Optimal allocation of buffer times to increase train schedule robustness

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KAJT dagarna, 27 April 2016

Dala Storsund

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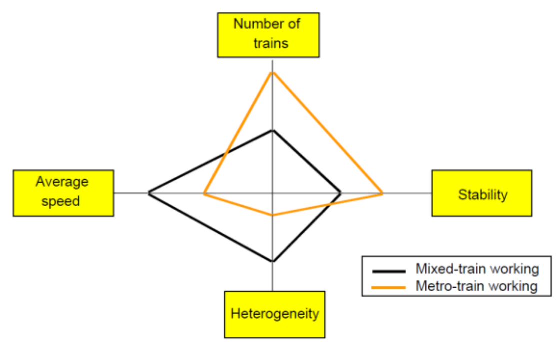
Contents

- Introduction and motivation
- Knapsack problem approach
- Parameter computation
- Case study and results

Capacity4Rail WP3.2

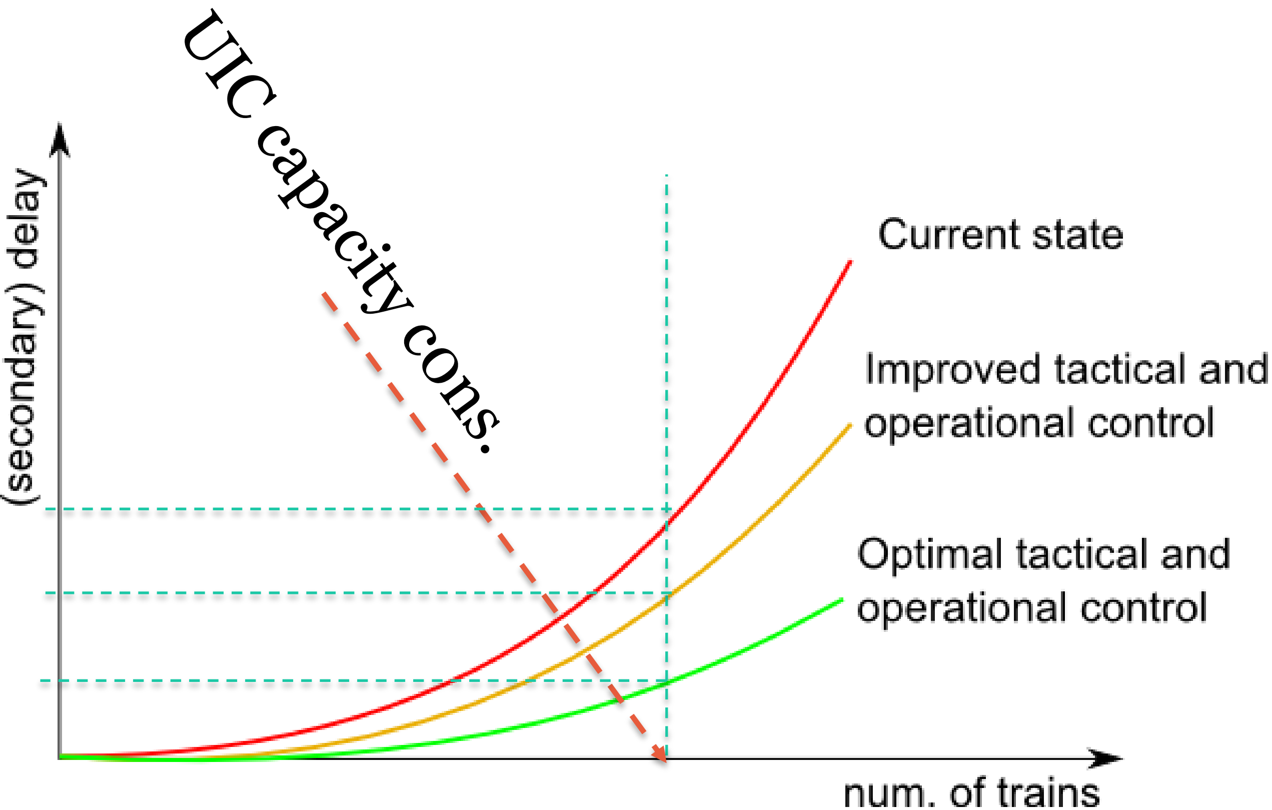
- Simulation and models to evaluate enhanced capacity
- The aim of this task is to evaluate existing tools for their suitability to assess and ***improve*** capacity utilization
- ”Capacity depends on the way it is utilised” (UIC 406)
- Timetabling (and traffic control) determine the way capacity is utilised

