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Combining optimization and simulation to improve railway timetable robustness

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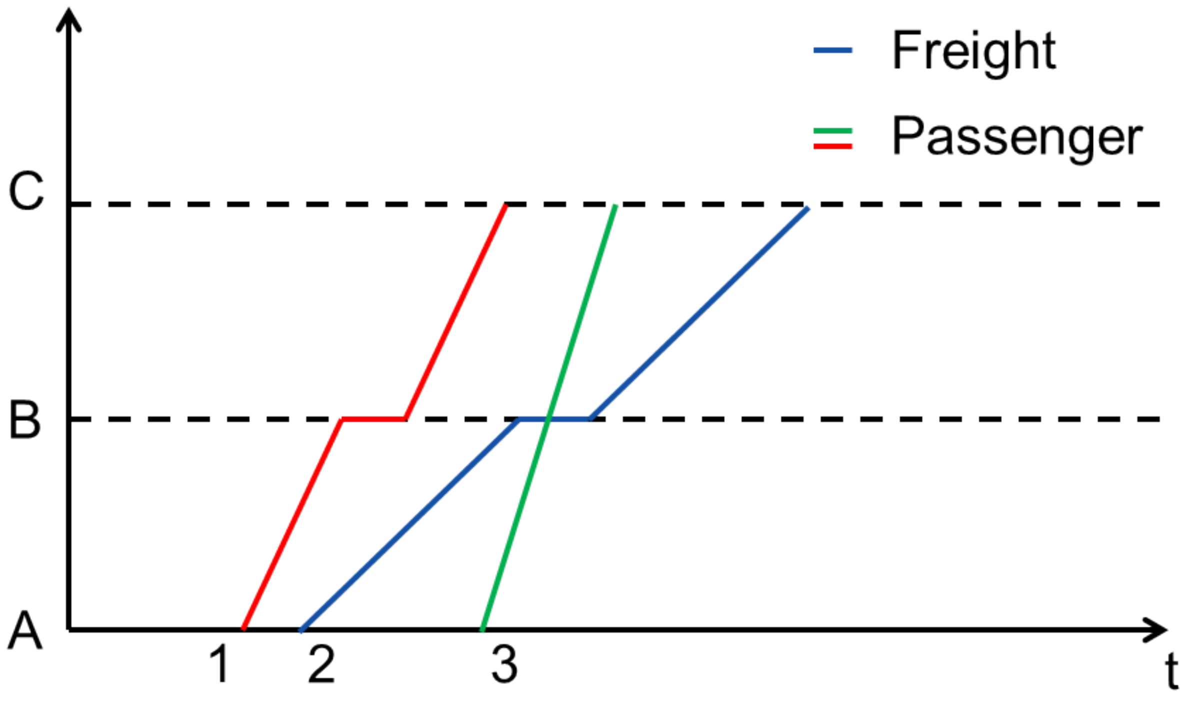
Background

- Timetables are constructed to maximize quality parameters (e.g. punctuality, travel time, frequency of travel, etc.)
- However, quality parameters depend also on a large number of complex factors incl. other trains and the infrastructure (signals, switches, etc.)
- Real-world quality data exists only for traffic that actually happened.

Combining simulation and optimization

- Use microscopic simulation to generate data for a large number of timetables.
- Base decisions on this data, through multi-criteria timetable optimization.
- Advantages:
  - Simulation allow estimation of delays for new timetables
  - Optimization allows the “best” timetables to be found.
- Future: iteration to find local optima, random sampling to approximate global optima.

