

Mathematical Modelling For Tackling Covid19 In Public Transport Networks

Nikola Bešinović

*Including contribution of Cristopher Szymula, Egidio Quaglietta,
Rob Goverde*

Delft University of Technology, The Netherlands

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Introduction

- Physical distancing (1.5m)
- Reduced passenger demands
 - Up to 90% drop, slowly recovering (and dropping again)
- Restricted train capacity (#seats)
 - About $\frac{1}{4}$ of original capacity



Introduction

Capacity
Timetabling
Conclusions

Introduction

- What is the transport capacity of our system under physical distancing?
 - ➔ S1: Capacity assessment for covid19
- How to redesign rail services to accommodate as much demand as possible?
 - ➔ S2: Stable network timetabling for covid19

Introduction

Capacity
Timetabling
Conclusions

S1: Capacity assessment

- Typically, passenger assignment models focused mostly on normal conditions, so overcapacity was rarely under scope.
- **Given:** planned timetable, origin-destination demand matrix, new **limited** train/seat capacity
- **Find:** maximum number of transported passengers and attractive passenger routes through the network

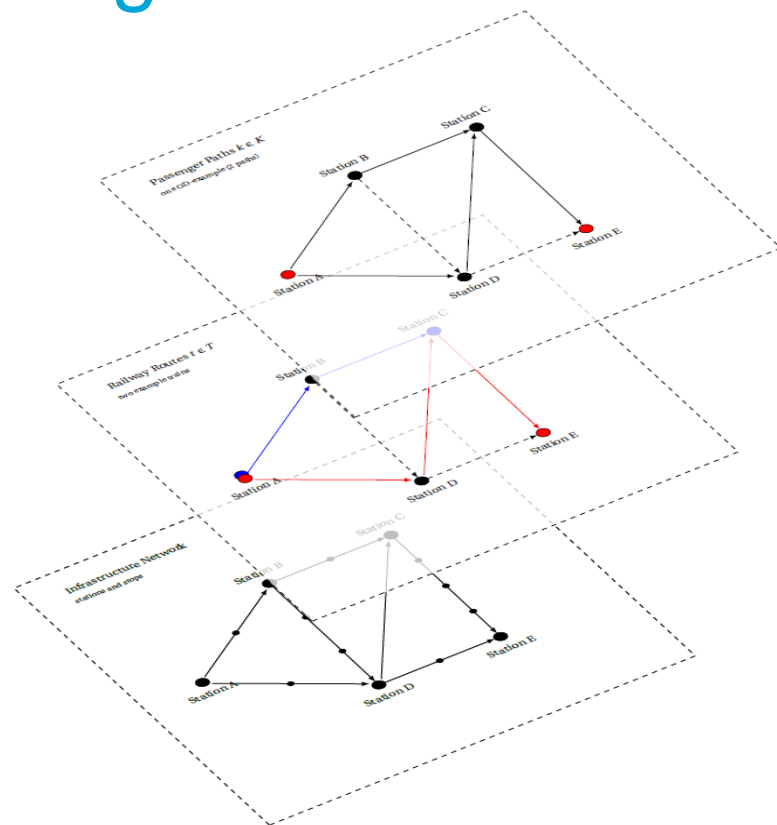
S1: Network modelling

3 network layers:

- Infrastructure
- Train services
- Passenger flows

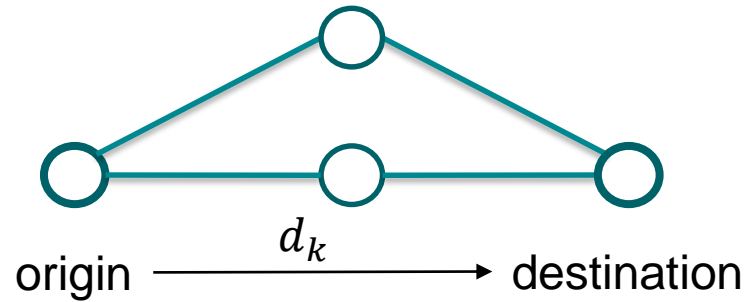
Assumptions:

- Passengers are routed via shortest paths
- One OD can use multiple paths



S1: Passengers

Passenger OD-pair k



Decision variables:

f_p^k : passenger flow share of OD-pair k on path p

x_{ij}^t (0/1): train t runs on arc (i,j)