Timetabling & Traffic control



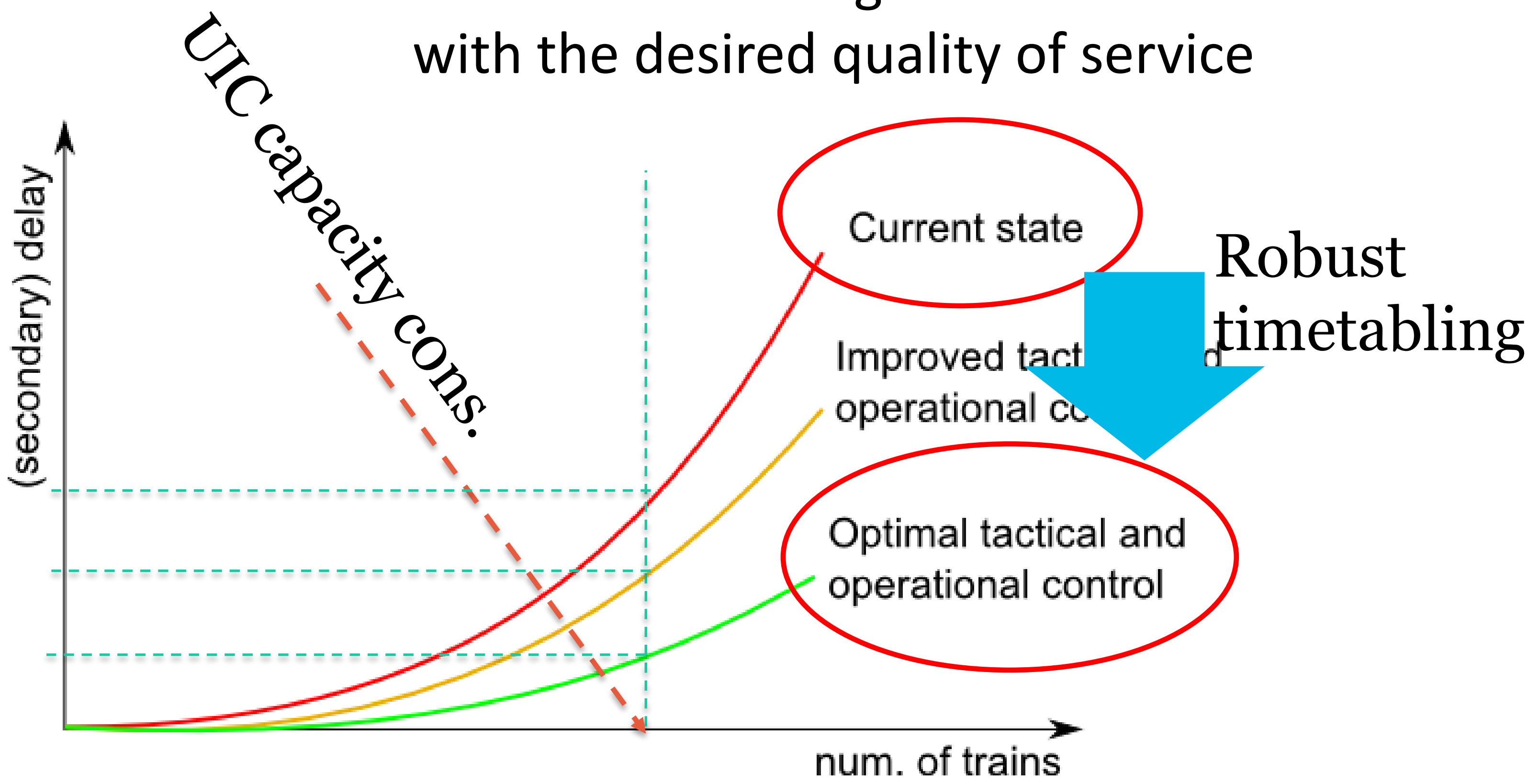
UIC 406

Timetabling – C4R Perspective

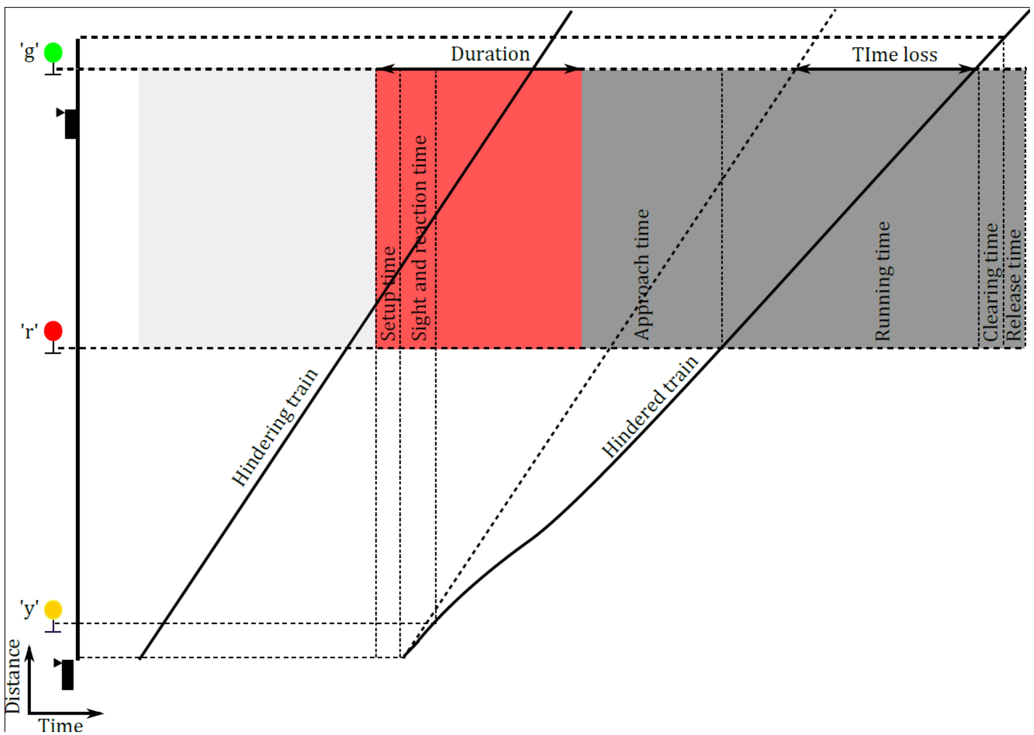


Research question

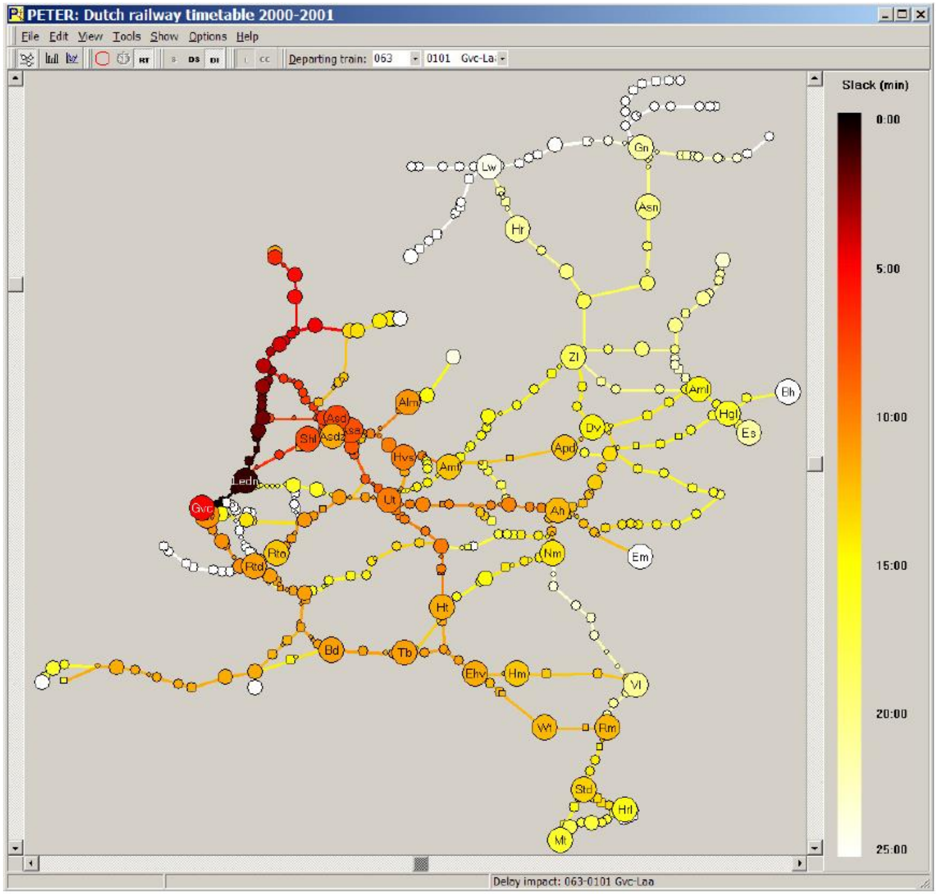
Robust timetabling enable more trains to run with the desired quality of service



