Optimizing periodic stability in railway timetables

A microscopic model for networks with a macroscopic comparison

Other Conference Item

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Publication date:
2025-04-02

ETH zürich

Optimizing Periodic Stability in Railway Timetables: A Microscopic Model for Networks with a Macroscopic Comparison

Florian Fuchs, Bernardo Martin-Iradi, Francesco Corman

Rail Dresden Conference, April, 2025

Motivation and Context; Yearly performance of RhB (Rhätische Bahn)

2023 to 2022

▪ Passenger-km:	431'138	+15.7%
▪ Train-km:	7'749	+3.4%
▪ Network-Occupancy:	63.43%	+2.8%
▪ Punctuality:	88.1%	**-1.4%**

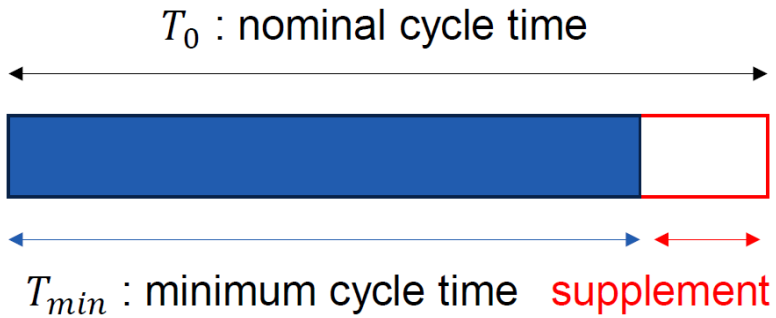
Source: RhB Annual Report 2023

Can we help RhB to improve?
Focus on increasing Periodic Stability

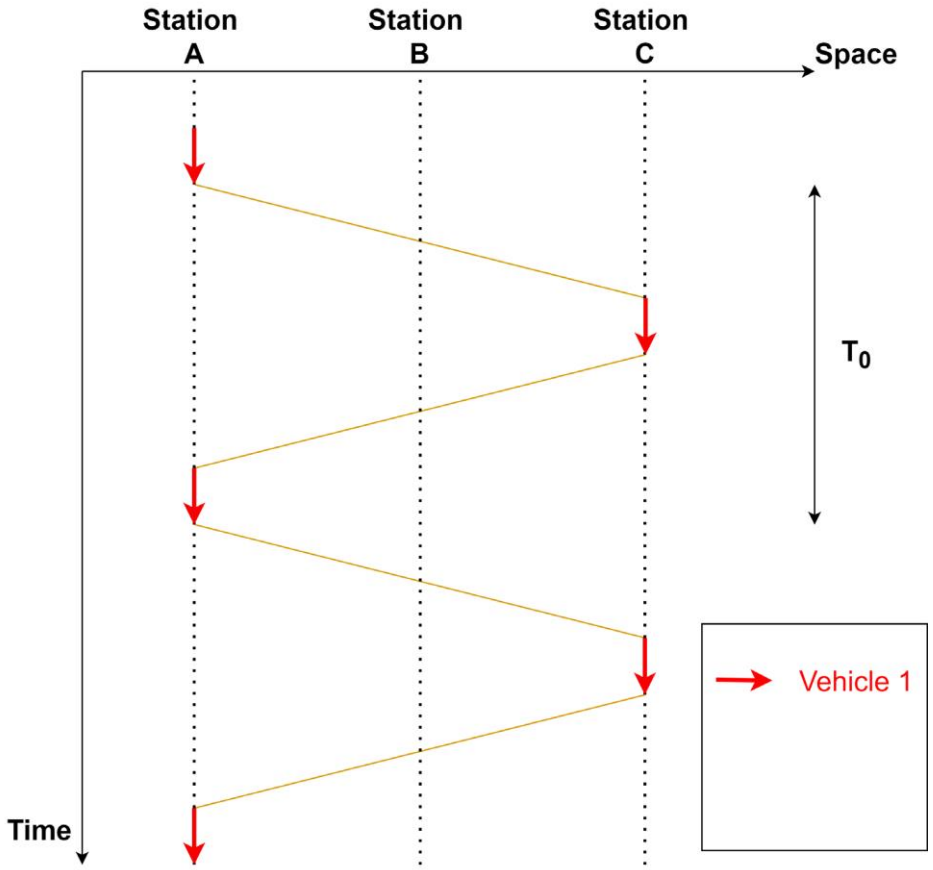
- **From growing demand to operational stress:**
  RhB's increased occupancy and ridership coincide with declining punctuality.

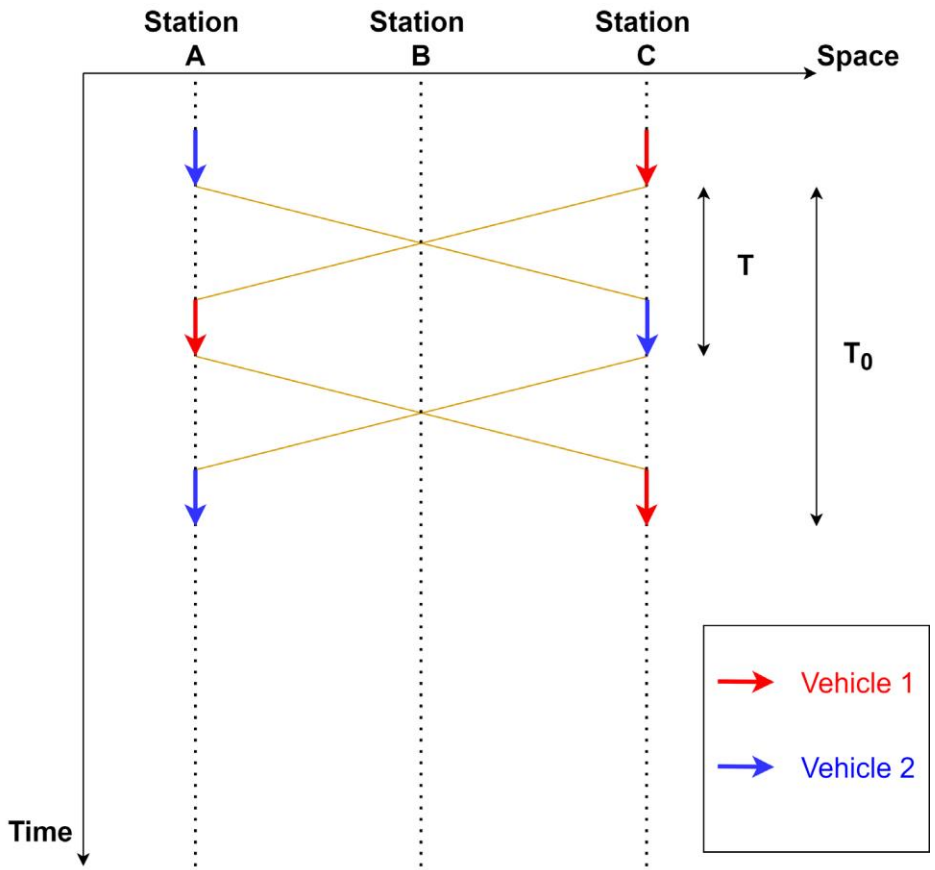
- **Periodic Stability***:*
  Stability is the ability of a timetable to absorb delays so that delayed trains return to their scheduled train paths without rescheduling (Goverde and Hansen, 2013)