A simple example



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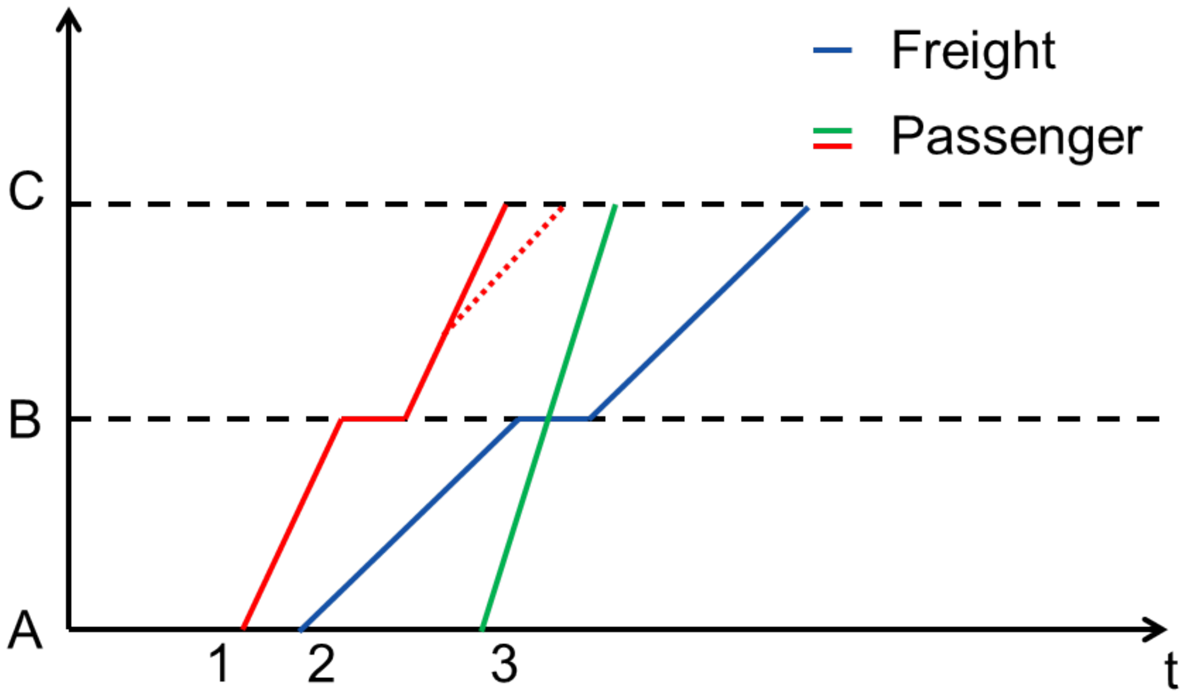

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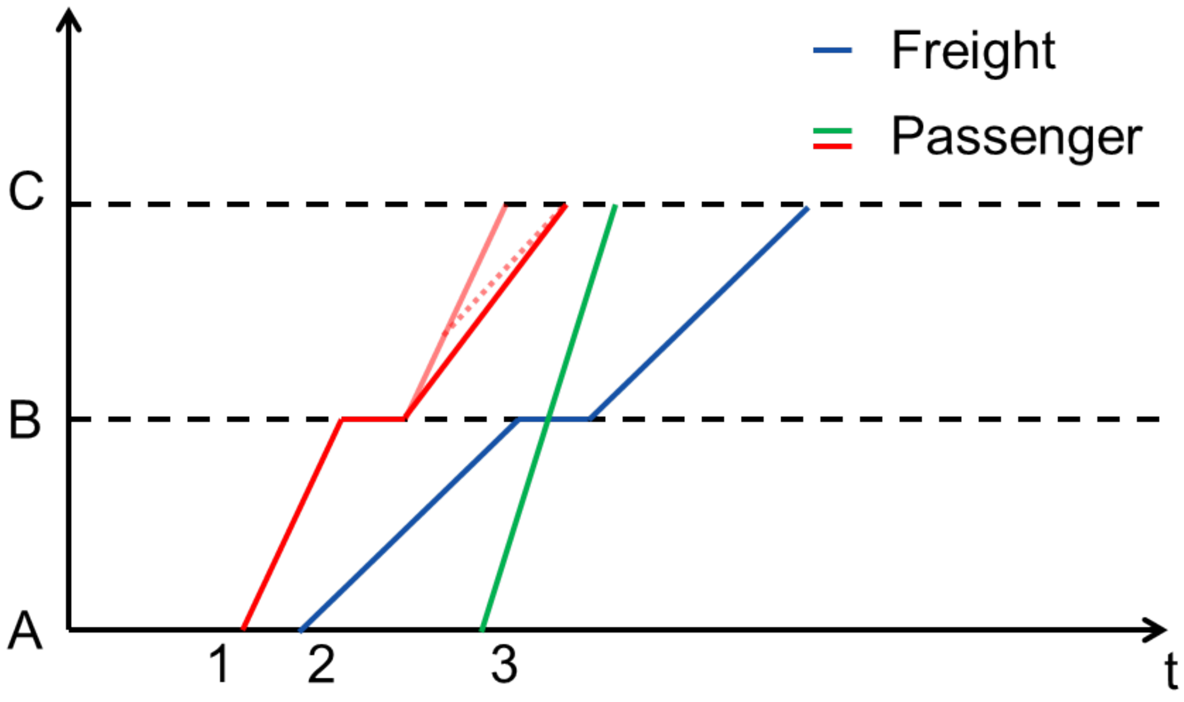