Delay propagation - microscopic

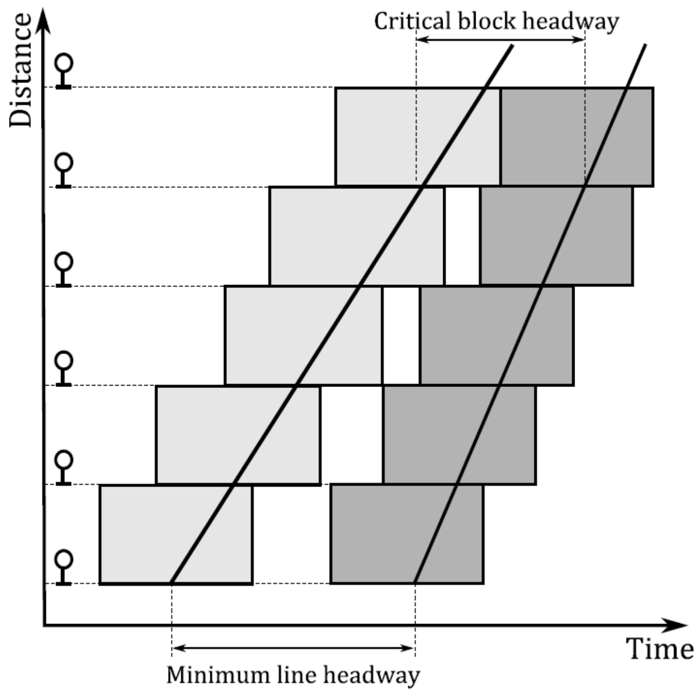


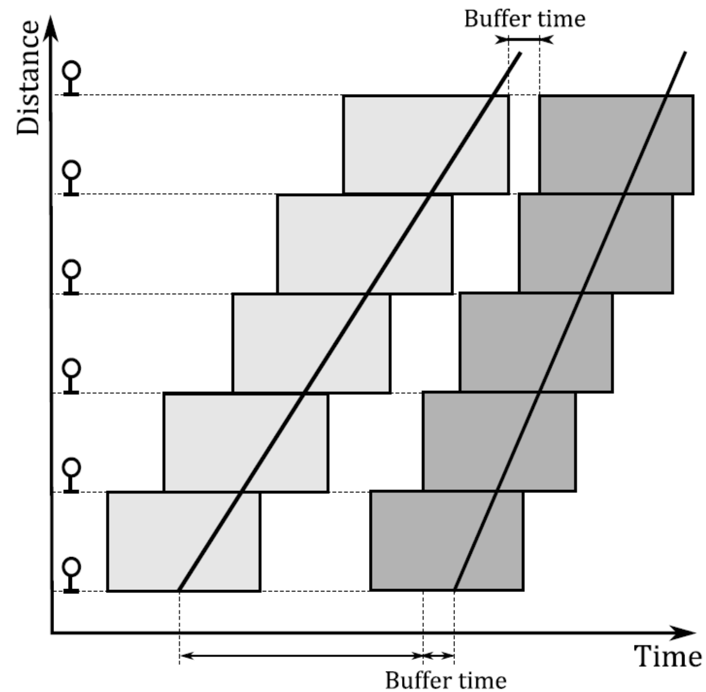
Delay propagation - macroscopic



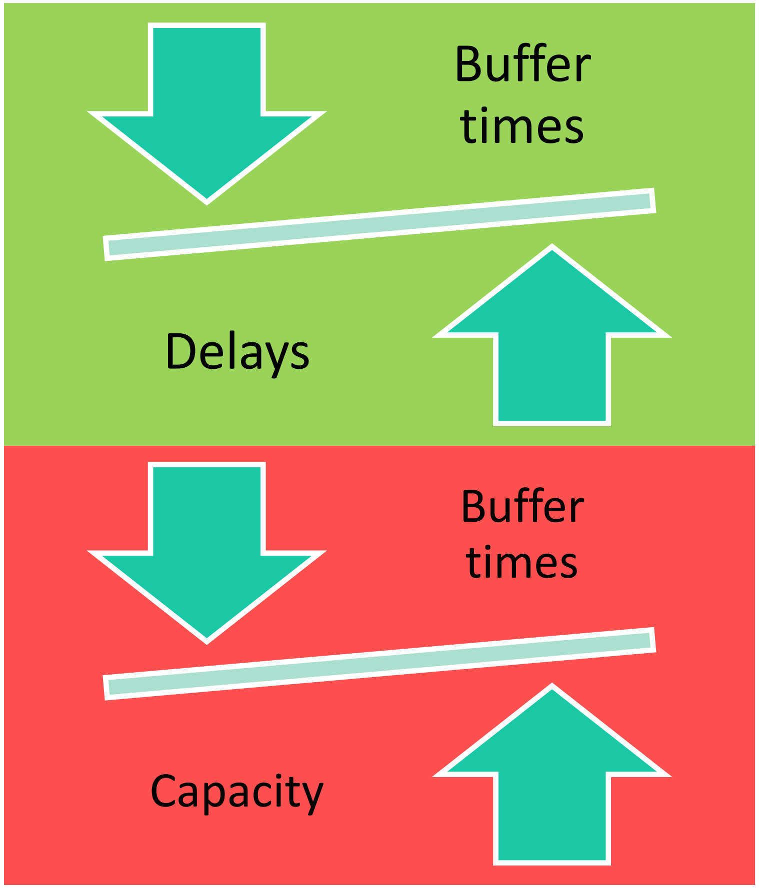
Source: Goverde, R.M.P. Punctuality of Railway Operations and Timetable Stability Analysis, Ph.D. Thesis, TU Delft.

