Robust routing in station areas with reducing capacity utilisation (PPT)

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Robust train routing in station areas with reducing capacity utilization

Nikola Bešinović, Rob M.P. Goverde

Outline

- Introduction
- Motivation
- Solution approach
    - Preprocessing
    - Original Train Routing Problem (TRP)
    - Extension to Robust Train Routing Problem (RTRP)
    - RTRP heuristics
- Case study

Introduction

- High capacity consumption (sometimes over recommended norms)
- Growing demand (e.g., NL - a train every 5')
- Stations as bottlenecks

- New planning methods and algorithms that should provide:
  - High-quality and reliable service,
  - Improved experience for planners and dispatchers
  - Satisfied customers

- Train routing problem: 1. platform assignment
  2. route selection

State-of-the-art of Train Routing Problem (TRP)

- TRP is NP-hard
- So far: Sels et al. (2014), Cacchiani et al. (2014)
  - Aggregated routes
  - Only platforming
  - Node/set packing
  - Conflict graph
  - Multi-commodity flow
  - Fixed/flexible event times

- Still missing:
  - Not proven operational feasibility
  - Infrastructure occupation and maintenance not considered

Robust train routing problem (RTRP)

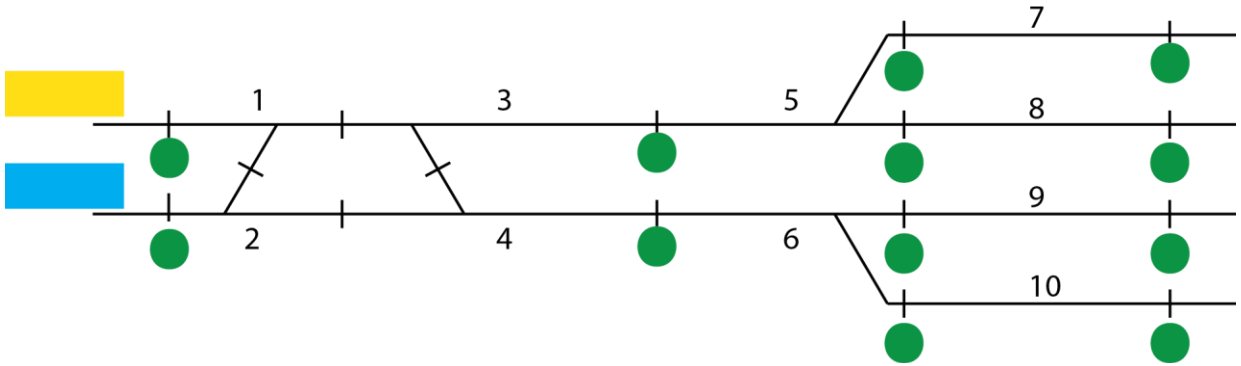
Problem:

Find the feasible, stable and robust route plan (RP), i.e., platform allocation and routing, that uses the infrastructure more evenly within a station area

Input:

- Station topology
- Train lines
- Set of alternative routes
- Fixed event times (arrivals and departures) – output from a macroscopic timetabling model
- Preferred platforms for train lines
- Passenger connections

Some definitions



- Station topology – detailed infrastructure
- Resource – subset of infrastructure elements
  - Track section, switch, crossing
- A train route – set of resources
- Blocking time – a time that a resource is reserved exclusively for a single train