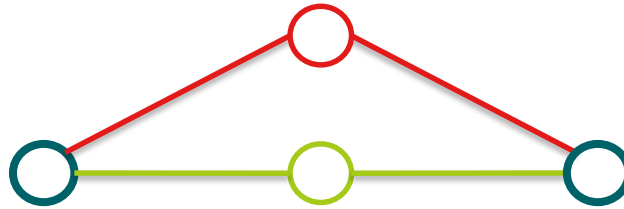
Parameters:

$\delta_{i,j}^p$: arc (i,j) is part of path p

d_k : demand of OD-pair k

s^t : seats on train t

S1: Passengers



Path 1 —

Path 2 —

Decision variables:

f_p^k : passenger flow share of OD-pair k on path p

x_{ij}^t (0/1): train t runs on arc (i,j)

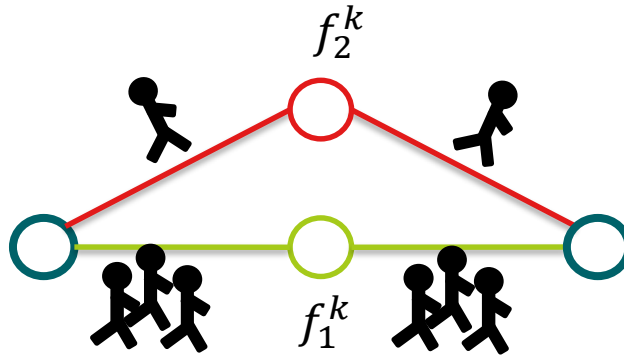
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S1: Model