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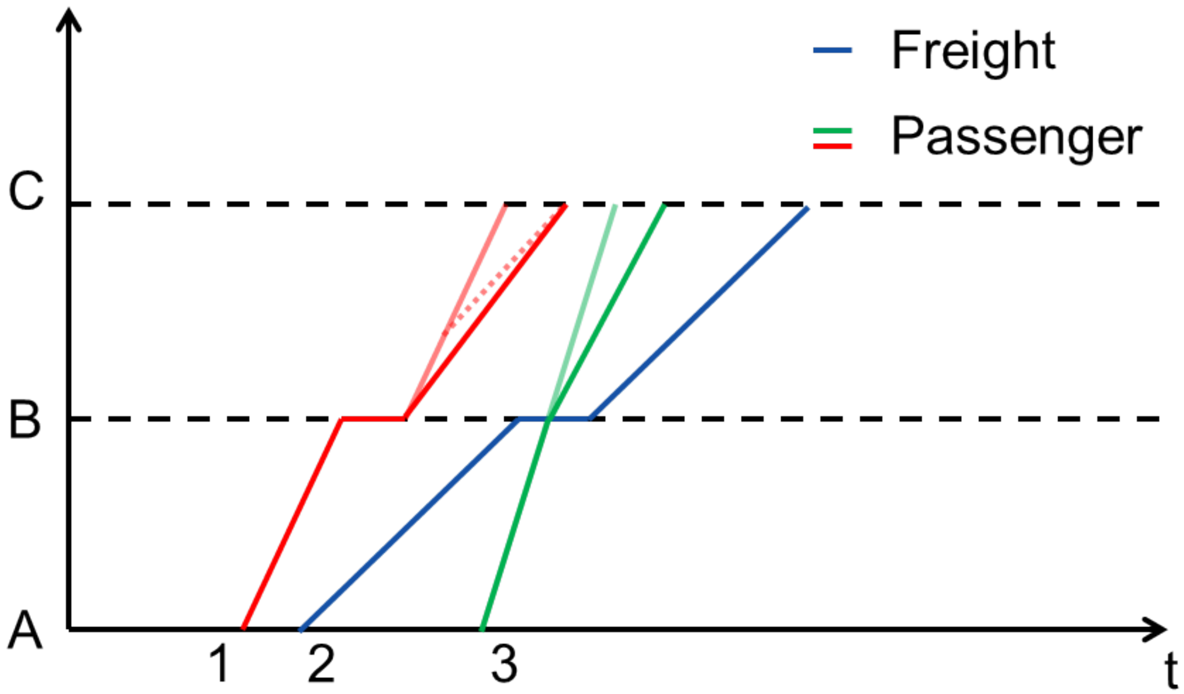
