controller emulates central dispatch and control unit:

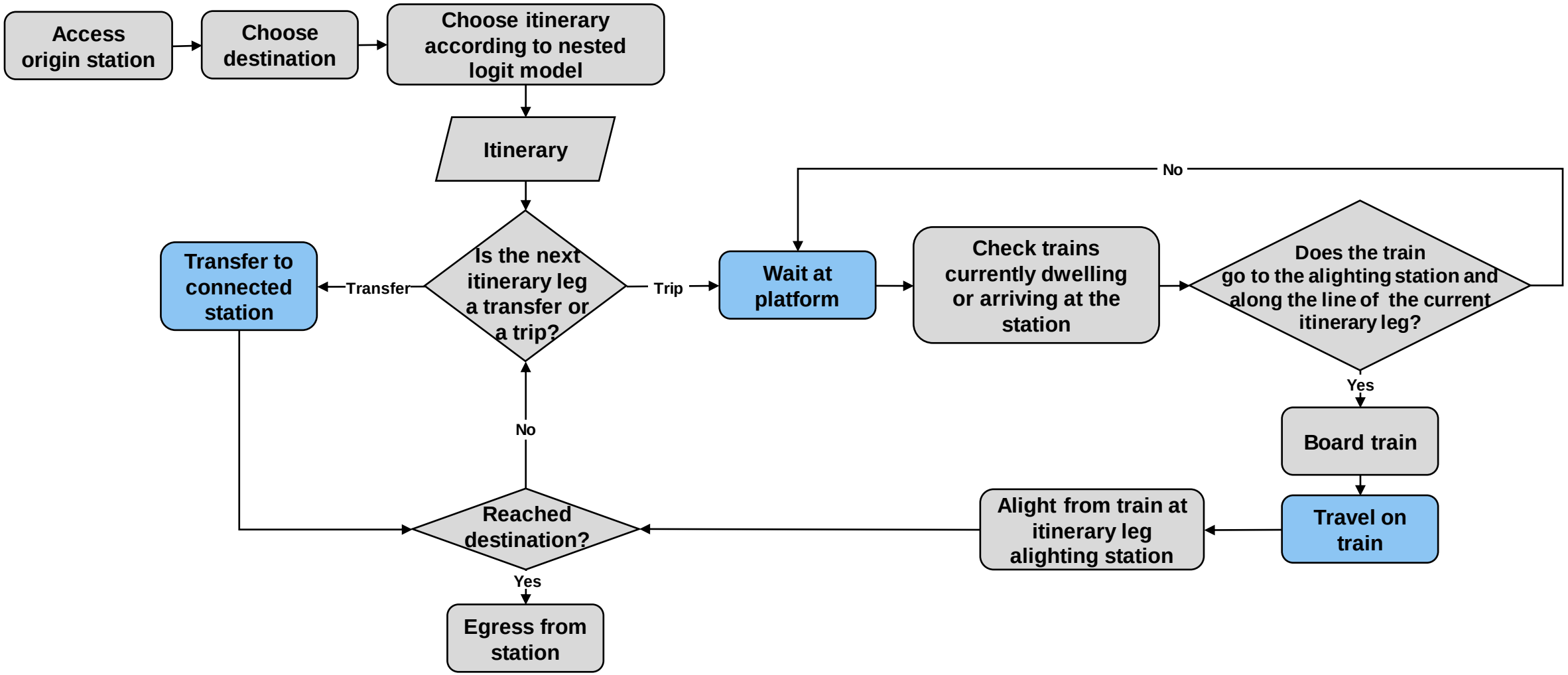
- Broadcast passenger announcements (incl. timetable adjustments)
- Invoke rescheduling measures (e.g., cancelling trains, re-timing, short-turning)

Processes (incl. passenger movement) are embedded into a Discrete-Event Simulation

Passenger Agent Model: Itinerary-Based Assignment

Instances when re-routing may occur

Process flow



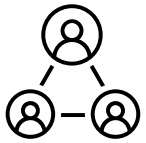
ASSESS

Predicting the Effects of a Real-World Scenario

Testing the Simulation

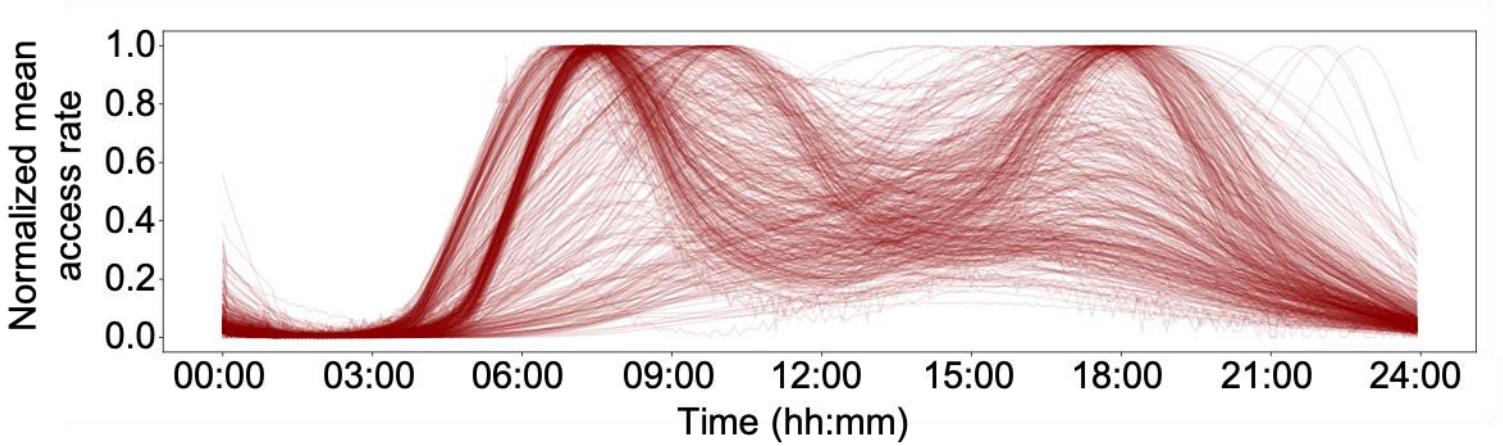
All models are wrong but some are useful – George Box (1976)