- **We want to increase Periodic Stability:**
  Using an optimisation model,
  we aim to improve the punctuality.

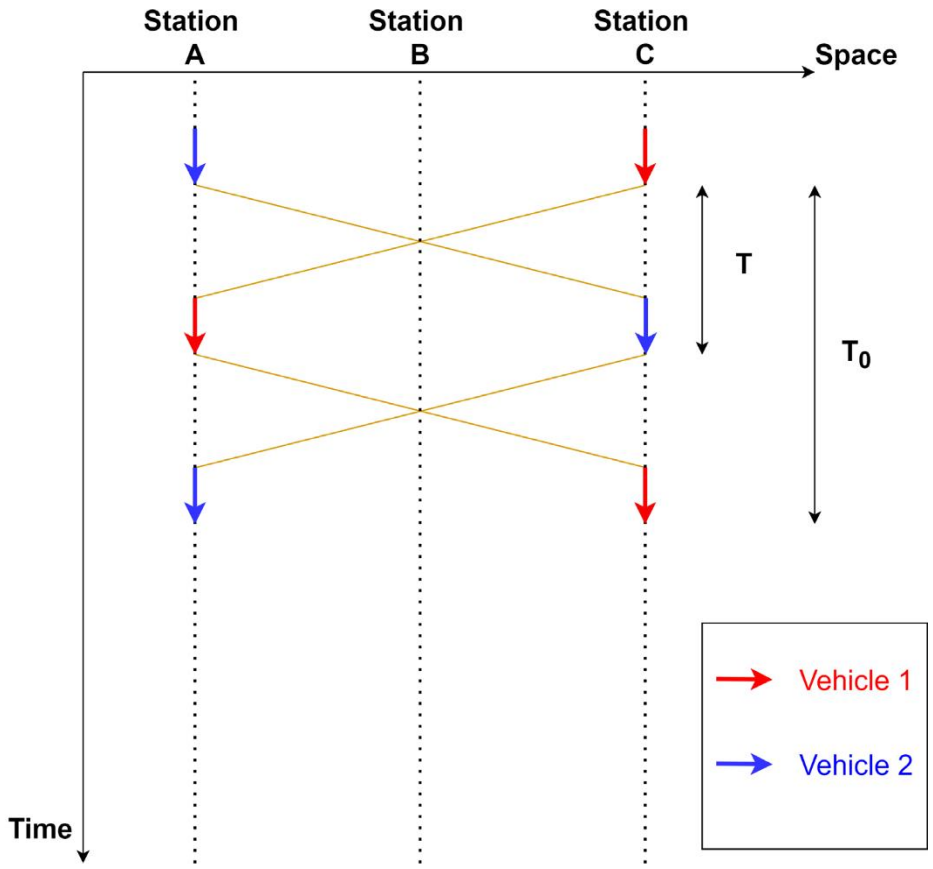


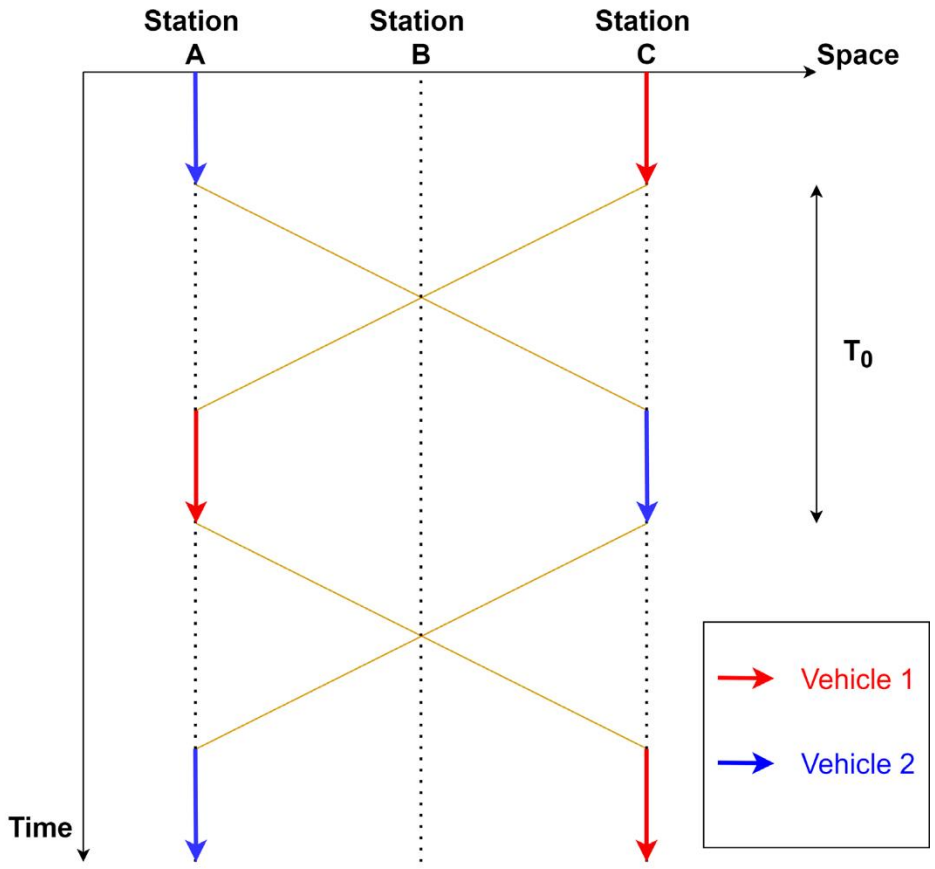
The Idea behind Periodic Stability:
1) Reduce minimal cycle time