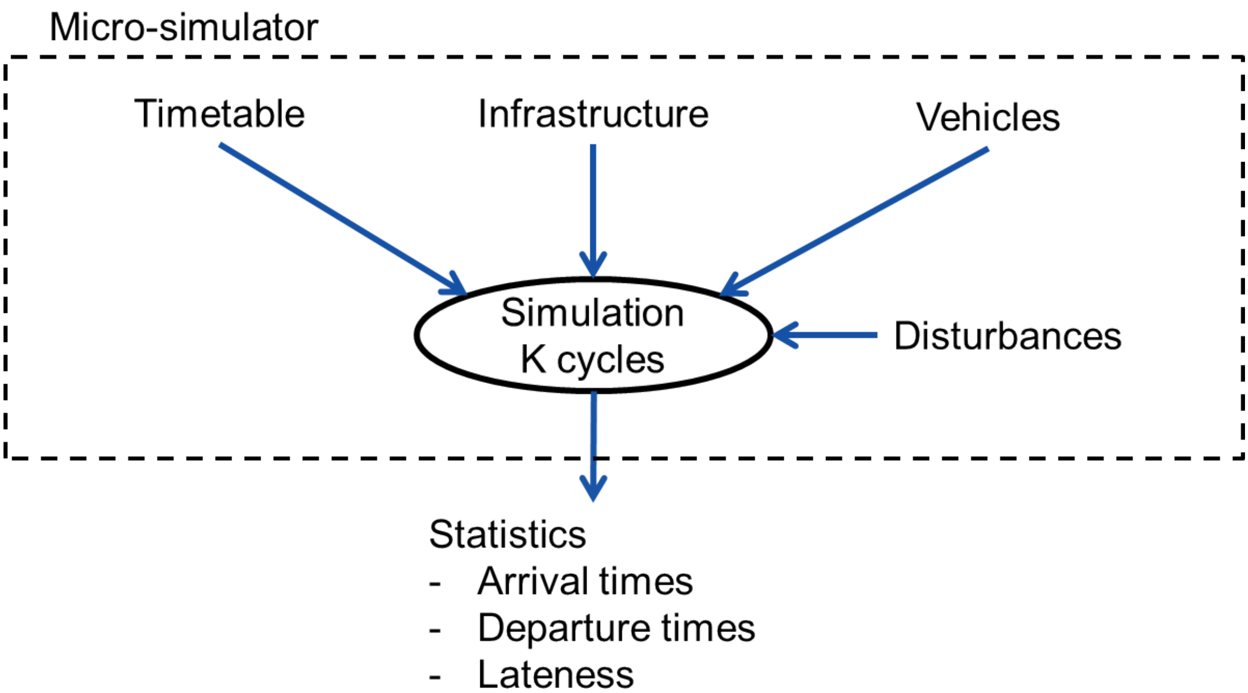
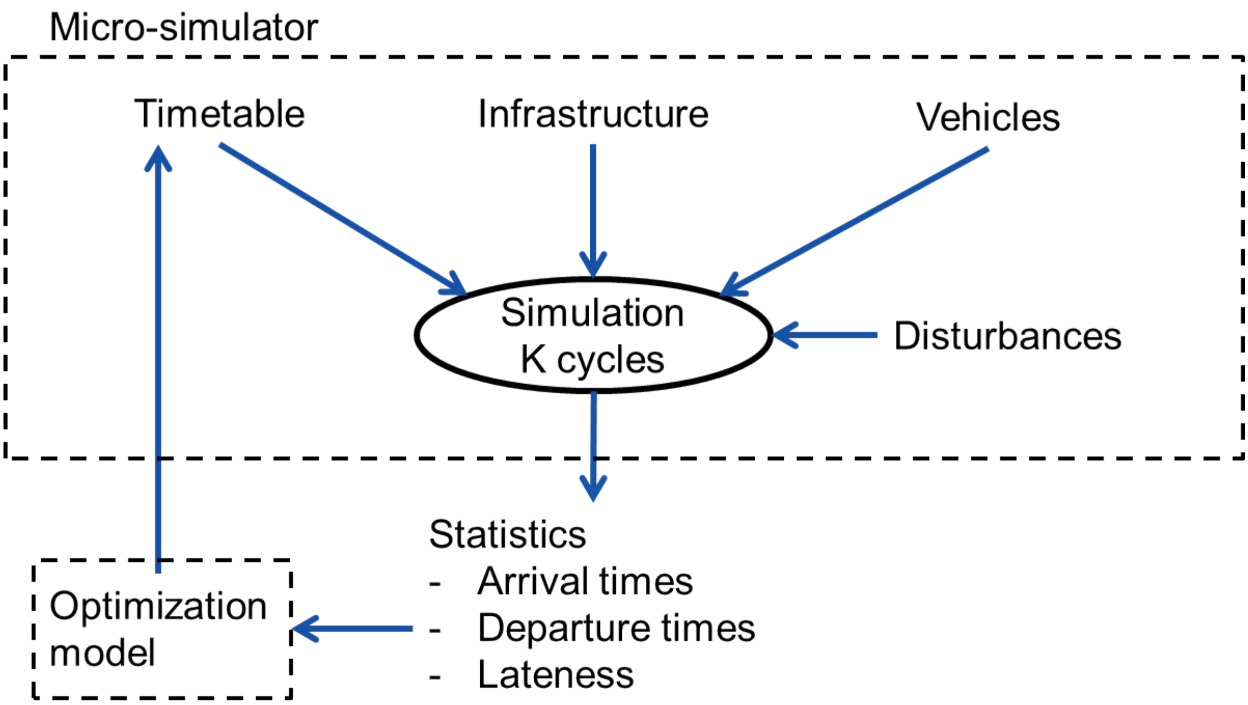