- How wrong? How useful?
- Test case: NYC Subway Network



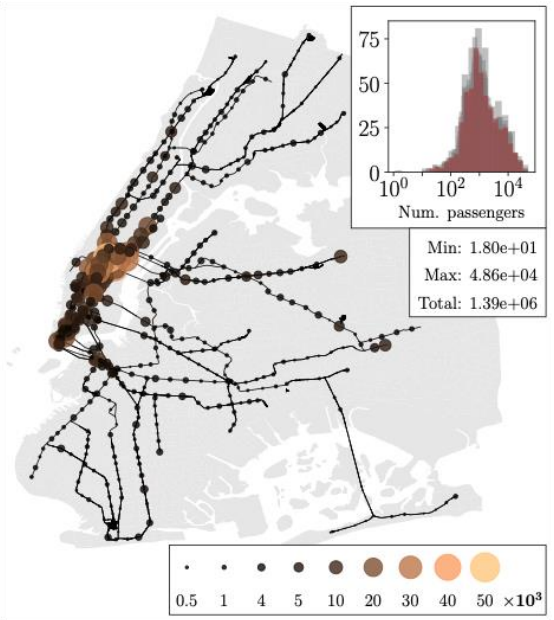
Passenger demand data

- Average weekday demand in May 2016
- OD-coefficient estimates (morning, midday, evening)