Solution - Buffer times





Another problem



Existing solutions

Robust optimisation:

+ Attacks general problems

- Very difficult to solve

Domain knowledge used to relax the problem:

+ Emma: Critical points

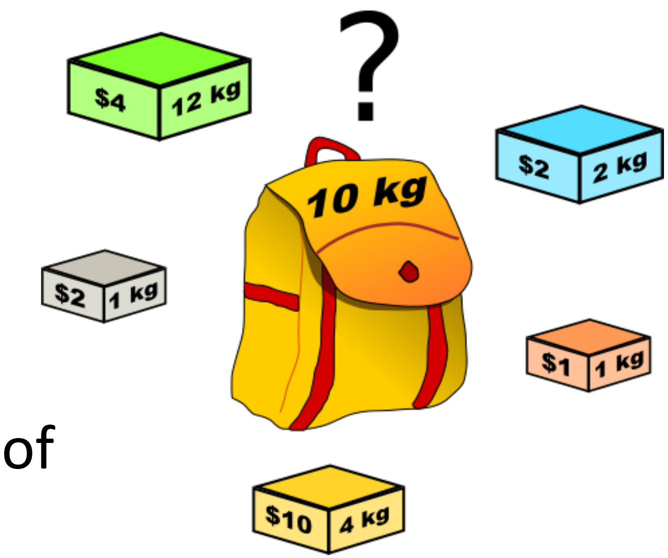
+ Fahimeh: Travel time dependent buffering

Produce a general solution using the domain knowledge

Problem definition

- Input – Timetable A
  - Number of trains
  - Scheduled running and dwell times
  - Fixed train sequence
  - Time window constraint
- Output – Timetable B
  - All properties of Timeble A are kept
  - Buffer times (re)distributed to increase robustness

Knapsack problem (1/2)



- Hikers wants to go on a trip
- The backpack is small, no more than 10 kg of things in the bag
- He has prepared a list of items that he would like to bring on a trip
- Water, bread, cans, maps & compass, laptop, trousers, jacket, socks & underwear, knife and cutlery, sweater, tent, sleeping bag

Knapsack problem (2/2)

Item	Weight [kg]	Utility: 1 (not useful) to 10 (very useful)
Cans	2.2	7
Water	2	4
Tent	3.5	8
Food	3	8
Jacket	0.5	7
Maps & compass	0.1	10
Sleeping bag	0.8	9
Laptop	1.5	3
Trousers	0.3	6
Socks & underwear	0.2	9
Knife & cutlery	0.5	9
Sweater	0.5	5

Knapsack problem (2/2)

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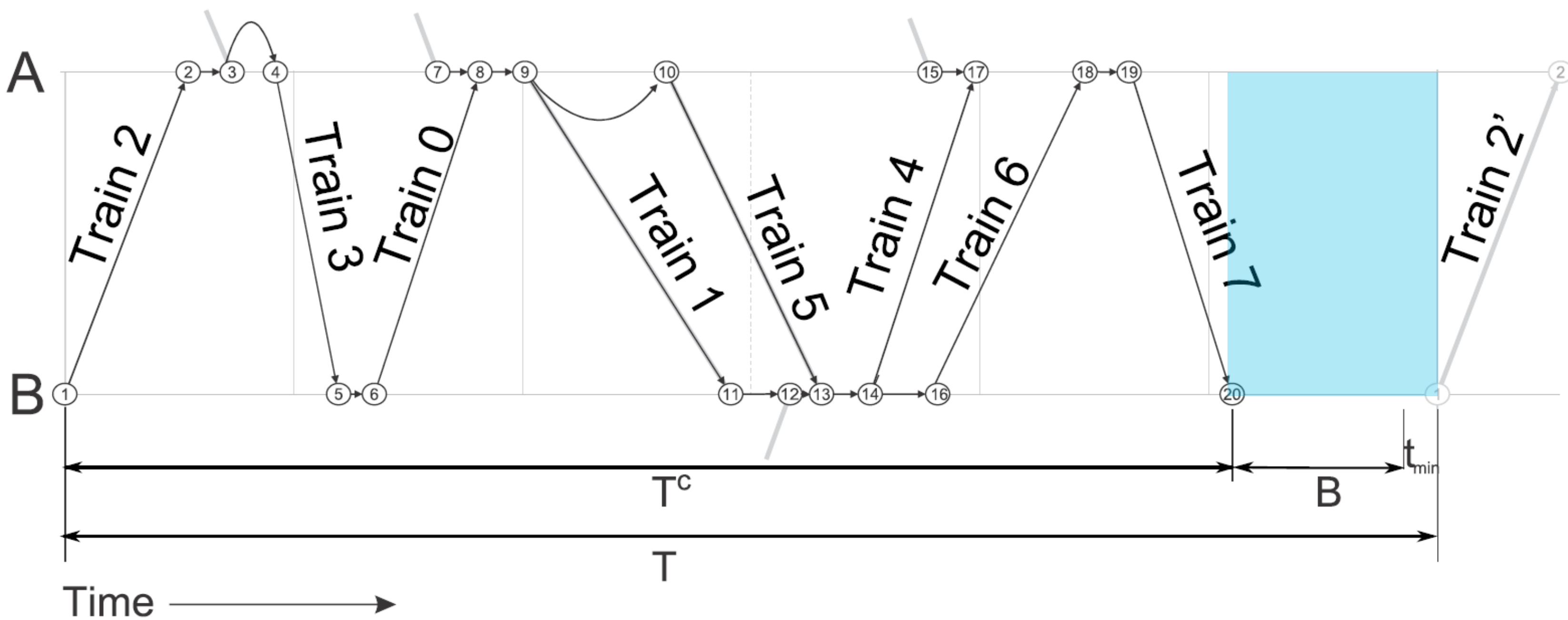
Socks & underwear	0.2	9
Knife & cutlery	0.5	9
Sweater	0.5	5