$$\max \sum_{k \in K} \sum_{p \in P^k} c_f^{p,k} f_p^k$$

Such that

arc-based constraints for trains

path-based constraints for passengers

train capacity

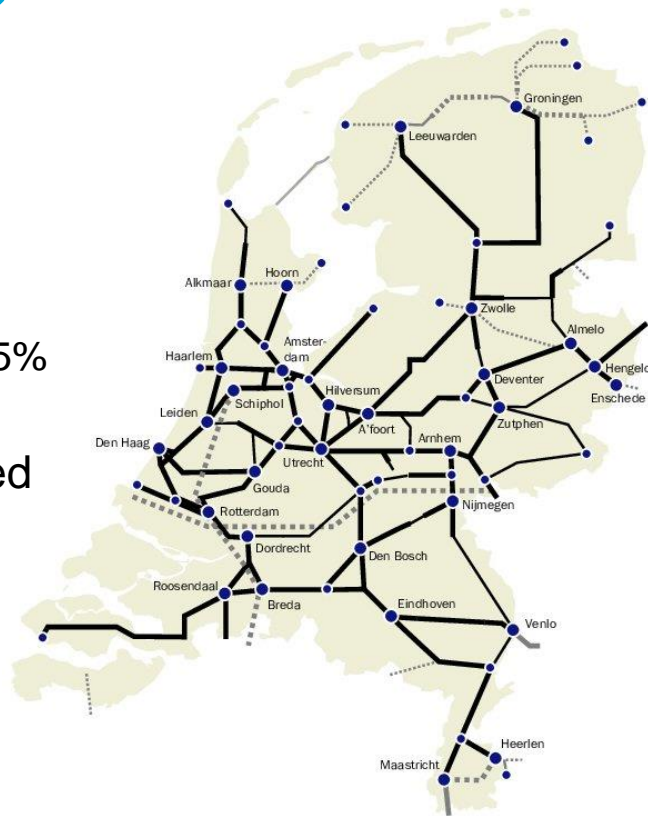
infrastructure link capacity

!! Large number of potential paths → a column generation approach

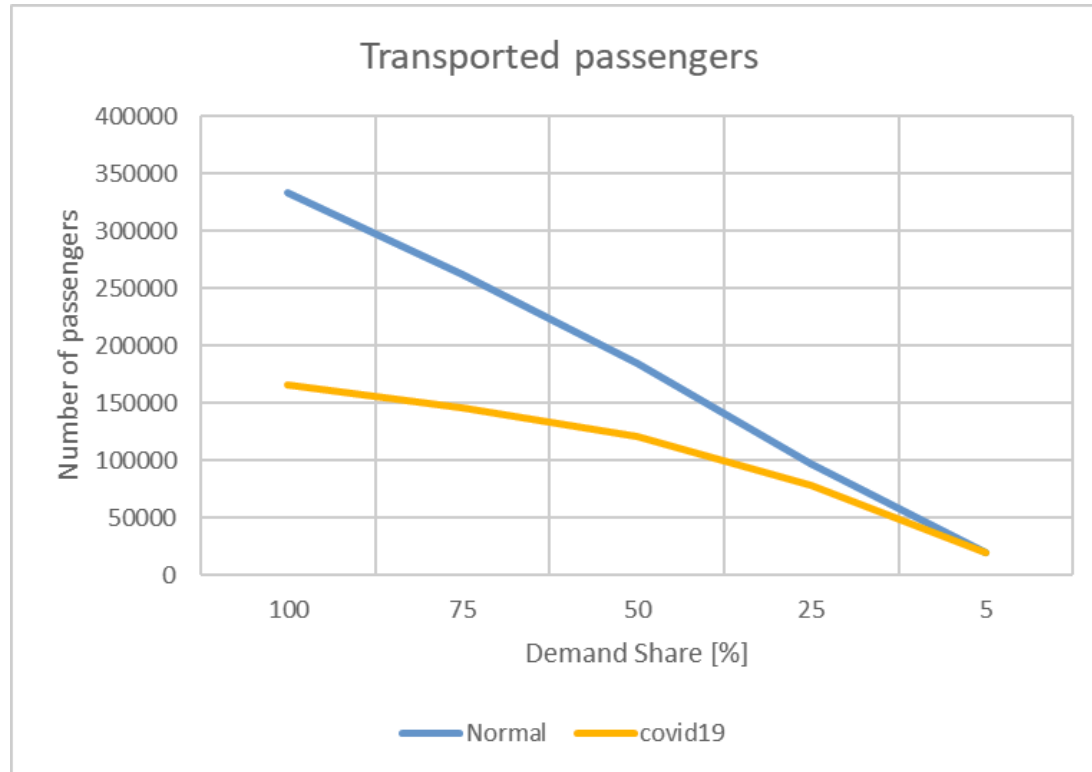
Szymula & Bešinović (2020). Passenger-centered vulnerability assessment of railway networks. *Transportation Research Part B: Methodological*.