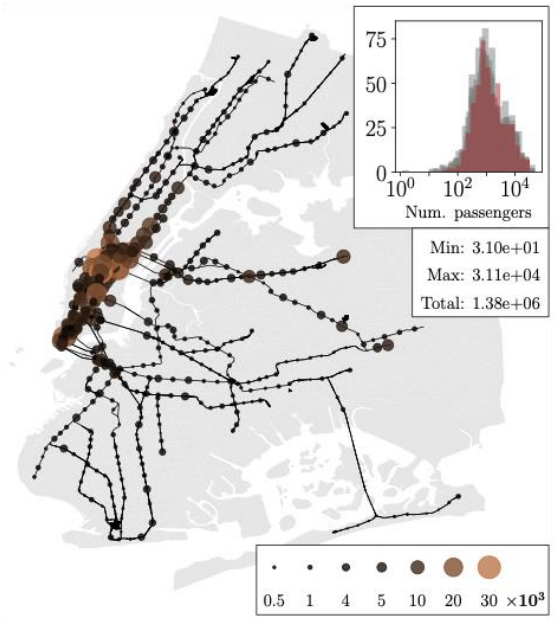


Simulation Validation – Undisrupted conditions

Exit counts

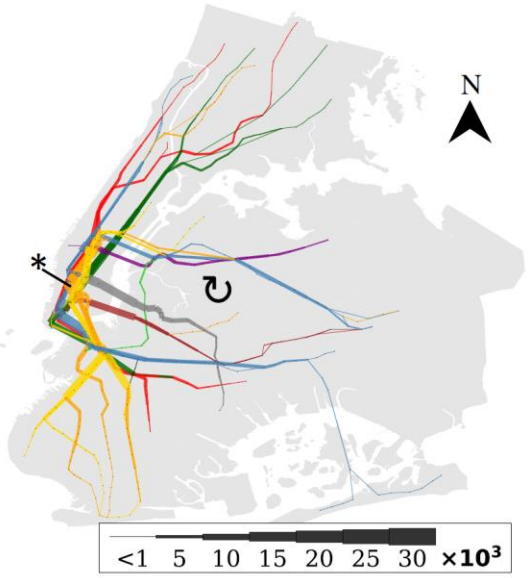


Observation

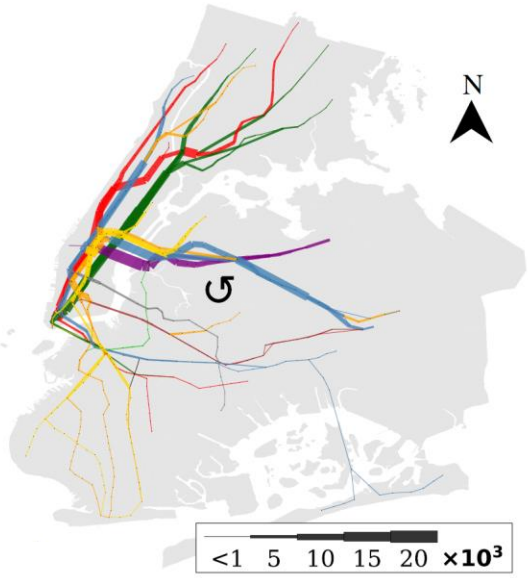


Prediction

Predicted link flow levels



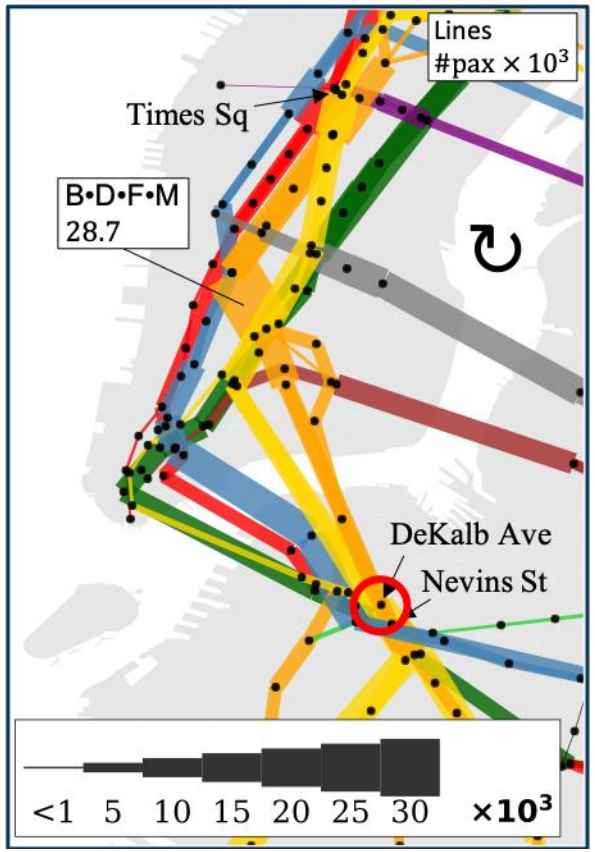
Northbound



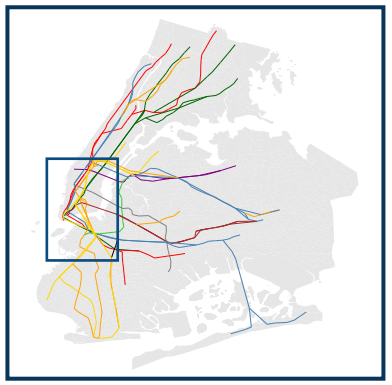
Southbound

The Starting Point

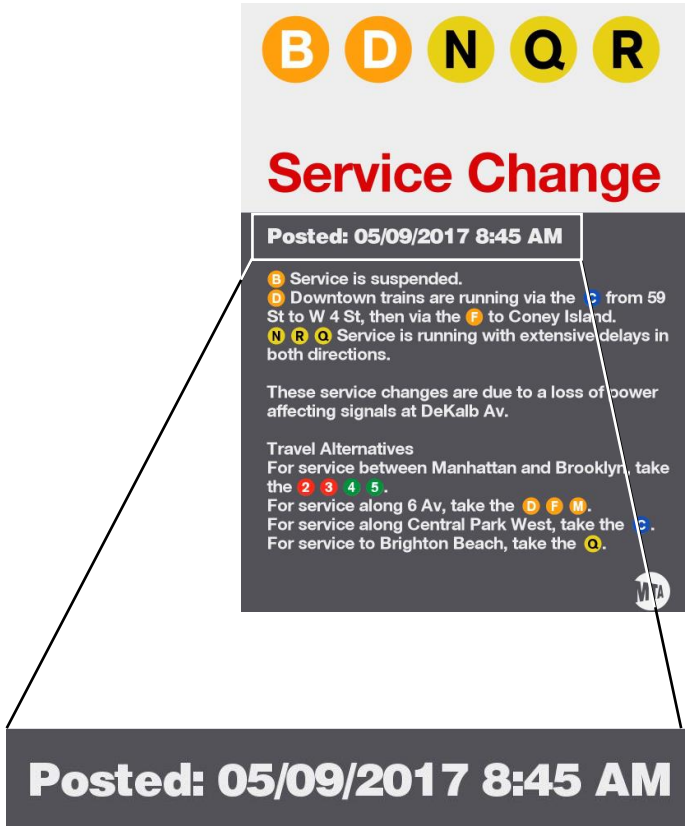
Nominal conditions: Hourly link flow levels (8:30 to 9:30 AM)



Northbound



Disruption scenario
Power outage and signalling fault at
DeKalb Ave
on May 9th, 2017