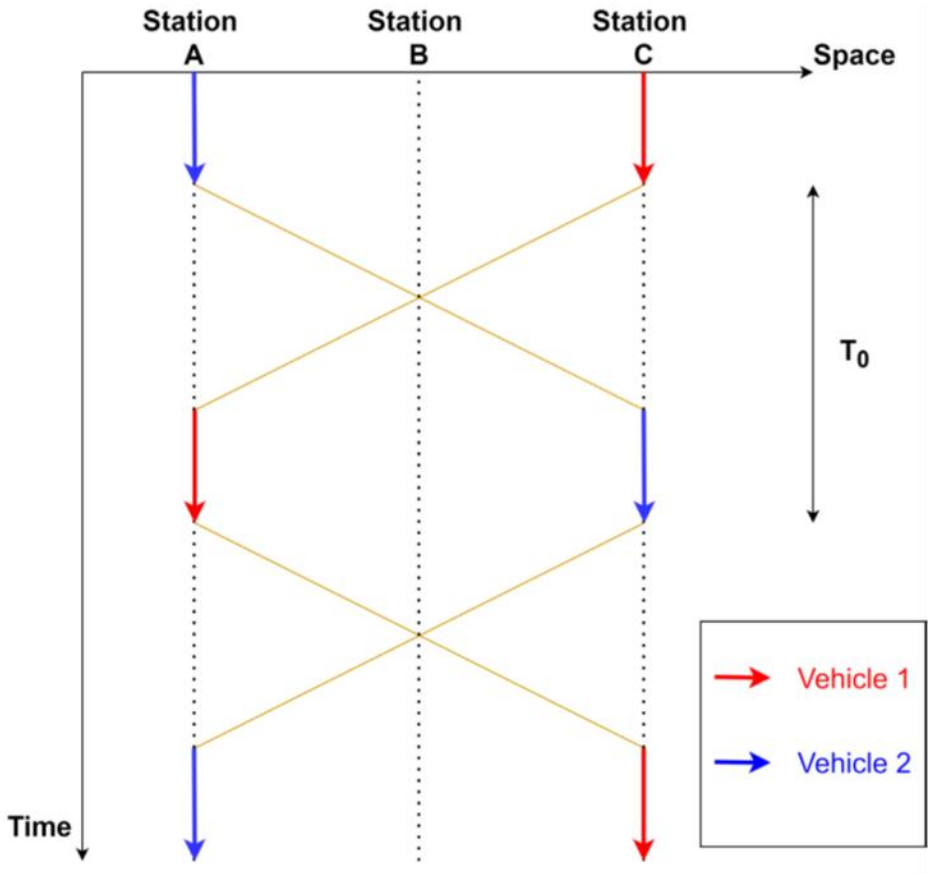


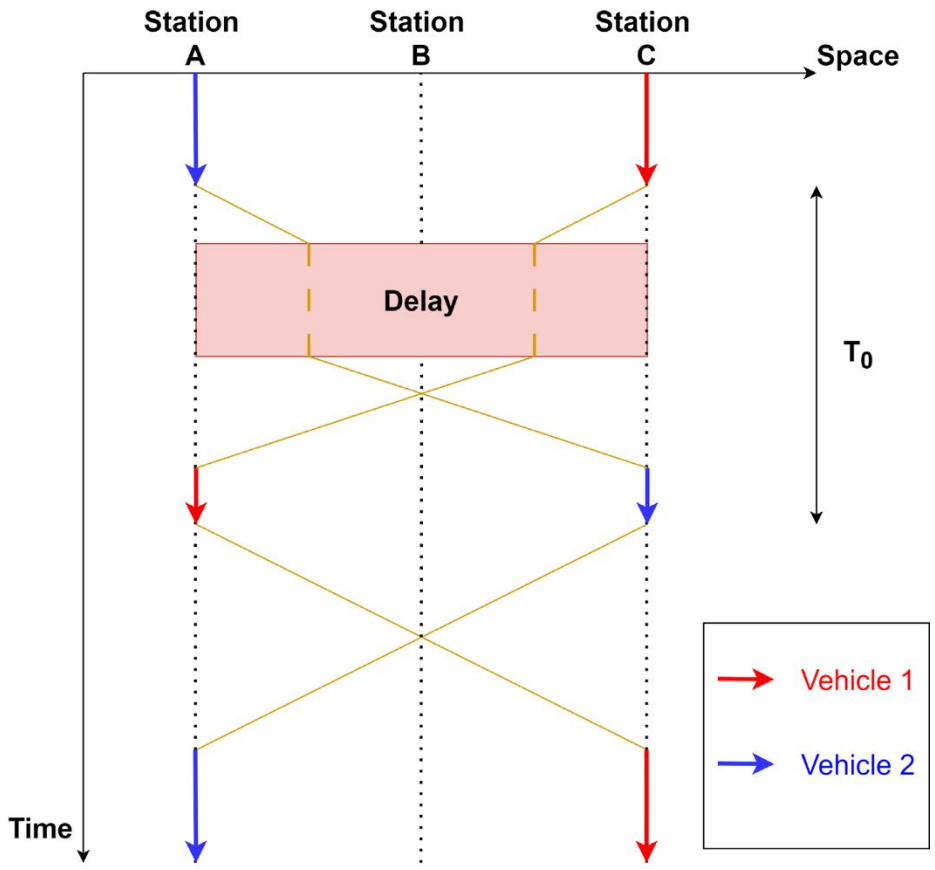
The Idea behind Periodic Stability:
2) Re-scale to original period (T_0)