S1: Experimental setup

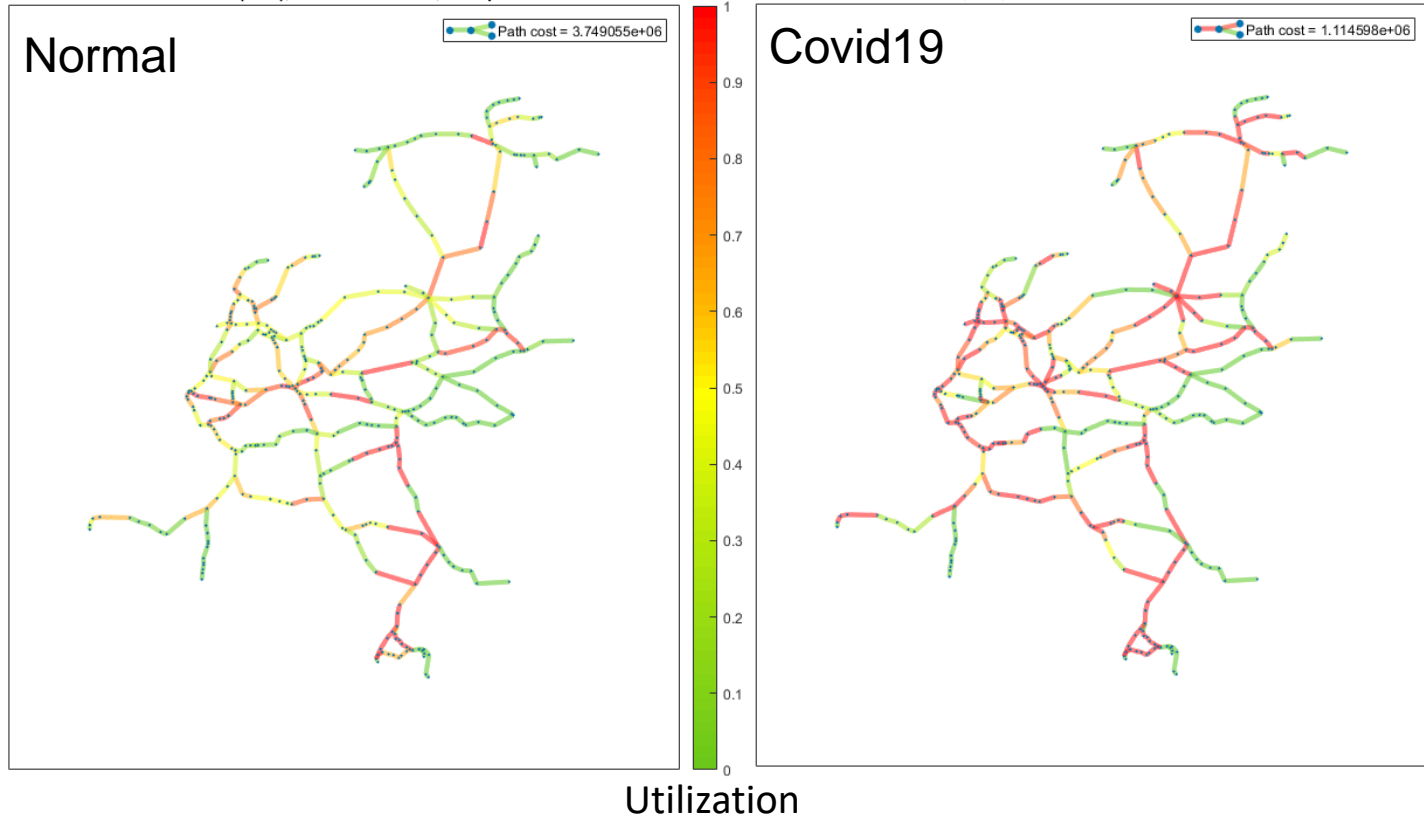
- Dutch railway network
- 5 variants of demand size:
 - Normal conditions: 100%
 - 4 restricted conditions: 5%, 25%, 50%, 75%
- Train capacity (#seats): $\frac{1}{4}$ of the designed capacity
- Report:
 - the transported demand
 - link utilization and
 - train utilization