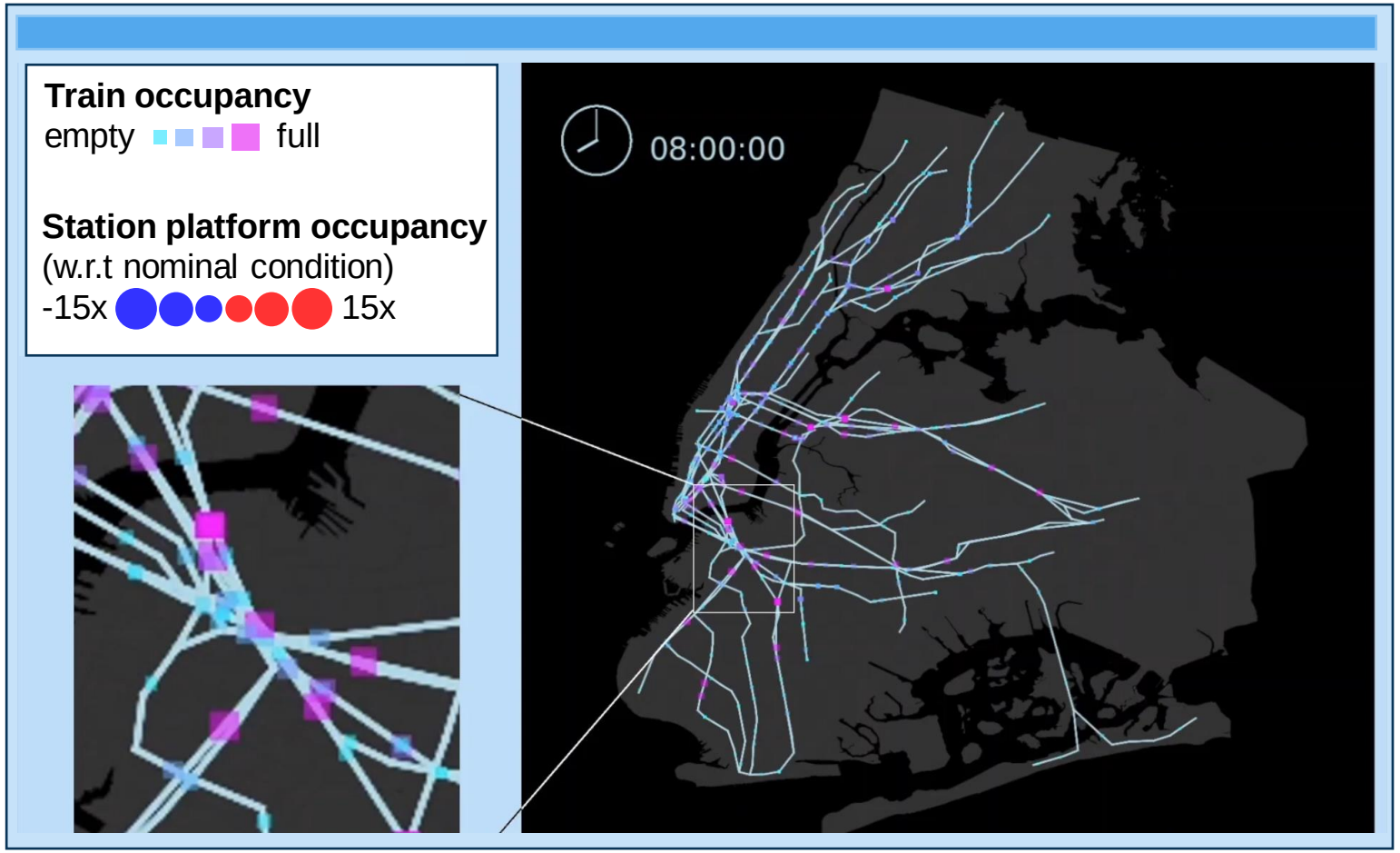


Reference: https://twitter.com/NYCTSubway

Dynamic Prediction Results

Disruption Simulation

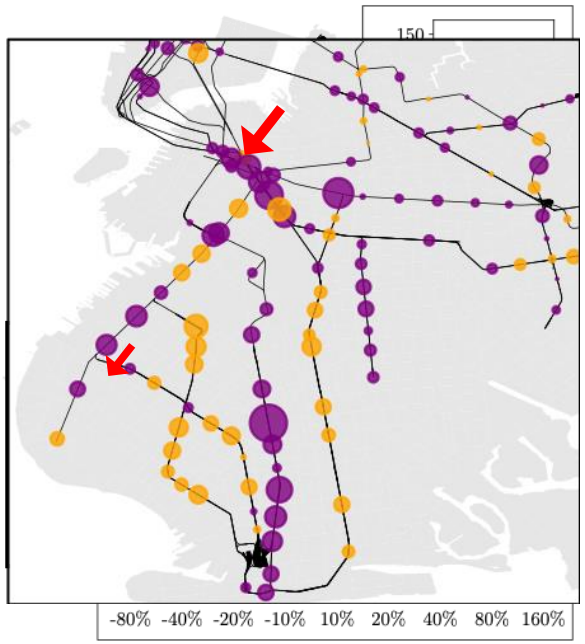
Based on 1-year ahead passenger demand data and real-world track blockage scenario at DeKalb Ave station