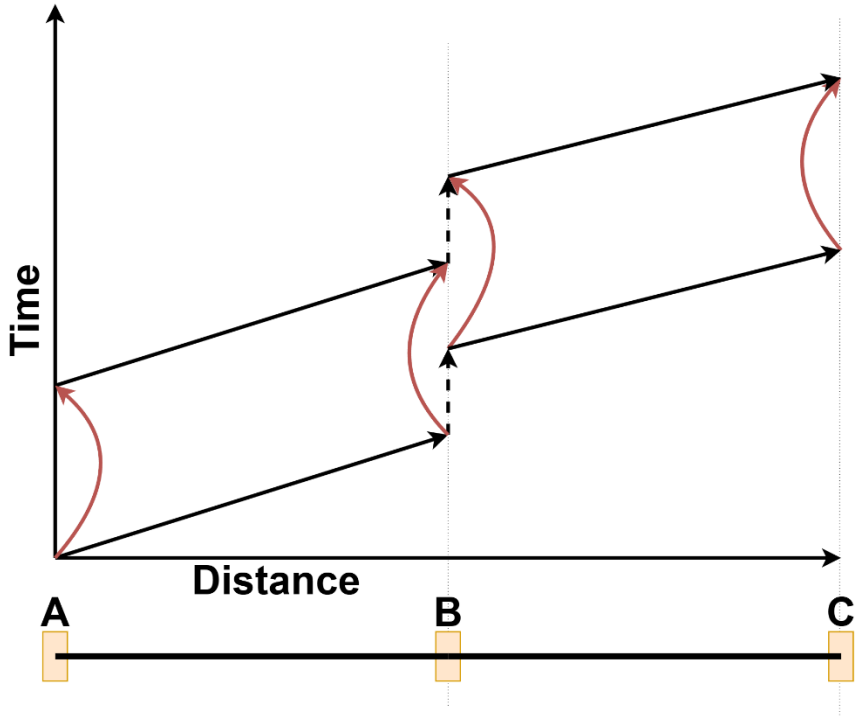


The Idea behind Periodic Stability:
3) Absorb Delays





Basic of timetabling:
The two ways of modelling of conflicts



Time-Based separation (Macroscopic Modelling)

Our contribution:
A Microscopic Model to find the minimal cycle time in Networks

- **Resource-based train separation**
  Model infrastructure use explicitly with resource-based conflicts (blocking time)

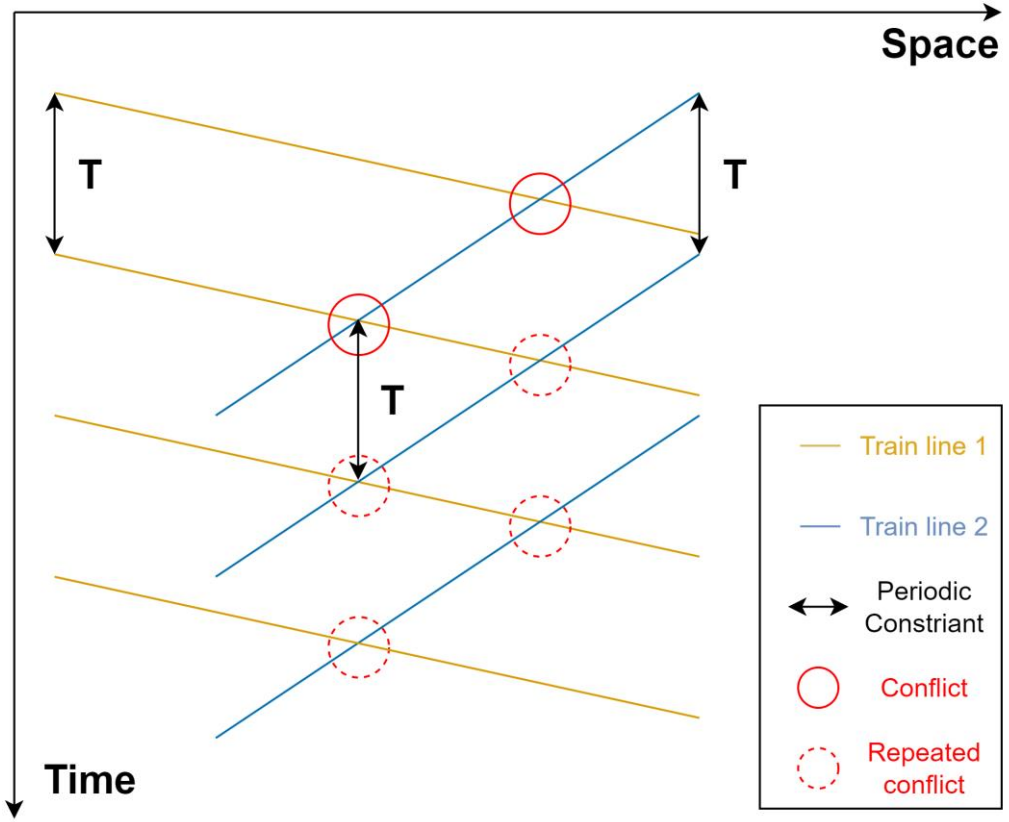
- **Integrated train routing**
  Optimise over train orders and routes

- **Include commercial interactions**
  Model transfers and vehicle circulation to assess the impact

Approach:

Our Model:
Consider Sufficiently many Repetitions

- **Not PESP based**
  Use time-expanded formulation instead.
- **Based on job-shop scheduling**
  Explicit enforcement of periodicity.
- **Conflicts recur periodically**
  Only limited number of repetitions needed.