S1: Transported passengers

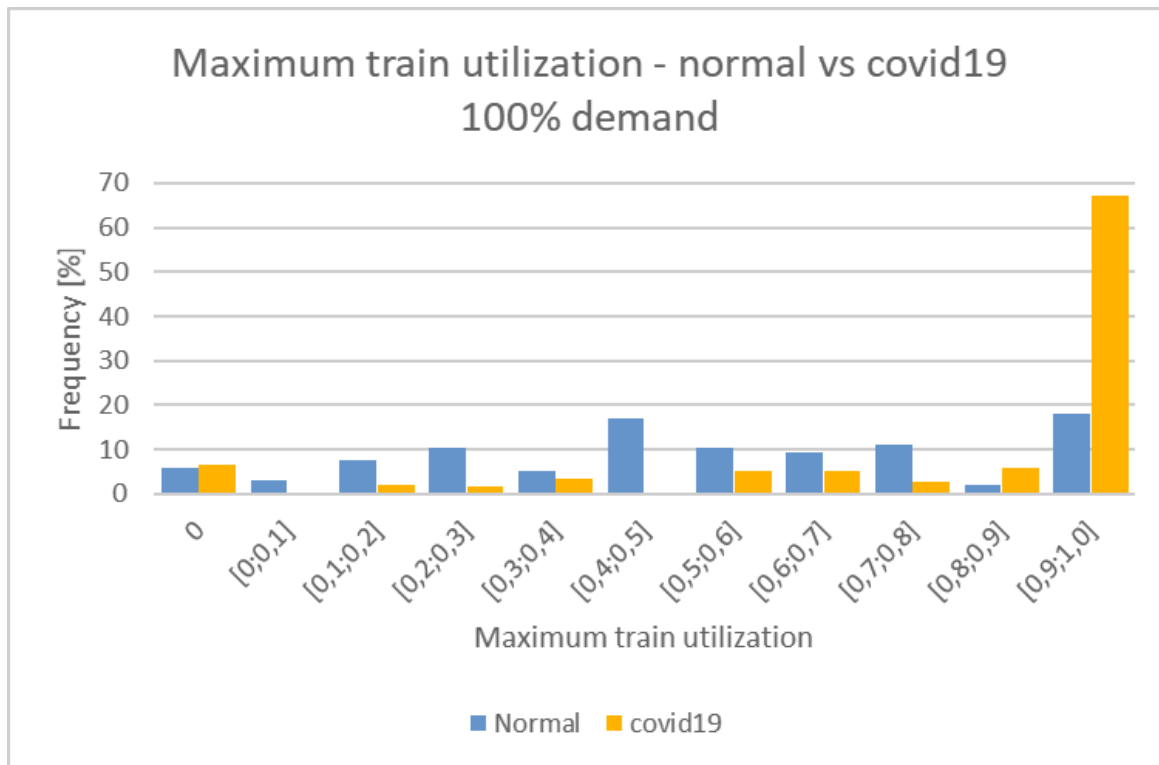


S1: Link utilization



S1: Train utilization

*Maximum =
over at least one
line section



S2: Stable network timetabling

!! Serious transport capacity issues

- Q2: How to redesign rail services to satisfy as much demand as possible?
- ➔ Stable network timetabling

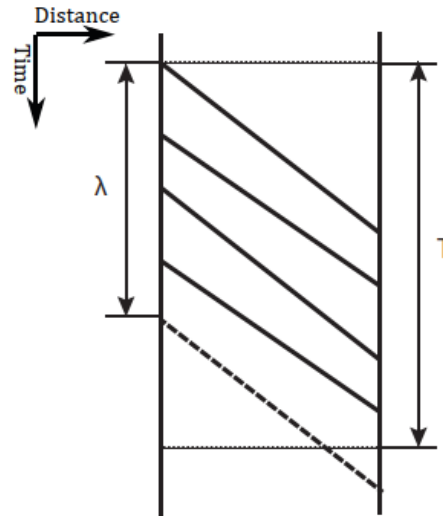
S2: Line plan and stability

- **Target line plan:**
 - ideal services including origins, destinations, stops and frequencies
 - Created based on the expected passenger demand
 - E.g. existing demand with existing train lines **but much higher frequencies** (due to covid19)
- Scheduled cycle time T (period that repeats over day)
- **Timetable stability:** the availability of the periodic timetable to return to its schedule from disturbance causing delays.

S2: Minimal cycle time

- **Minimal cycle time** (λ): the smallest time duration in which all events are feasible in the period.

- Example



S2: Minimal cycle time and stability

- **Minimal cycle time** (λ): network-level stability measure

Timetable stability (Goverde, 2017):

- $\lambda < T$: stable
- $\lambda > T$: unstable
- $\lambda = T$: critical (no time supplements available)

S2: Stable network timetabling

- **Given:** demand, target line plan, scheduled cycle time T
- **Find:** optimal and stable timetable (with $\lambda < T$) that satisfies the most demand
- **Modelling:** minimal cycle time model, relaxation measures
- **Solution approach:** iterative heuristic to resolve instability

S2: Modelling

- periodic event-activity network $G = (N, A, T)$
- periodic events $i \in N$: arrival, departure times $\pi_i \in [0, \lambda)$

$$(PESP - \lambda) \min f(\lambda, \pi, z)$$

such that

$$l_{ij} \leq \pi_j - \pi_i + z_{ij}\lambda \leq u_{ij}, \quad \forall \text{run, dwell, connection, headway}$$

$$\pi_j - \pi_i + z_{ij}\lambda = \lambda / \text{freq}_{line} \quad \forall \text{regularity arcs, } \forall \text{train lines}$$

$$0 \leq \pi_i \leq \lambda - 1, \quad \forall \text{events}$$

$$z_{ij} \text{ binary}, \quad \forall \text{run, dwell, connection, headway}$$

S2: Relaxations

Relax line plan (→ passenger demand)

- M1. relax train line frequency
 - remove some (critical) train services from the line plan
 - Train line priority based on covered transport demand

Relax timetable design parameters (→ level of service)