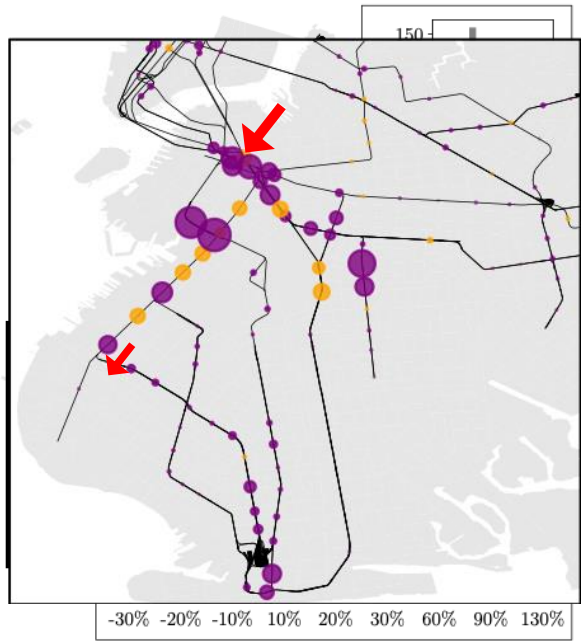
Simulation Validation

Testing the Limits – Comparing Relative Changes w.r.t. Nominal Conditions

Entry count changes

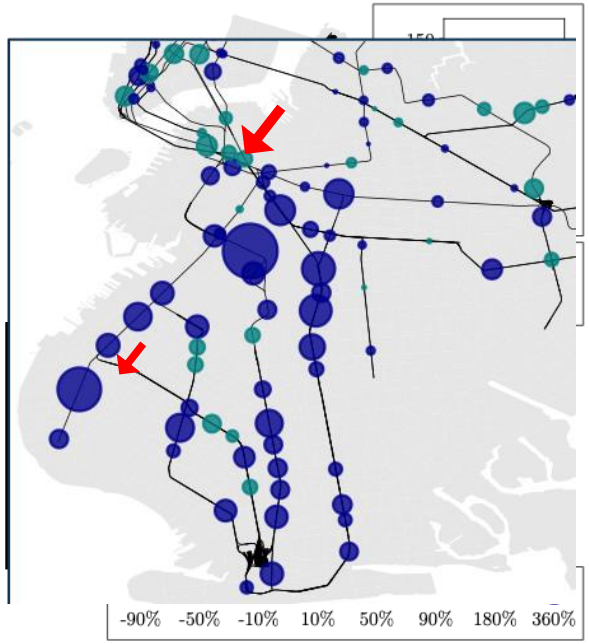


Observed

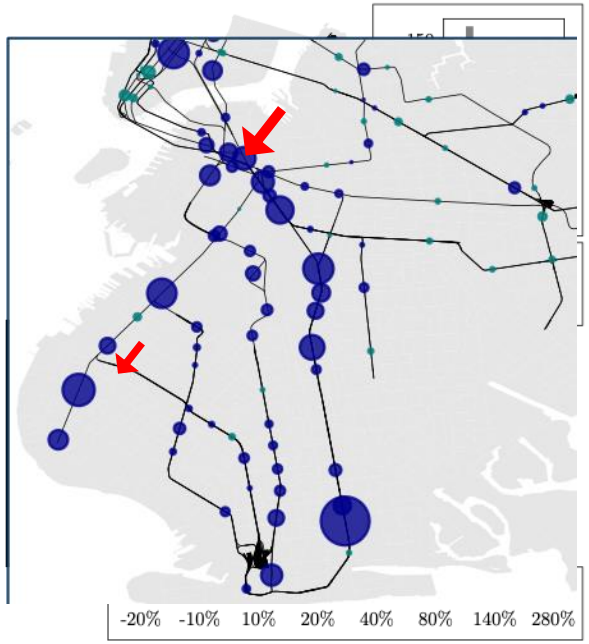


Simulated

Exit count changes



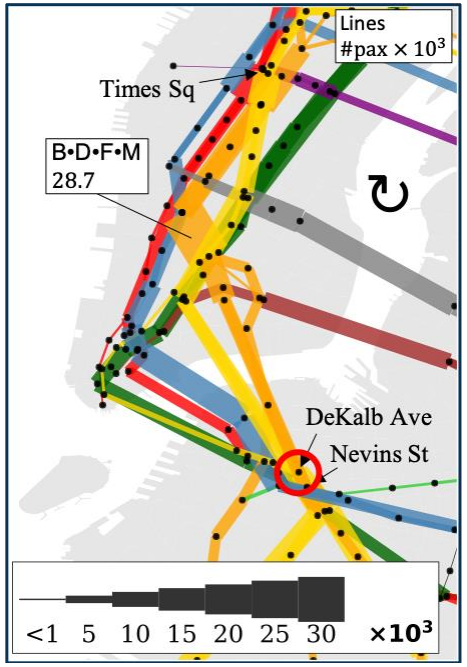
Observed