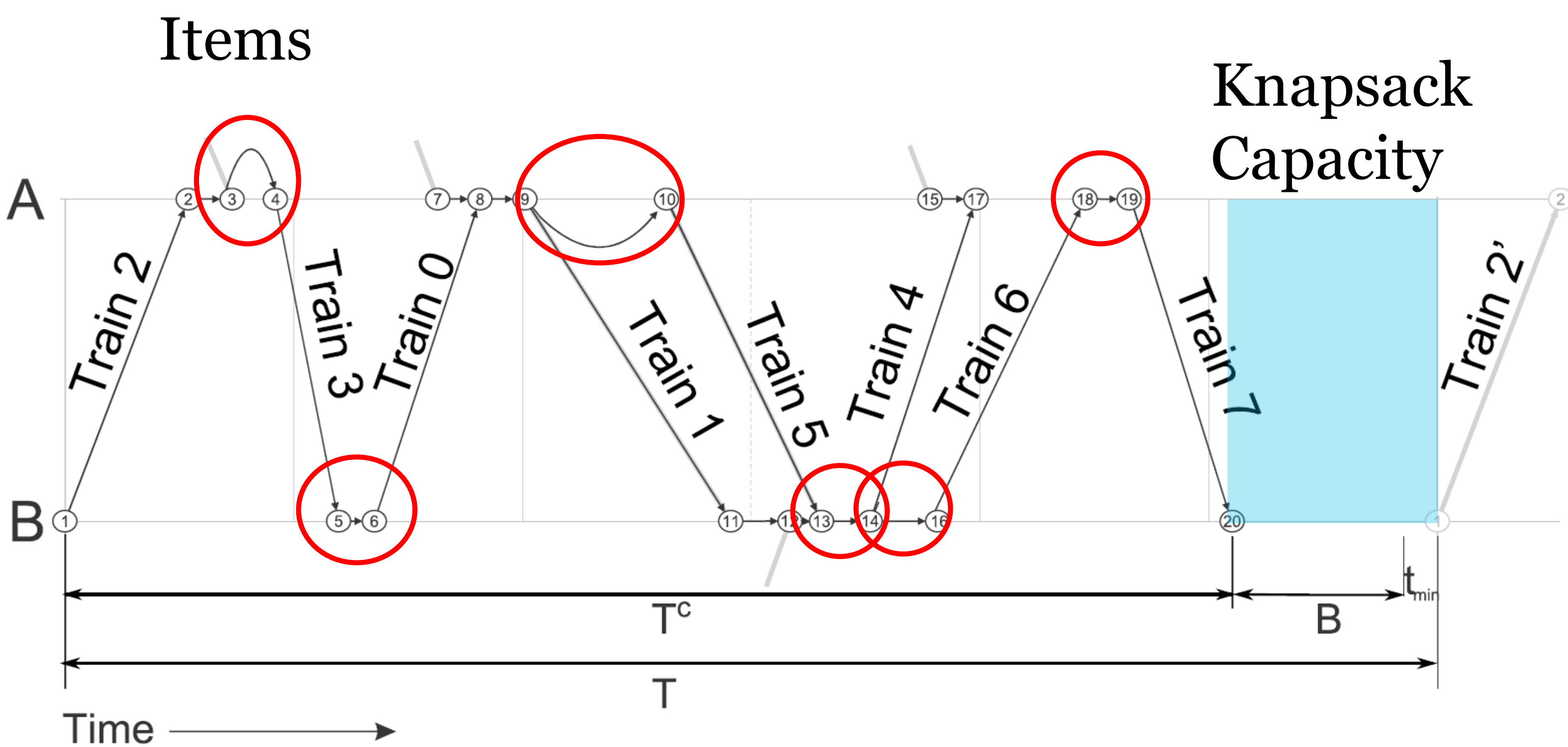
15.1 kg! Which items to bring to maximise utility?

Knapsack problem for buffer times (1/2)

Timetable compression UIC 406 -ish



Knapsack problem for buffer times (1/2)



Knapsack problem for buffer times (2/2)

- How to coordinate multiple sections?
- How to prioritize items (candidates)?
- Marginal profit: is the second minute (time unit) of buffer as valuable as the first? How about the third?