- M2. relax regularity constraints, by certain time S
$$\lambda / freq_{line} - S \leq \pi_j - \pi_i + z_{ij} \lambda \leq \lambda / freq_{line} + S$$
- M3. relax train-related constraints, by increasing upper bound for running times
$$l_{ij} \leq \pi_j - \pi_i + z_{ij} \lambda \leq u_{ij} \cdot W$$

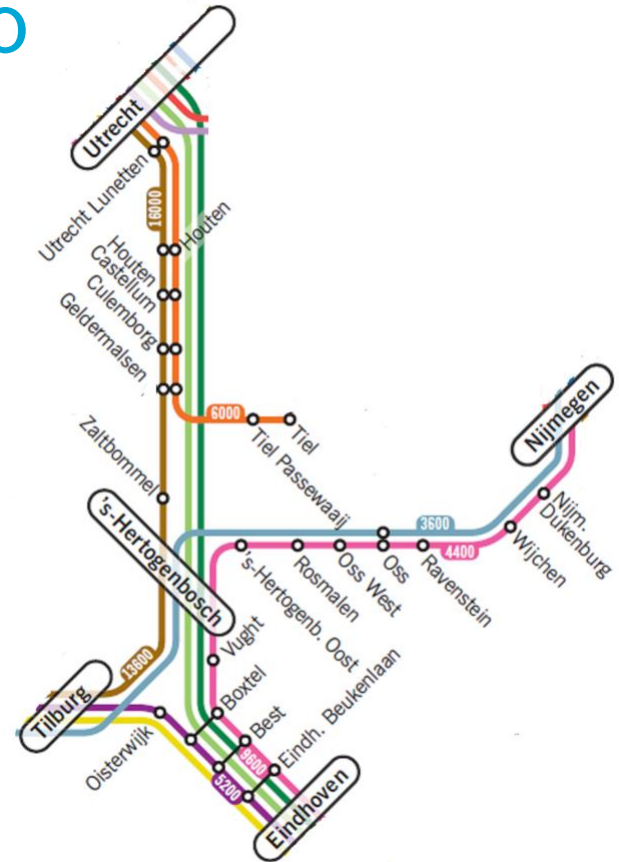
S2: Experimental setup

- Tested on a part of the Dutch railway network
- Scenario characteristics:
 - # of lines: [14,20]
 - Avg. frequency: [1,2]
 - # of train services: [20,60]
 - Schedule cycle time T : 1800s

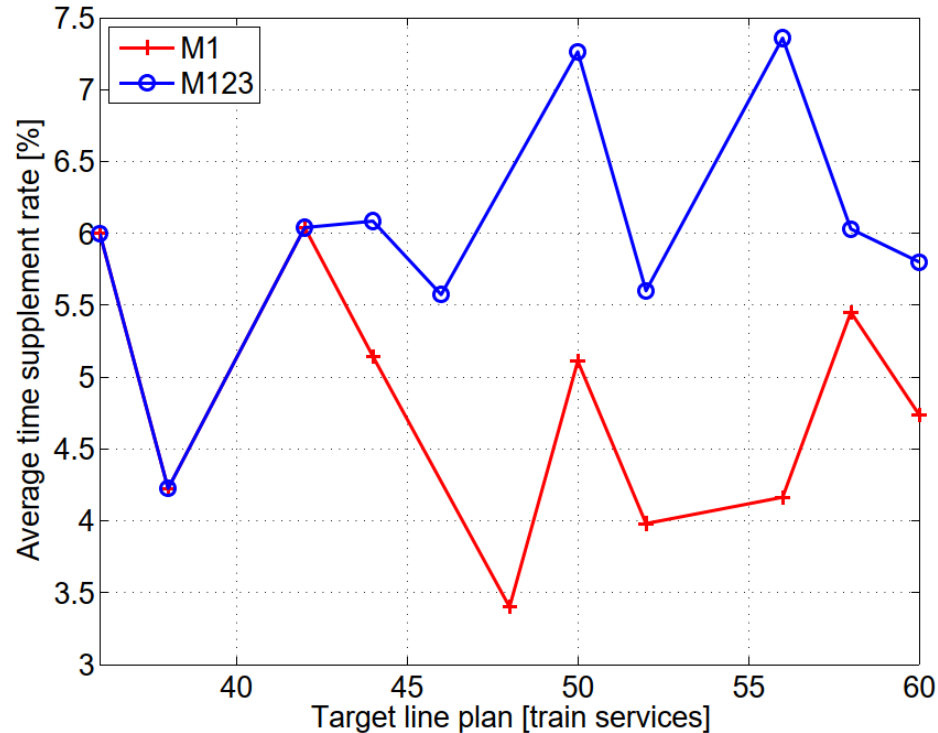
Table 2: Input parameters for Algorithms 1 and 2