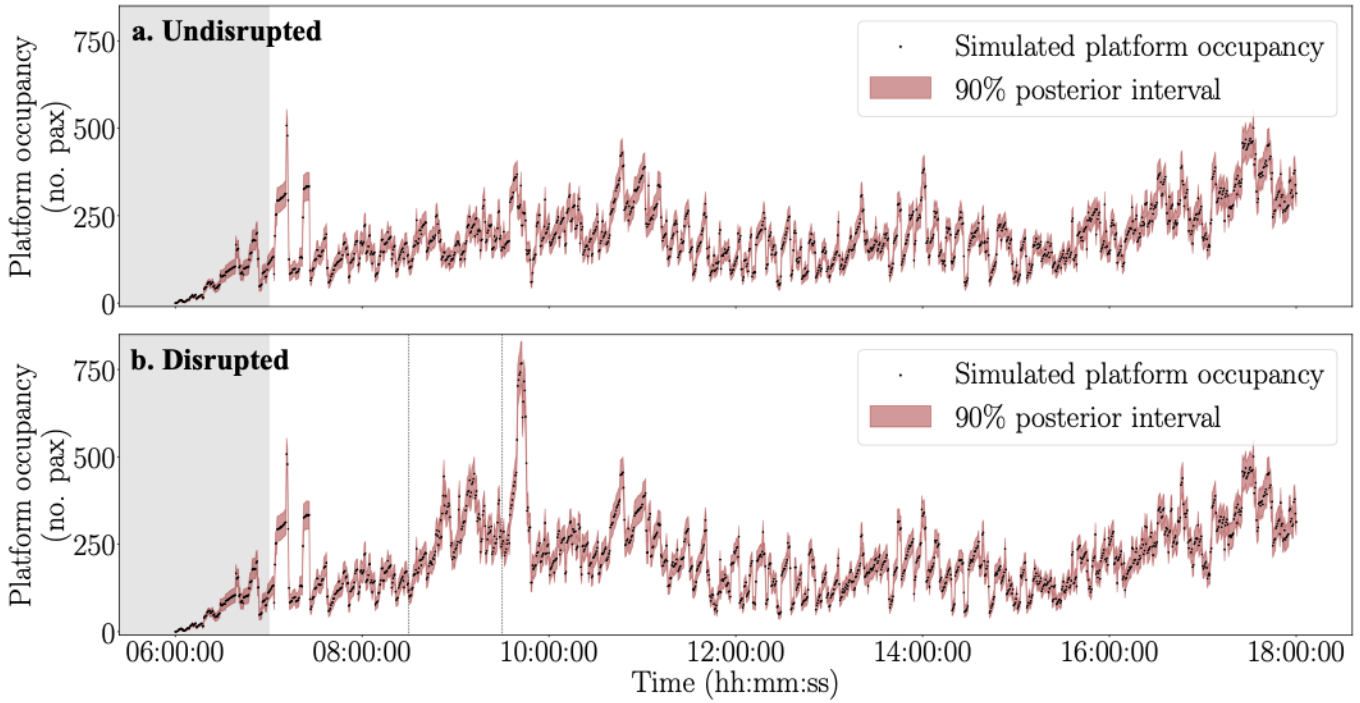


Simulated

Simulation Prediction

Platform Occupancy, Nevins Street Station





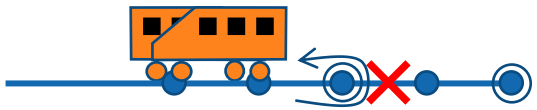
DESIGN

Testing an Alternative Rescheduling Measure

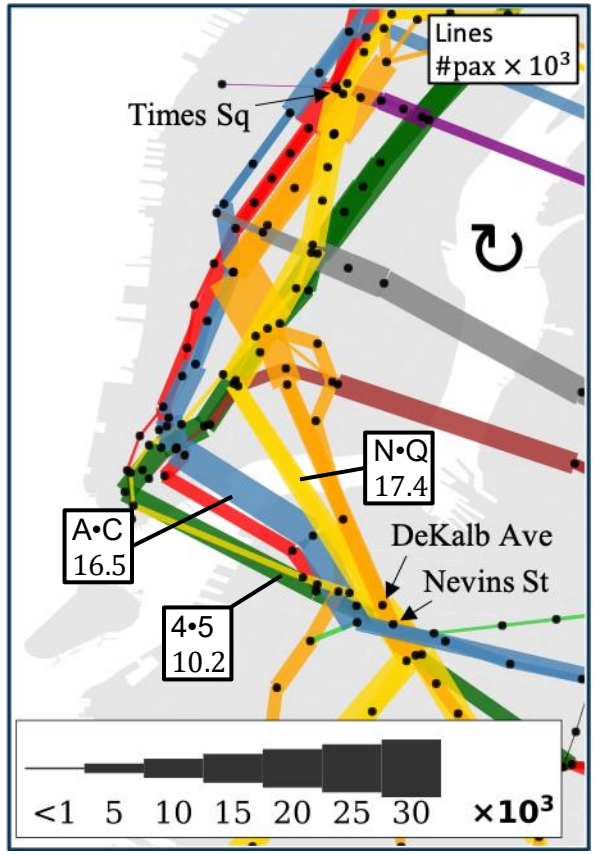
Testing an Alternative Rescheduling Measure

What if trains had been short-turned close to DeKalb Ave station?