Improved Scalability with SMT

Issue: Solving the MIP-Formulation is very challenging

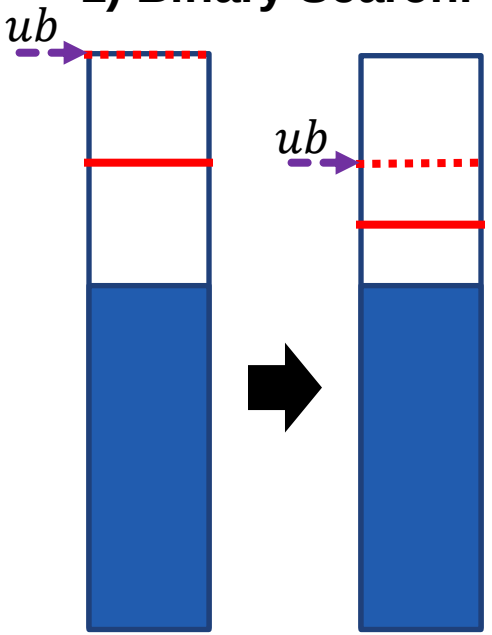
Solution: Use SMT to find T_{min}

Extend Boolean Satisfiability (SAT), with difference constraints (SMT)

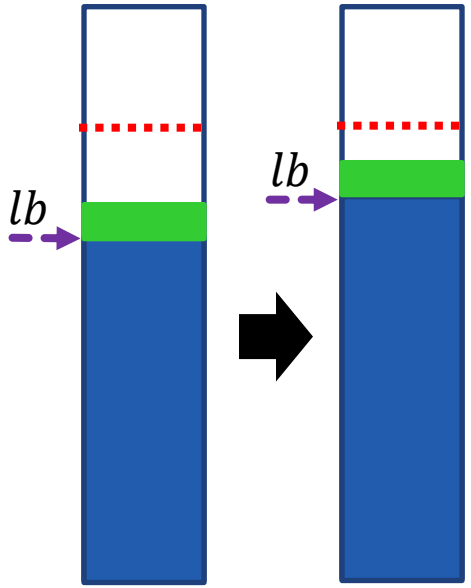
1) Binary search for upper bound

2) Linear search for lower bound

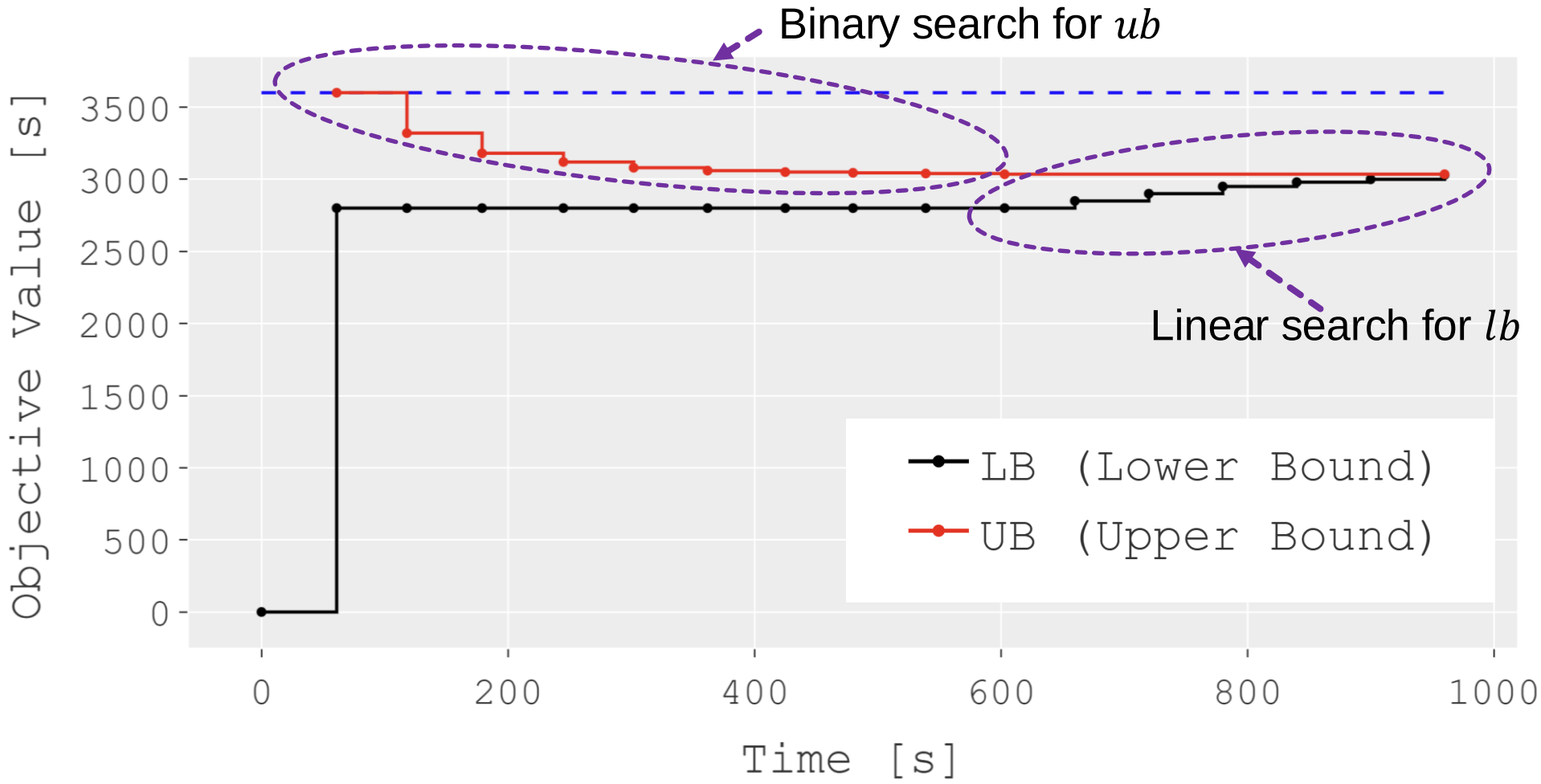
1) Binary Search:



2) Linear Search:

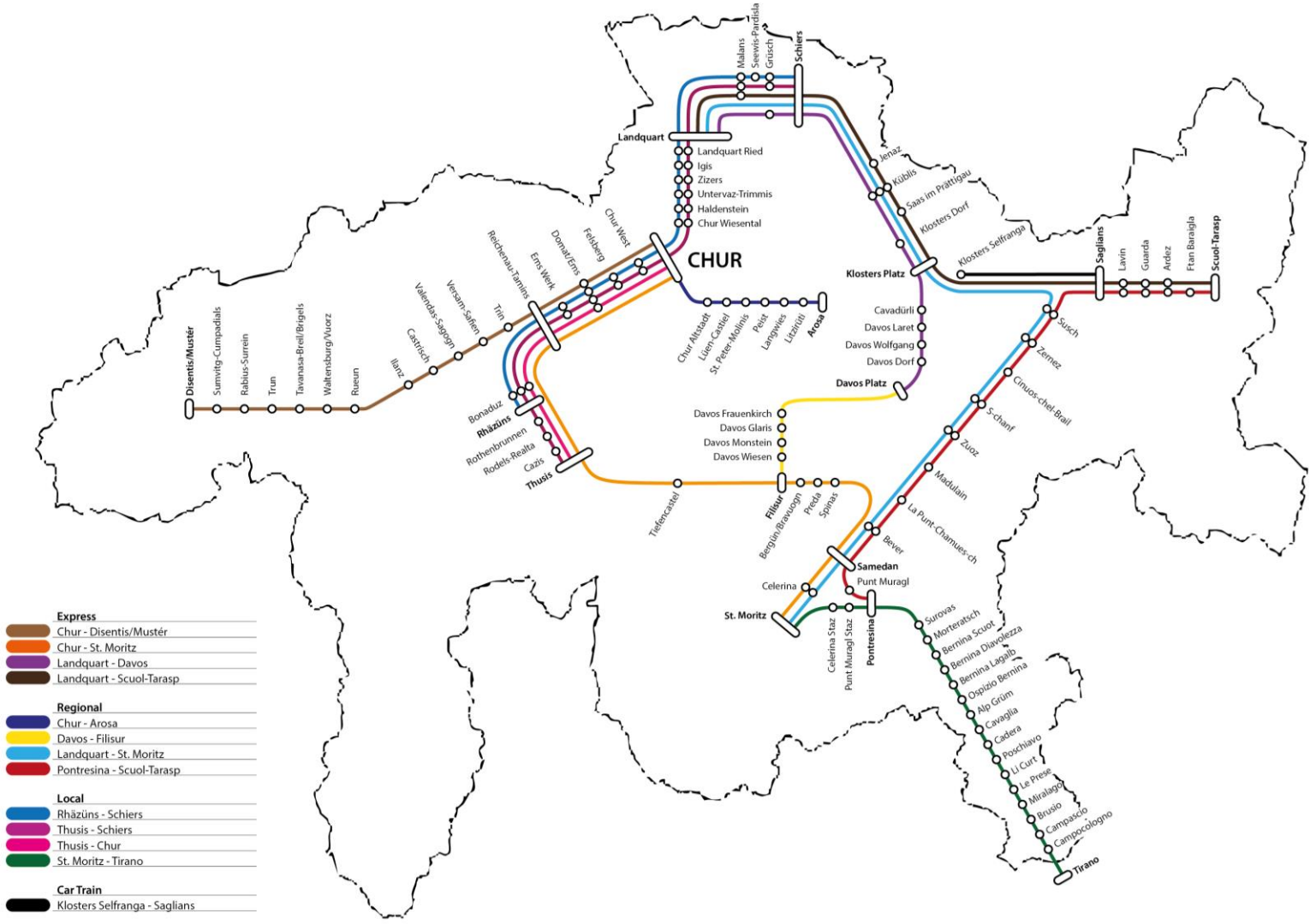


Scalability with SMT-based Algorithm
Example showing convergence



Case Study:

Line Plan of Rhätische Bahn (2023)



Characteristics:

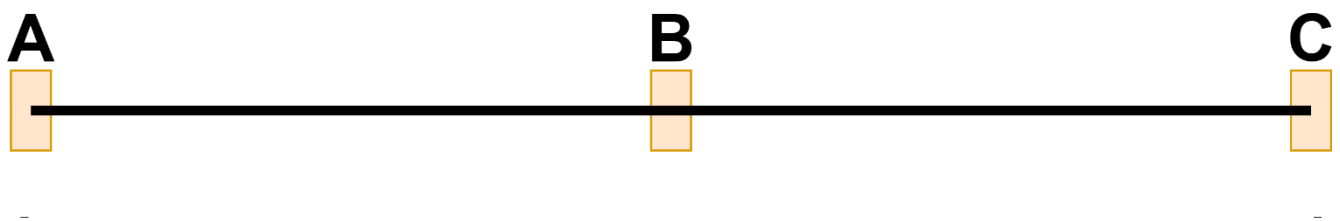
Network:

- 384 km tracks
- 102 stations
- Mostly single track

Timetable:

- 28 Trains
- 72 951 Conflicts
- 1307 Routing Decisions

Commercial constraints: Limiting the Local (L) and Global (G) Slack

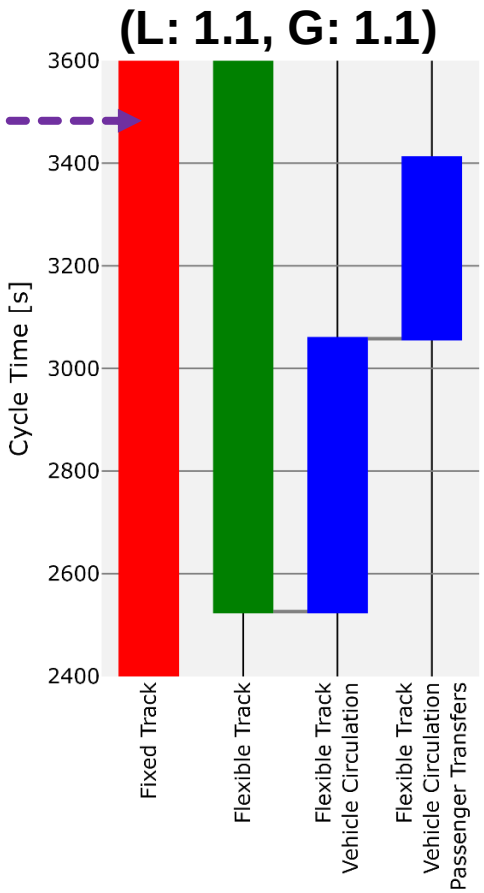


To avoid excessive travel times, we limit the maximum allowed time

- L: Local Slack
  Between two commercial stops
- G: Global Slack
  Between two termini

Impact of Constraints on T_{min}
Resource Based Separation (Microscopic Model)