Blocking time > running time over a resource

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  - RTRP model
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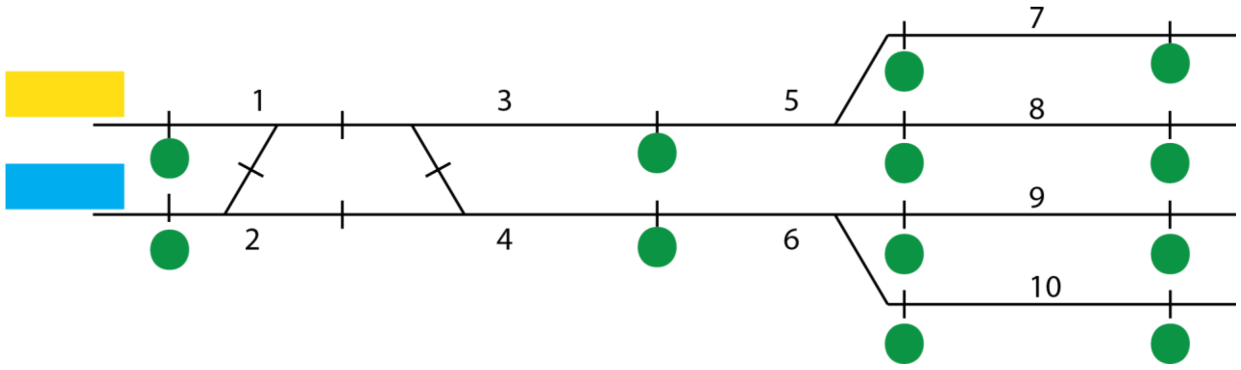
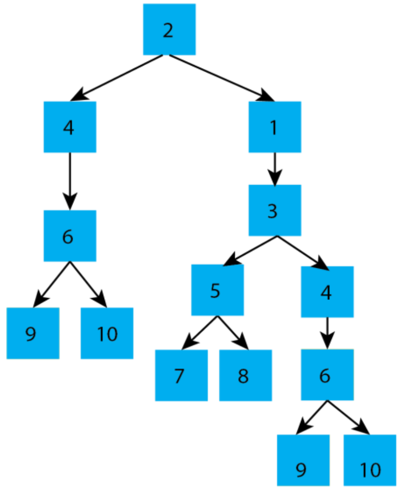
Resource trees
Blocking times
Conflict constraints

Building a graph…

Preprocessing (1)