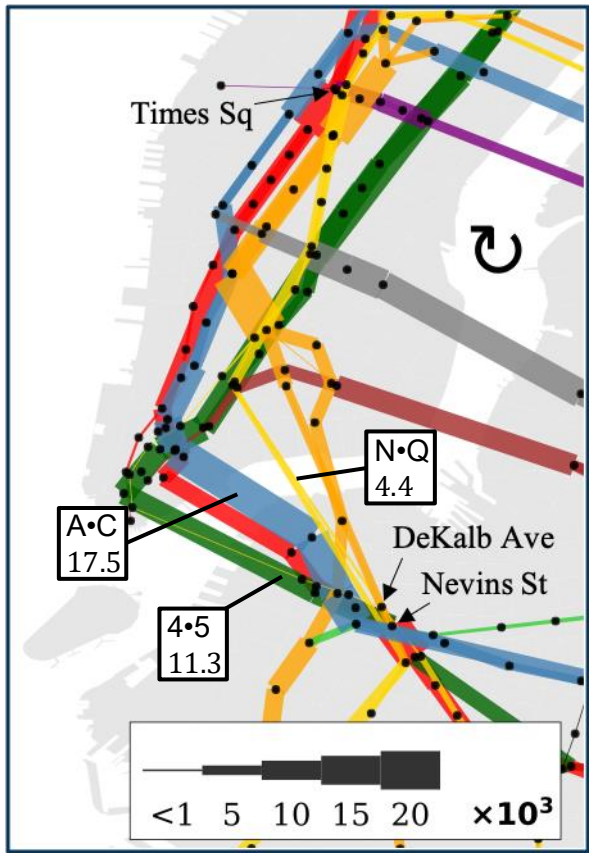
Hourly link flow levels
between 8:30 and 9:30 AM