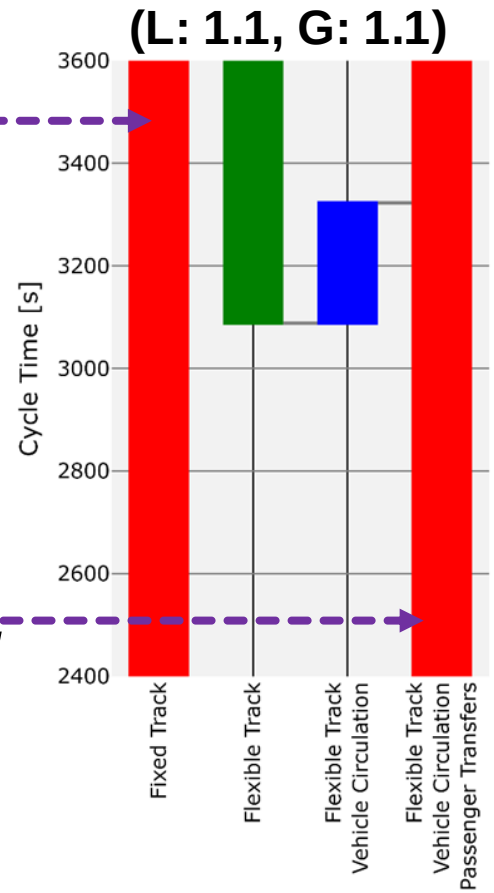
Infeasible with fixed track



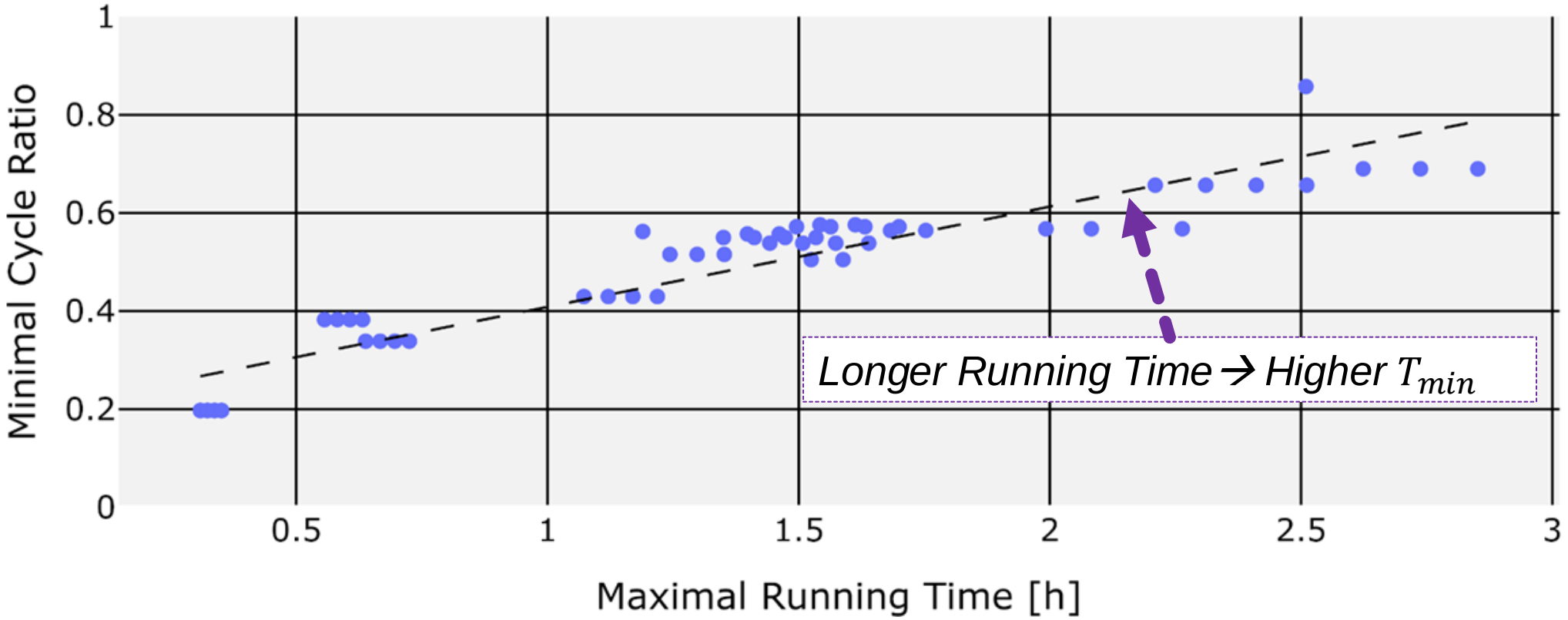
Impact of Constraints on T_{min}
Time Based Separation (Macroscopic Model)