Parameter	Notation	[unit]	Value
M2 minimum	S_{\min}	[s]	0
M2 step	S_{step}	[s]	60
M2 maximum	S_{\max}	[s]	120
M3 minimum	W_{\min}		1
M3 step	W_{step}		0.1
M3 maximum	W_{\max}		1.2

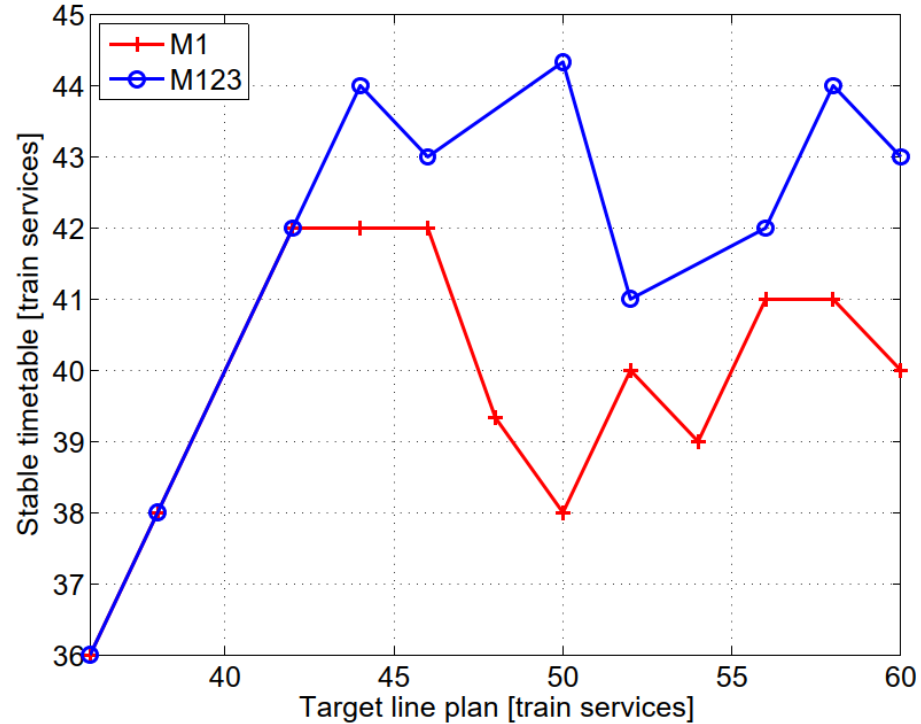
- Report:
 - Only relaxing train services: **M1**
 - All 3 measures: **M123**



S2: Level of service



S2: Number of scheduled train services



Conclusions

3 main takeaways:

- Using **advanced math models and algorithms** for addressing present challenges
- Evaluate **impacts and bottlenecks** in capacity
- **Redesign railway services** to suit better the new conditions
- Next steps:
 - Modelling for integrating assessment and TT redesign
 - Real-time: optimal spacing people within vehicles (allocation)
 - Demand prediction (more/less, changed patterns)
 - New technology (swarming, smaller pods, on-demand services)

A black steam locomotive pulling several red passenger cars through a lush green mountain valley. The train is emitting a large plume of white steam. The tracks curve through the landscape, and there are people standing on the platform next to the train. The background shows misty mountains under a cloudy sky.