Method overview



Method overview



Method overview - The optimization model

Sets

- T - the set of trains
- S - the set of stations
- X - the set of feasible timetables
- E_s - the set of events at station s

Parameters

- $\bar{t}_i^h$ - the time of event i for train h in the input timetable
- $\bar{x}_{i,j}^{h,k}$ - the order of event i and j for train h and k, respectively, in the input timetable.

Decision variables

- t_i^h - the time of event i for train h.
- $x_{i,j}^{h,k}$ - the order of event i and j for train h and k, respectively.

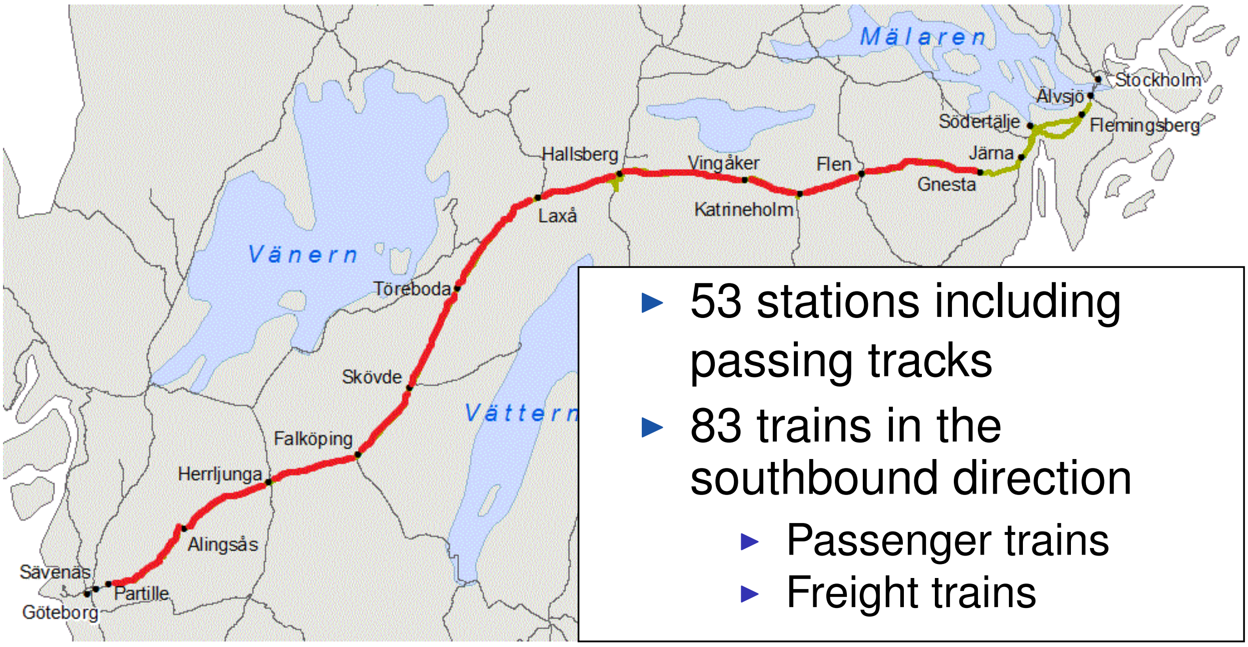
Method overview - The optimization model

We are considering the following timetabling problem:

$$\begin{array}{rrcll} \text{minimize} & f(t) = \alpha F(t) + (1-\alpha)\, G(t) & & & \\ \text{s. t.} & t & \in & X, & \\ & x_{i,j}^{h,k} & = & \bar{x}_{i,j}^{h,k}, & \forall (h,i),(k,j) \in E_s, \forall s \in S, \\ & & & & (h,i) \neq (k,j), \\ & t_1^h & = & \bar{t}_1^h, & \forall h \in T \end{array}$$

- $F(t)$ - total scheduled travel time for the passengers and freight.
- $G(t)$ - total predicted delay for the passenger and freight.
- α - a weighting parameter to balance the importance of F and G.

Computational experiment



- 53 stations including passing tracks
- 83 trains in the southbound direction
  - Passenger trains
  - Freight trains

Computational experiment

Experiment overview

1. The initial timetable have been simulated 200 cycles. The duration of each simulation cycles is from 5 AM to 6 PM. (All train that operates between 5AM and 12PM have been selected)
2. The arrival times have been extracted to compute the delay distributions.
3. The optimization problem have been solved for 100 values of α.
4. 11 timetables have been selected for validation.

Validation

- The timetable have been simulated 50 cycles and the punctuality have been evaluated.

Computational experiment - Results

- Each value of α represents an optimized timetable.
- A smaller value on α - increased importance of minimizing delays.

	Value of α					
Max delay	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**Input**
0	49.9	47.9	41.8	27.1	2.8	34.8
1	92.1	90.8	82.7	68.1	48.4	85.9
3	98.4	98.0	96.3	87.5	81.5	97.2

- Note: result is a convex upper hull of the Pareto frontier (not the exact frontier).

Conclusions and future work

Conclusions

- Based on the results from the experiments it seems possible to improve punctuality by combining optimization and simulation as suggested.
- The method does give one timetable which is the "best". Other methods and aspect may have to be considered to choose one timetable.
- The results indicate that the punctuality might be sensitive to small changes in the timetable.

Future work

- Evaluate the performance when the method is iterated.
- Model more complex networks and single track sections.
- Improve the delay predictor.