Infeasible with fixed track

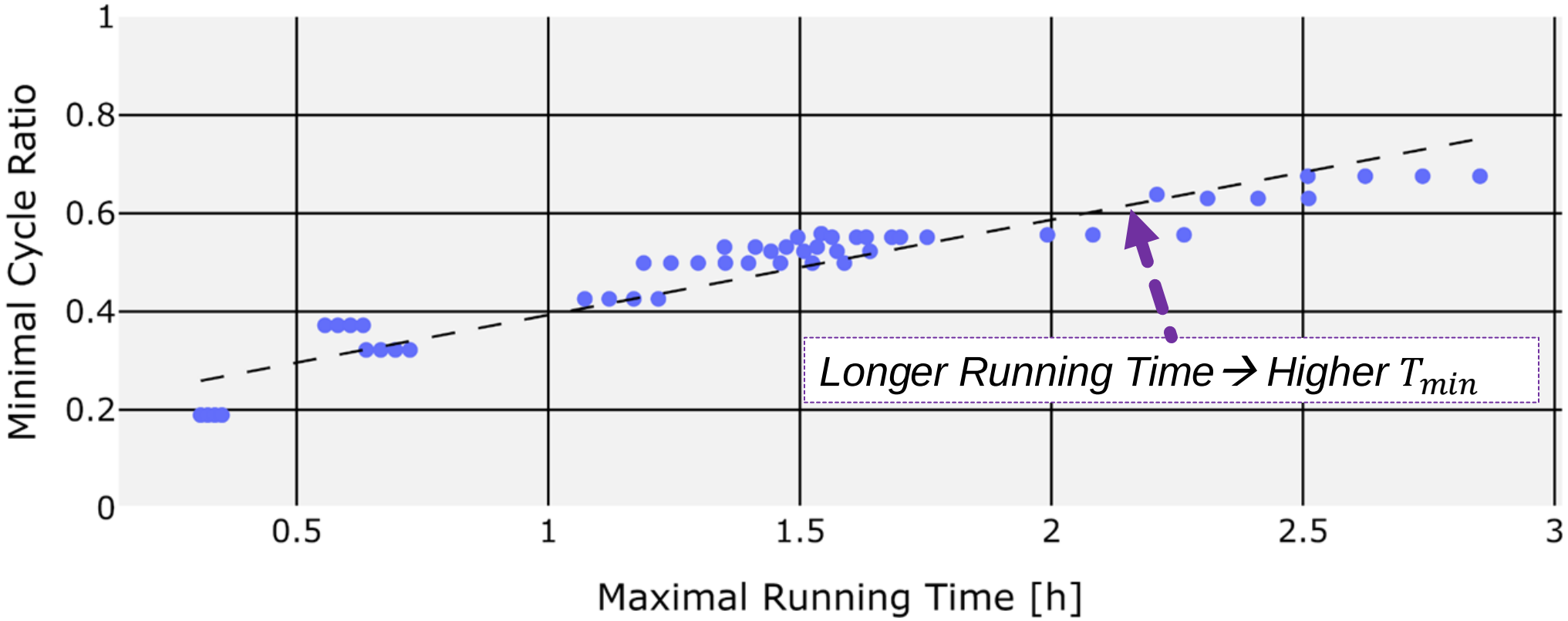
Infeasible with all commercial constraints



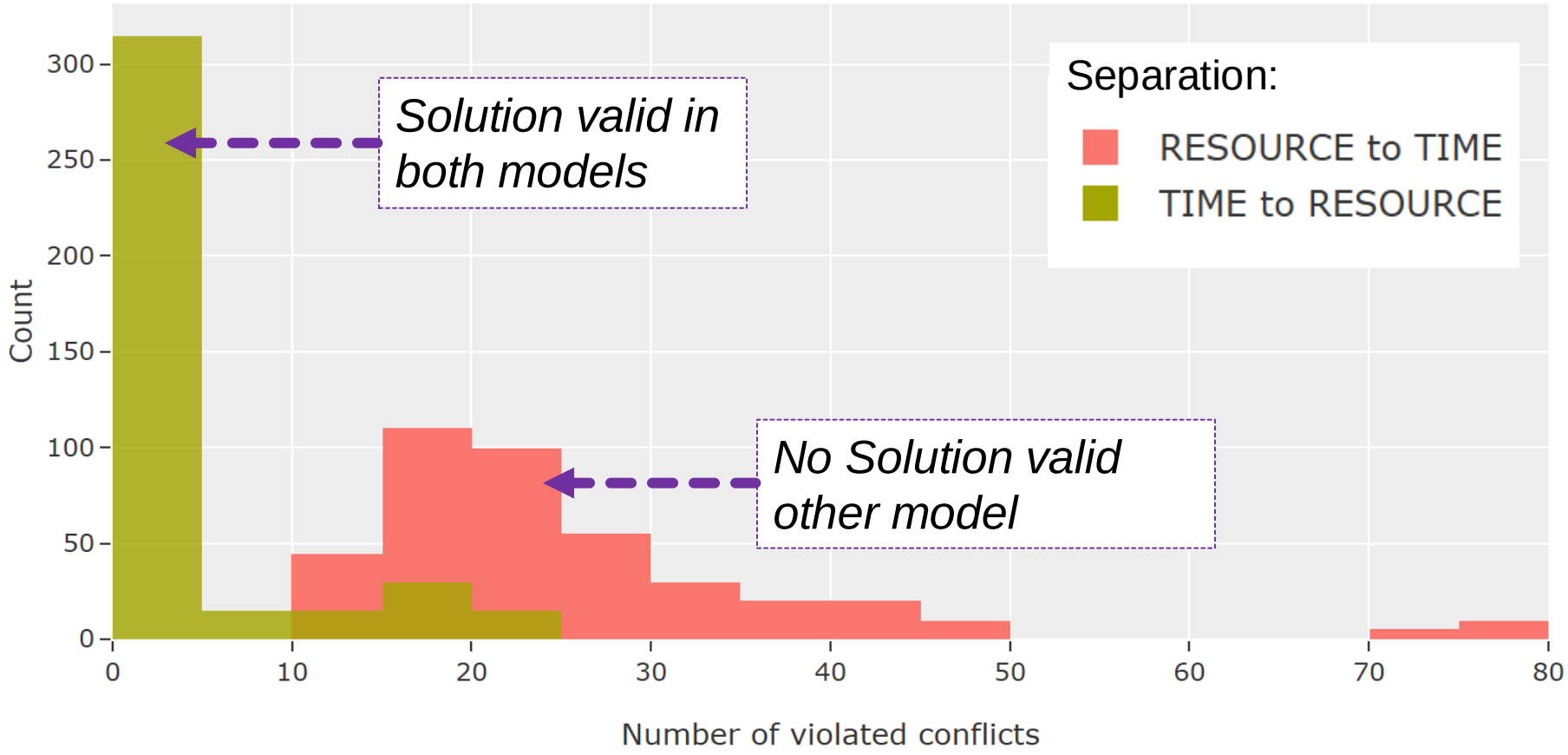
Effect of Line length on Minimal Cycle Ratio (T_{min}/T_0) Resource-Based Separation (Microscopic Model)



Effect of Line length on Minimal Cycle Ratio (T_{min}/T_0)
Time-Based Separation (Macroscopic Model)



Exchangeability of Solutions:
Making Conflicts «Soft» to Transform Results Between the Models



Conclusion:

- **Effect of train routing**:
  Including the flexibility of routing enables lower cycle times

- **Impact of total running time**:
  The longer a line, the higher (worse) the minimal cycle time

- **Difference between MICRO and MACRO:**
  a) The time-based separation (macroscopic) model leads to higher (worse) minimal cycle time.
  b) Transforming time-based solutions to resource-based violates less conflicts than a transformation vice-versa

Questions / Discussion

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