Multidimensional Knapsack Problem

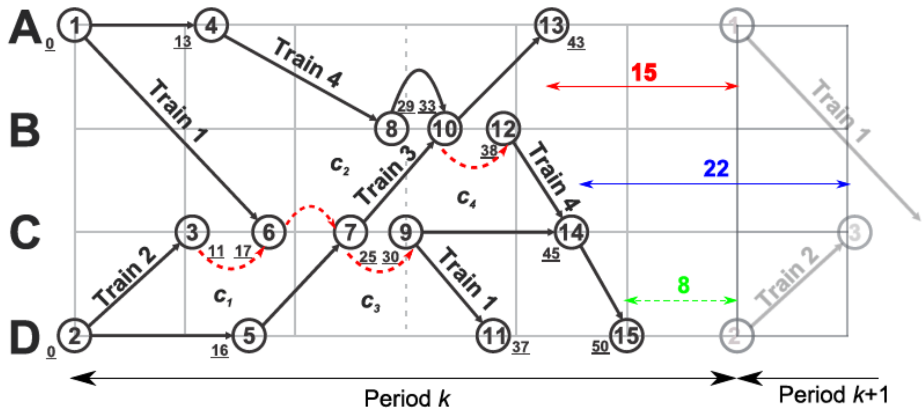


Figure 3: Illustrative example for the knapsack capacity

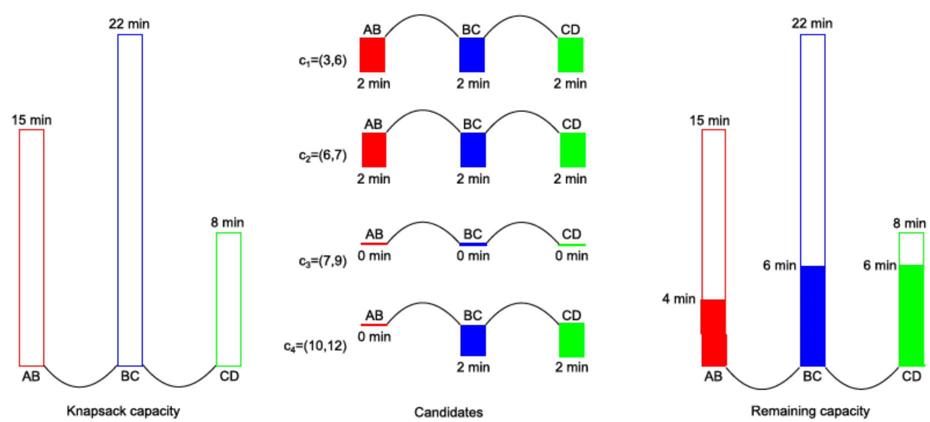
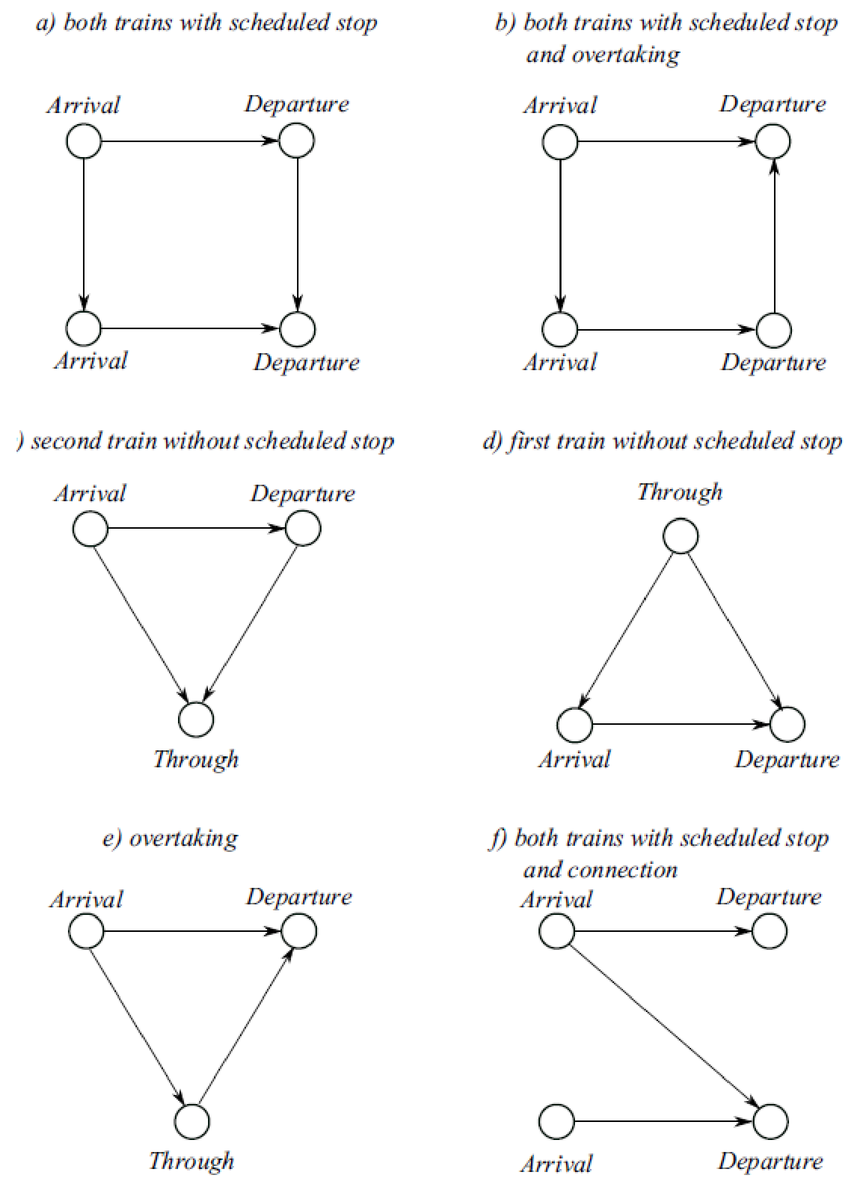


Figure 4: Illustrative example for the knapsack capacity

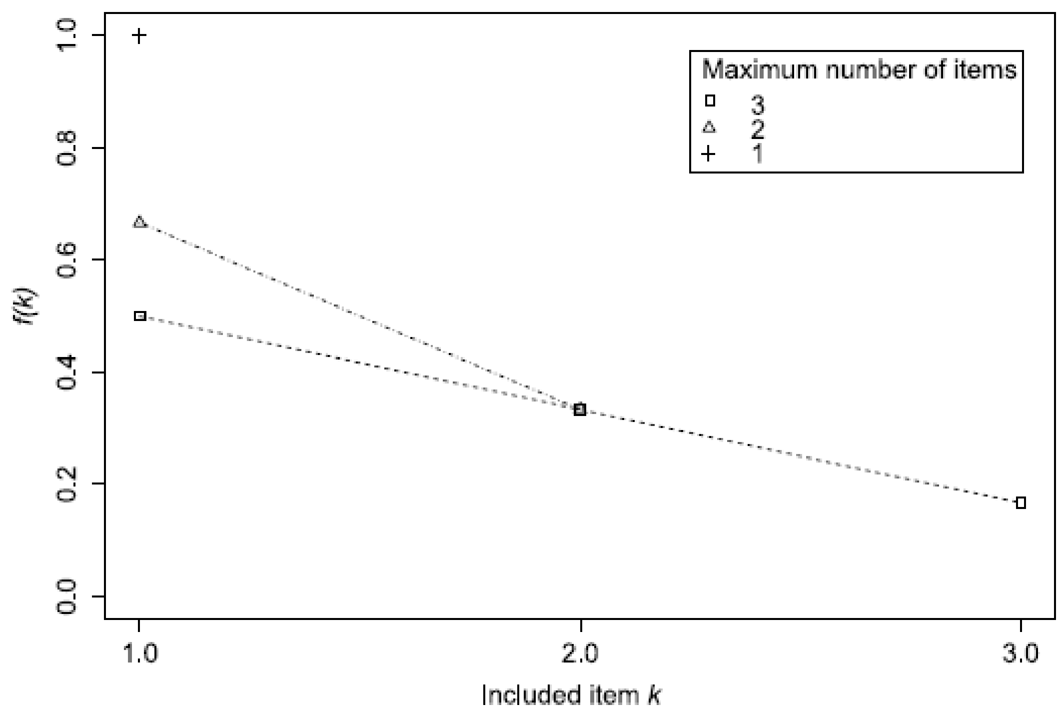
Prioritisation

- Efficient graph algorithms can be used to compute for each candidate:
  - 1. Delay impact (**I**): if the candidate is delayed for D, how many events will have secondary delay?
  - 2. Delay sensitivity (**S**): how many other events can be delayed for D so that it propagates to the candidate?
- **The bigger I and S, the bigger the profit for including the candidate!**