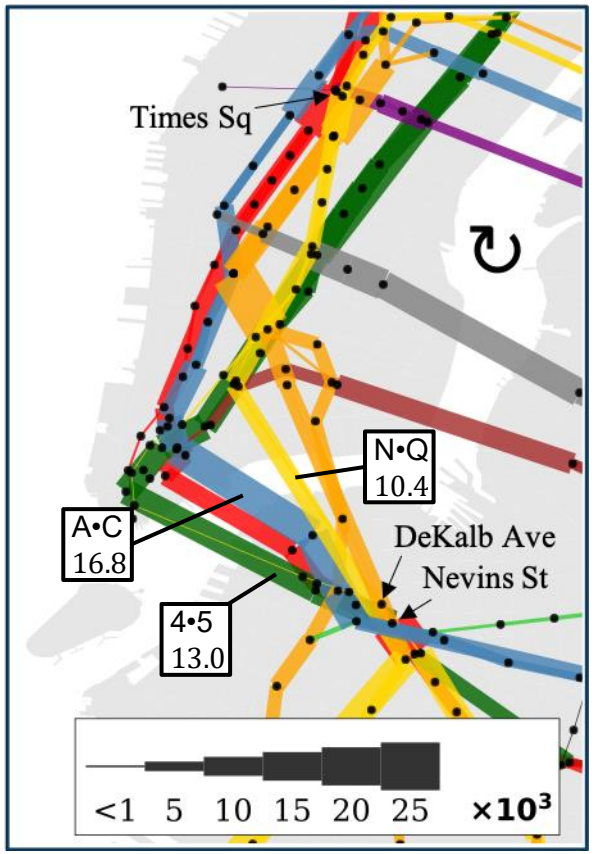
Nominal, Standard timetable



Disrupted, Standard timetable



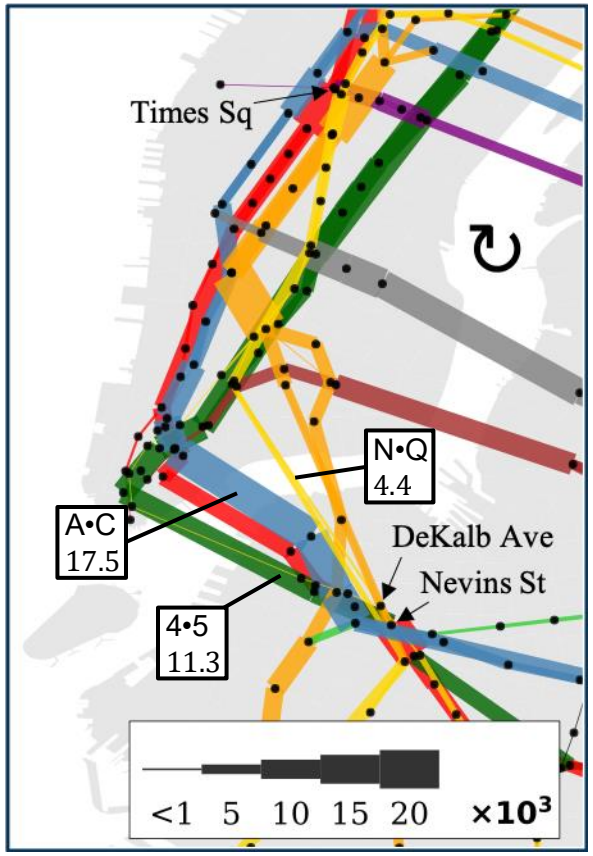
Disrupted, Short-turning enabled



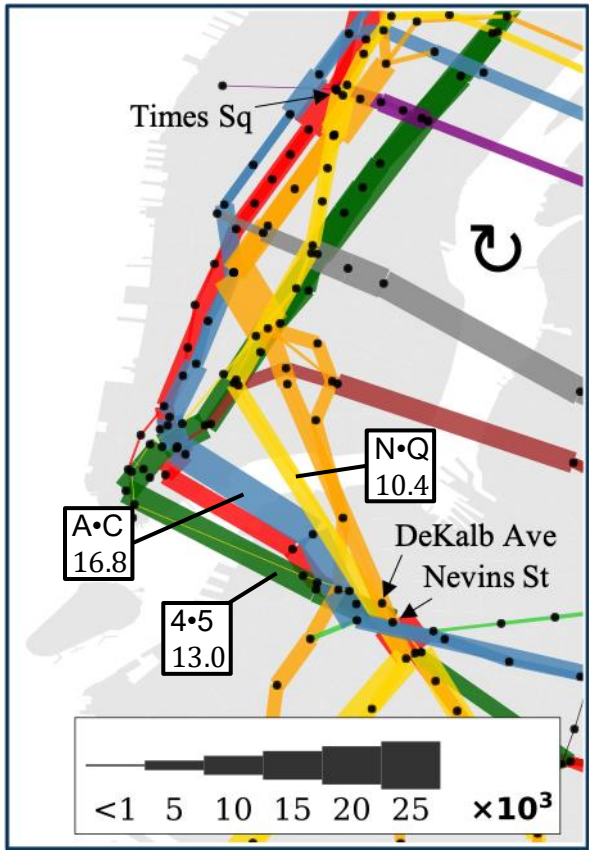
Testing an Alternative Rescheduling Measure

What if trains had been short-turned close to DeKalb Ave station?

Disrupted, Standard timetable

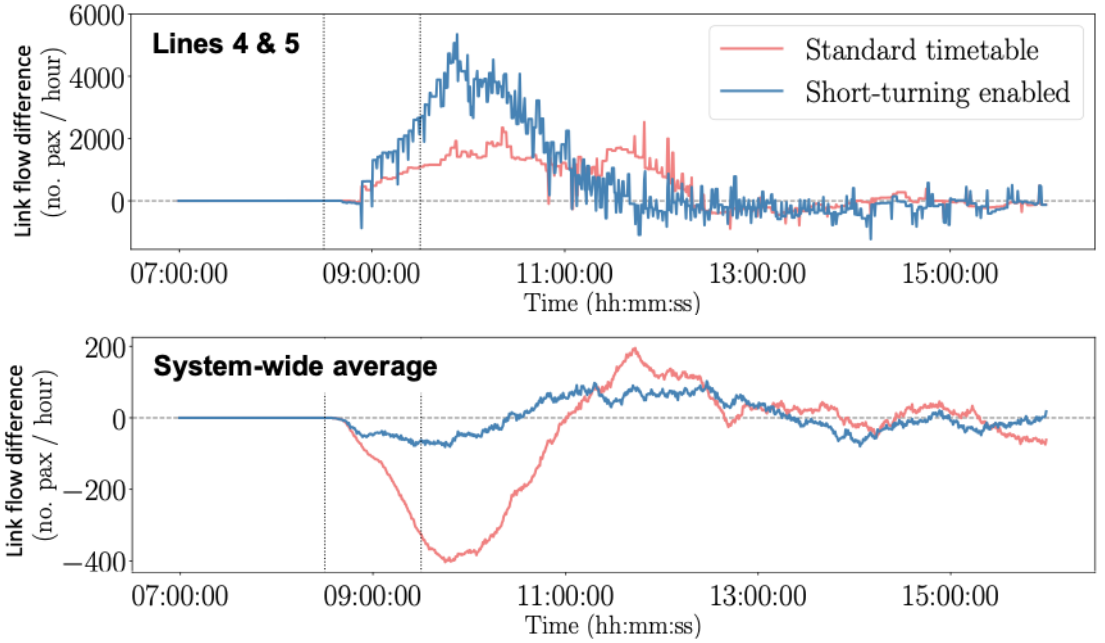


Disrupted, Short-turning enabled



Time-dependent link flow differences

(Rolling window hourly link flow difference w.r.t. nominal condition)



Conclusion

Take-Aways

Demand-Responsive Disruption Management in Mass Transit Systems

1 **UNDERSTAND**

- Developed agent-based transit system simulation model capable modelling the dynamic redistribution of passengers during disruptions

2 **ASSESS**

- Validated simulation predictions against a real-world disruption scenario

3 **DESIGN**

- Tested how rescheduling measures affect the system-wide/local resilience draw-down and draw-up cycle

For more details:

Steffen O.P. Blume, Demand-responsive Disruption Management in Mass Transit Systems, PhD Thesis, ETH Zurich, 2021, URL: https://www.research-collection.ethz.ch/handle/20.500.11850/508355?show=full

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Steffen O.P. Blume, Michel-Alexandre Cardin, Giovanni Sansavini, Dynamic Disruption Simulation in Large-Scale Urban Rail Transit Systems, 10th International Conference on Complex Systems Design & Management (CSDM 2019), Paris, France, Cham: Springer Nature, 12-13 December 2019, Pages 129-140, doi: 10.1007/978-3-030-34843-4_11

Steffen O.P. Blume, Michel-Alexandre Cardin, Giovanni Sansavini, Steps towards quantifying fragility in large-scale urban transit systems, 6th International Symposium on Reliability Engineering and Risk Management (6ISRERM), 31 May - 1 Jun 2018, Singapore, doi: 10.3850/978-981-11-2726-7_CRR16