Thank you

References

- Bešinović, N. (2020). Resilience in railway transport systems: a literature review and research agenda. *Transport Reviews*, 40(4), 457-478.
- Szymula, C., & Bešinović, N. (2020). Passenger-centered vulnerability assessment of railway networks. *Transportation Research Part B: Methodological*, 136, 30-61.
- Bešinović, N., Quaglietta, E., & Goverde, R. M. P. (2019). Resolving instability in railway timetabling problems. *EURO Journal on Transportation and Logistics*, 8(5), 833-861.
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M2: Relaxations

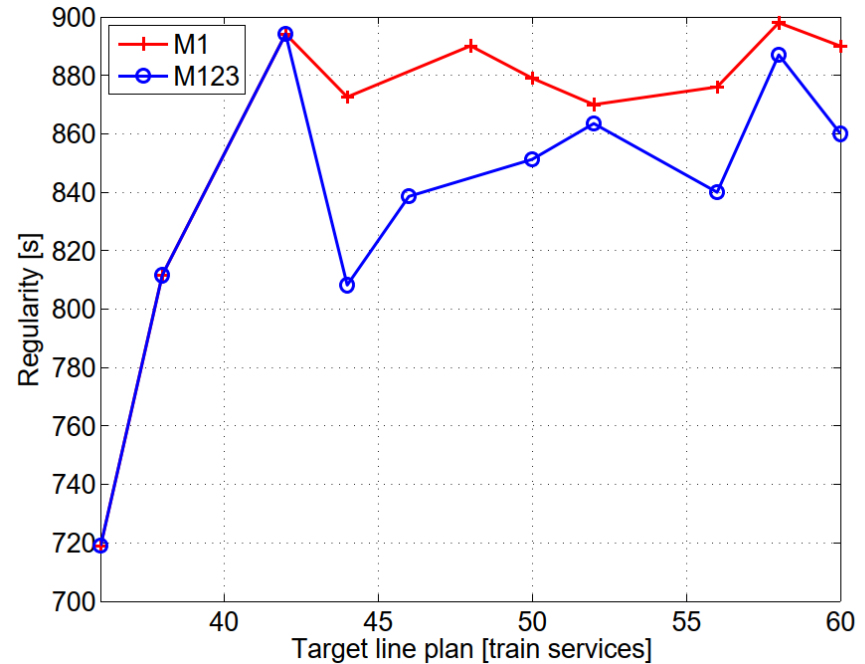
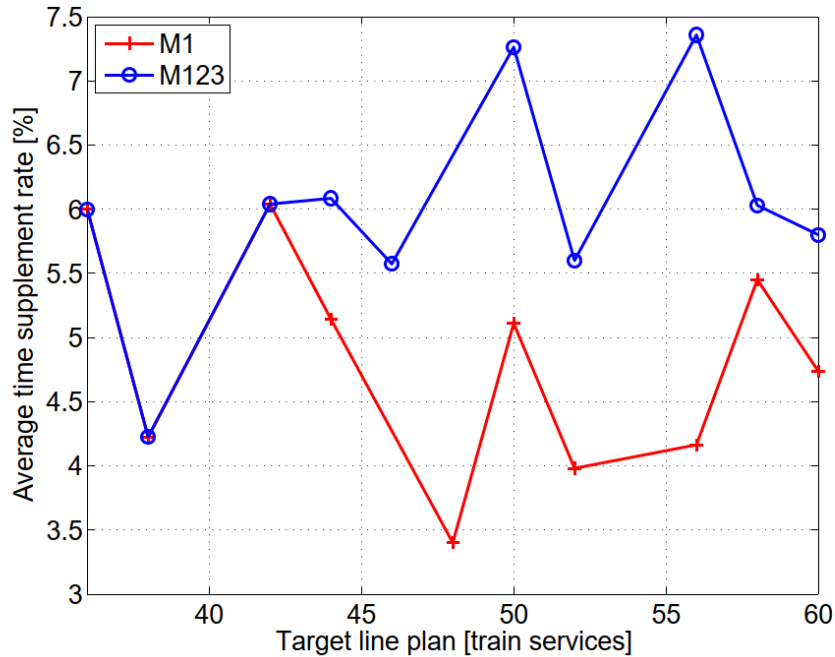
Relax line plan (→ passenger demand)

- M1. relax train line frequency
 - remove some (critical) train services from the line plan
 - Train line priority based on covered transport demand

Relax timetable design parameters (→ level of service)

- M2. relax regularity constraints
 - relax by S : $[T/freq_{line} - S, T/freq_{line} + S]$
- M3. relax train-related constraints
 - increase upper bound for running times $u_{ij} \times W$

S2: Level of service



Running time supplements

Regularity