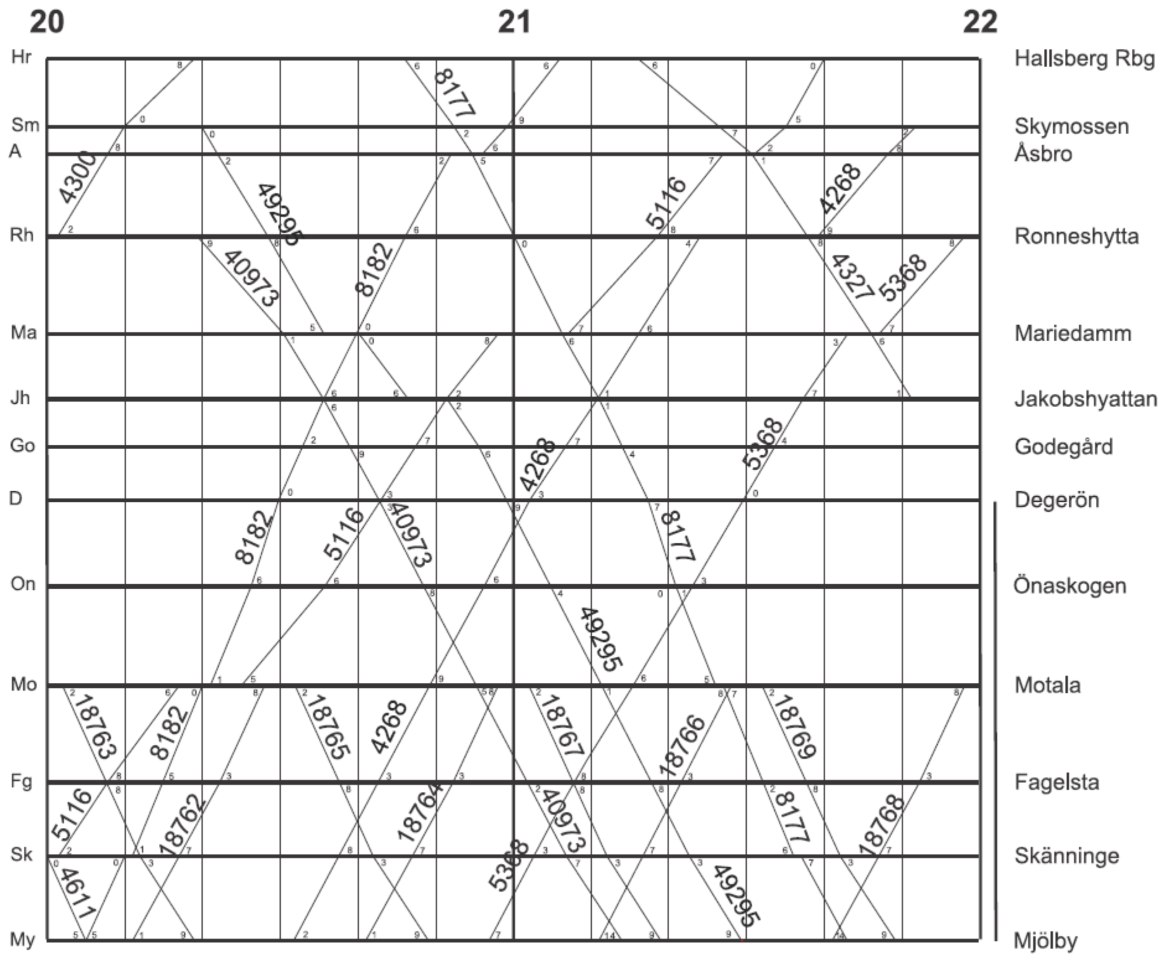


Marginal profit

- Marginal profit from including an additional minute depends on the number of already included minutes of the same buffer



Case study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Ronneshytta
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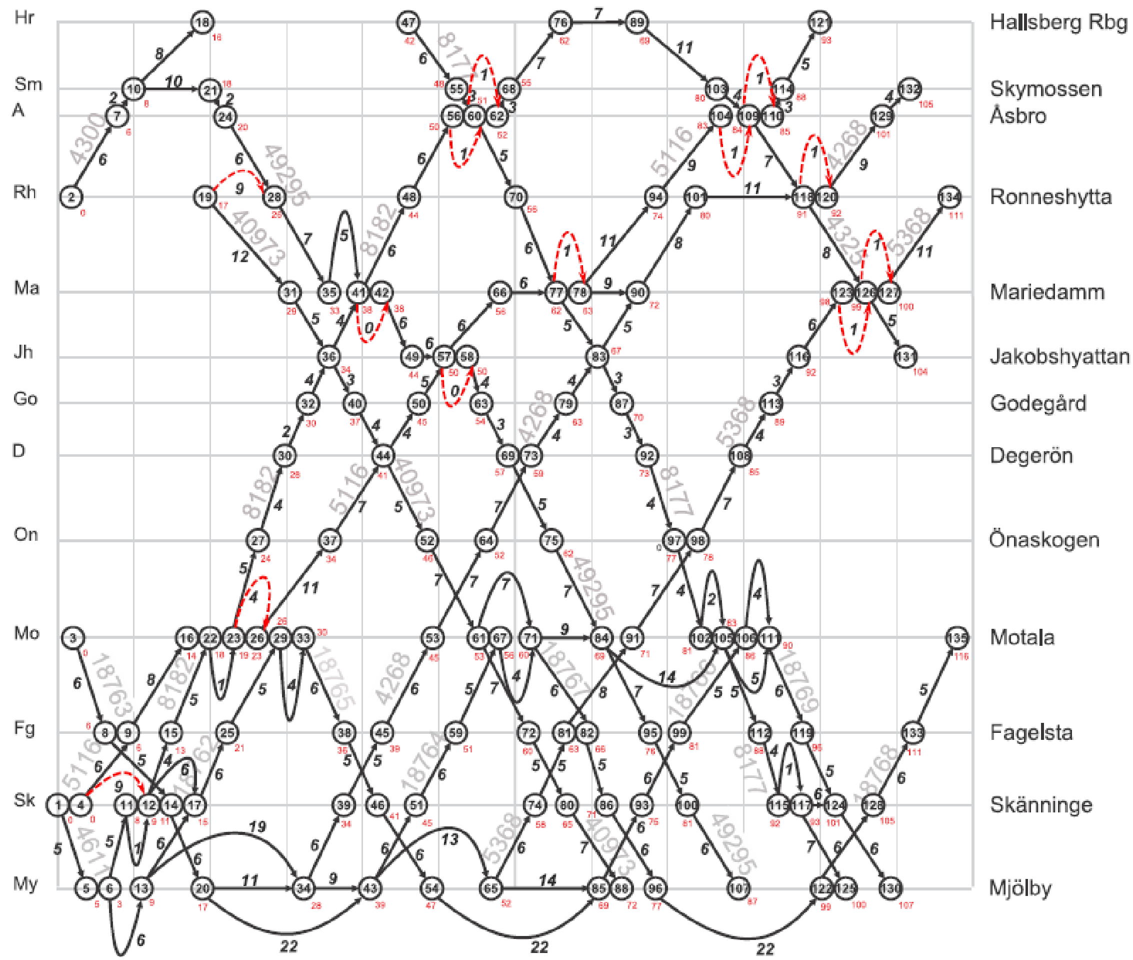
Skänninge
Mjölby

Case study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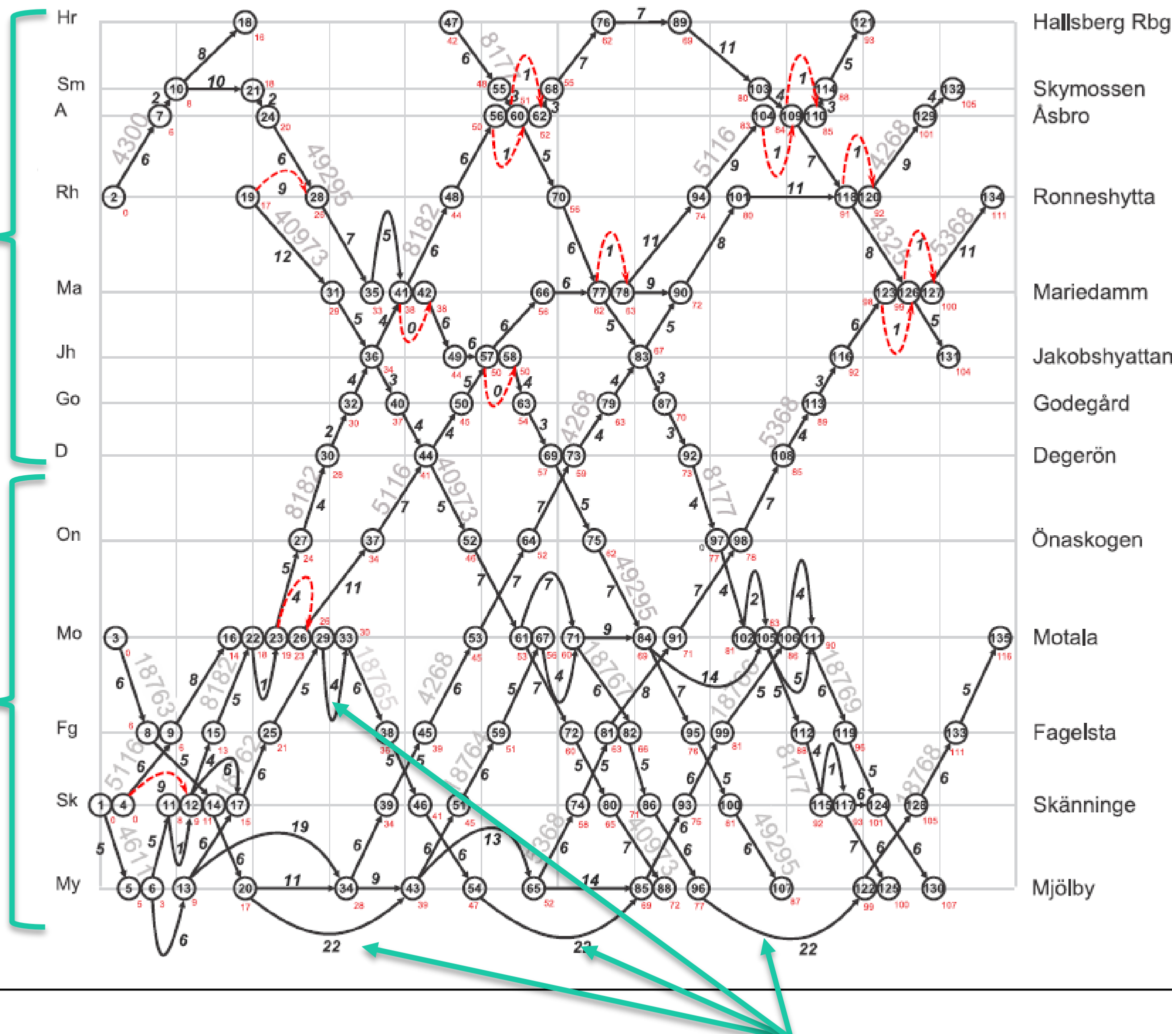
Mariedamm
Jakobshyattan
Godegård
Degerön
Önaskogen
Motala
Fagelsta
Skänninge
Mjölby

Case study

Single track

Double track



$$B = [19, 19, 7, 7, 46, 46, 57, 59, 14, 14, 11, 14]$$

Connections + 30min frequency

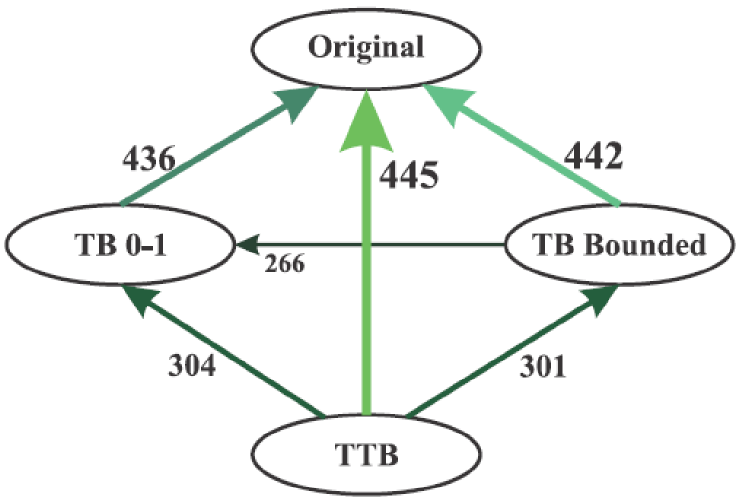
Experimental setup

- 3 schedules generated by using different parameter setup
- 500 hundred primary delay scenarios generated
- All departured events are delayed with a uniform distribution upto 10 minutes
- On average 28 events have primary delay
- Total primary delay 150.14 min on average
- Deterministic delay propagation algorithm computed secondary delays in each scenario for each timetable (500 x 4 experiments in total)

Results

- Upto 11% decrease in seconary delay

	Total delay [min]	Average delay per event [min]	Delay per 1 min prim. [min]	Delay per init. delayed event [min]
Original	1146.70	8.49	8.87	40.95
TB 0-1	1034.20	7.66	7.99	36.94
TB Bounded	1033.80	7.65	7.98	36.92
TTB	**1017.20**	**7.53**	**7.84**	**36.32**



- In upto 87% cases, original timetable performes worse

Next steps

- Prioritisation of buffering base don historical data
- Compuational experinements on networks
- More details about the approach available soon:
  - Jovanovic P., Kecman P., Bojovic N., Mandic D. Optimal allocation of buffer times to increase schedule robustness. European Journal of Oprerations Research (to appear soon)

Thank you for your attention

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