Resource trees
Blocking times
Conflict constraints

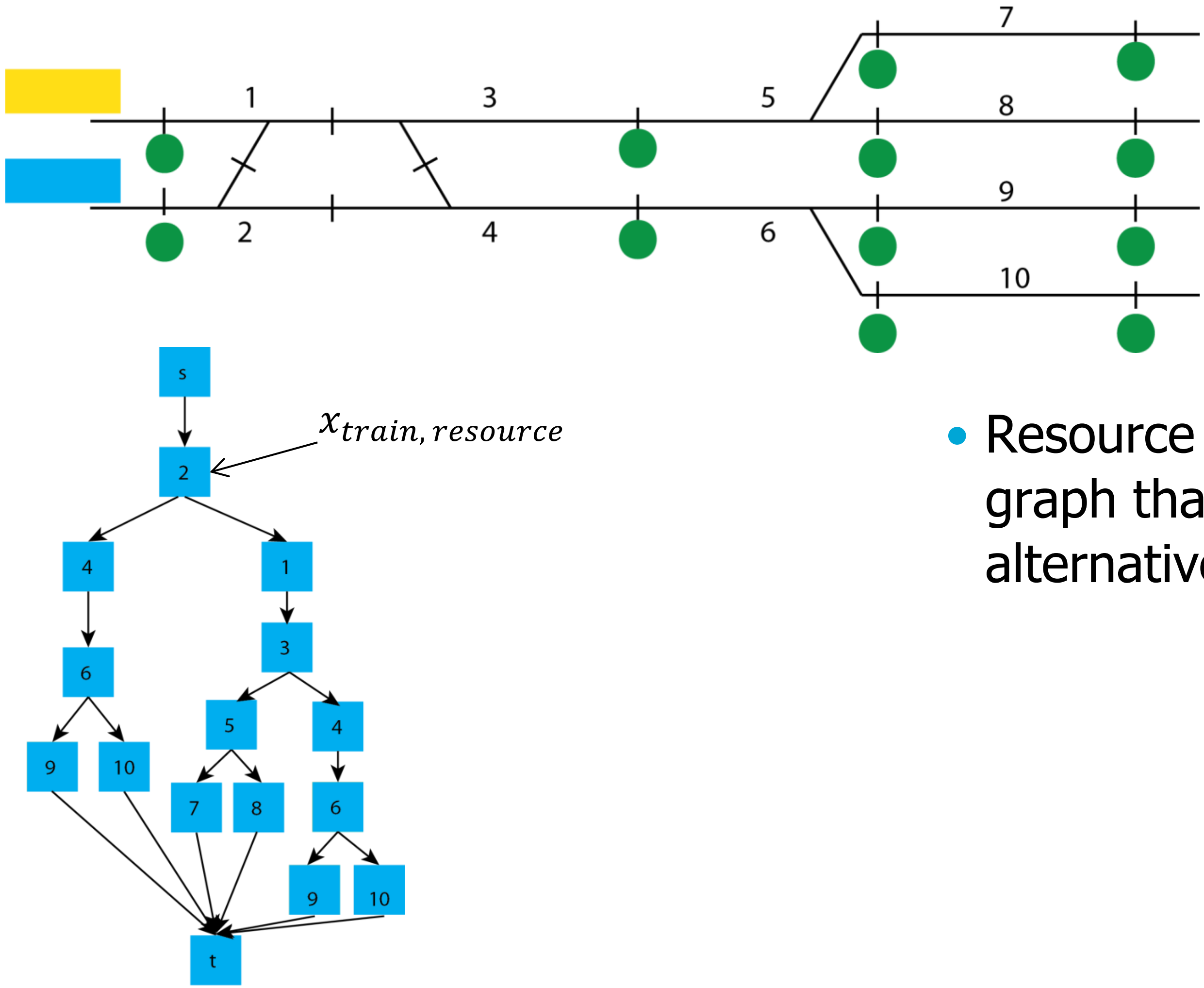




- Resource tree – acyclic graph that includes all alternative routes

Preprocessing (1)

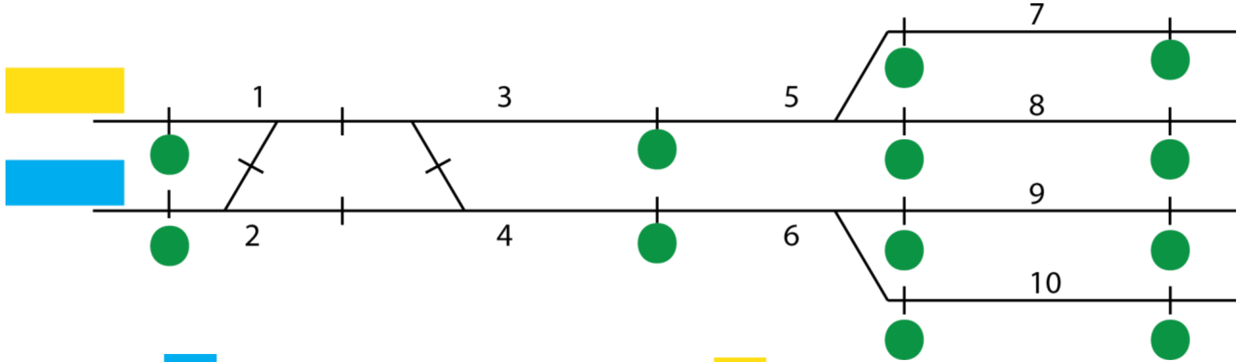
Resource trees
Blocking times
Conflict constraints

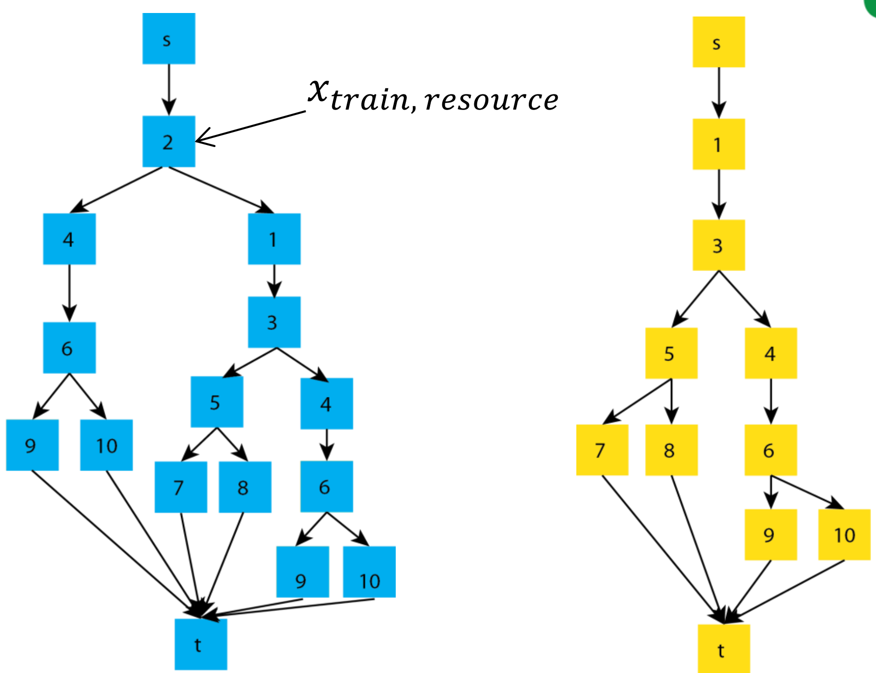


- Resource tree – acyclic graph that includes all alternative routes

Preprocessing (1)

Resource trees
Blocking times
Conflict constraints

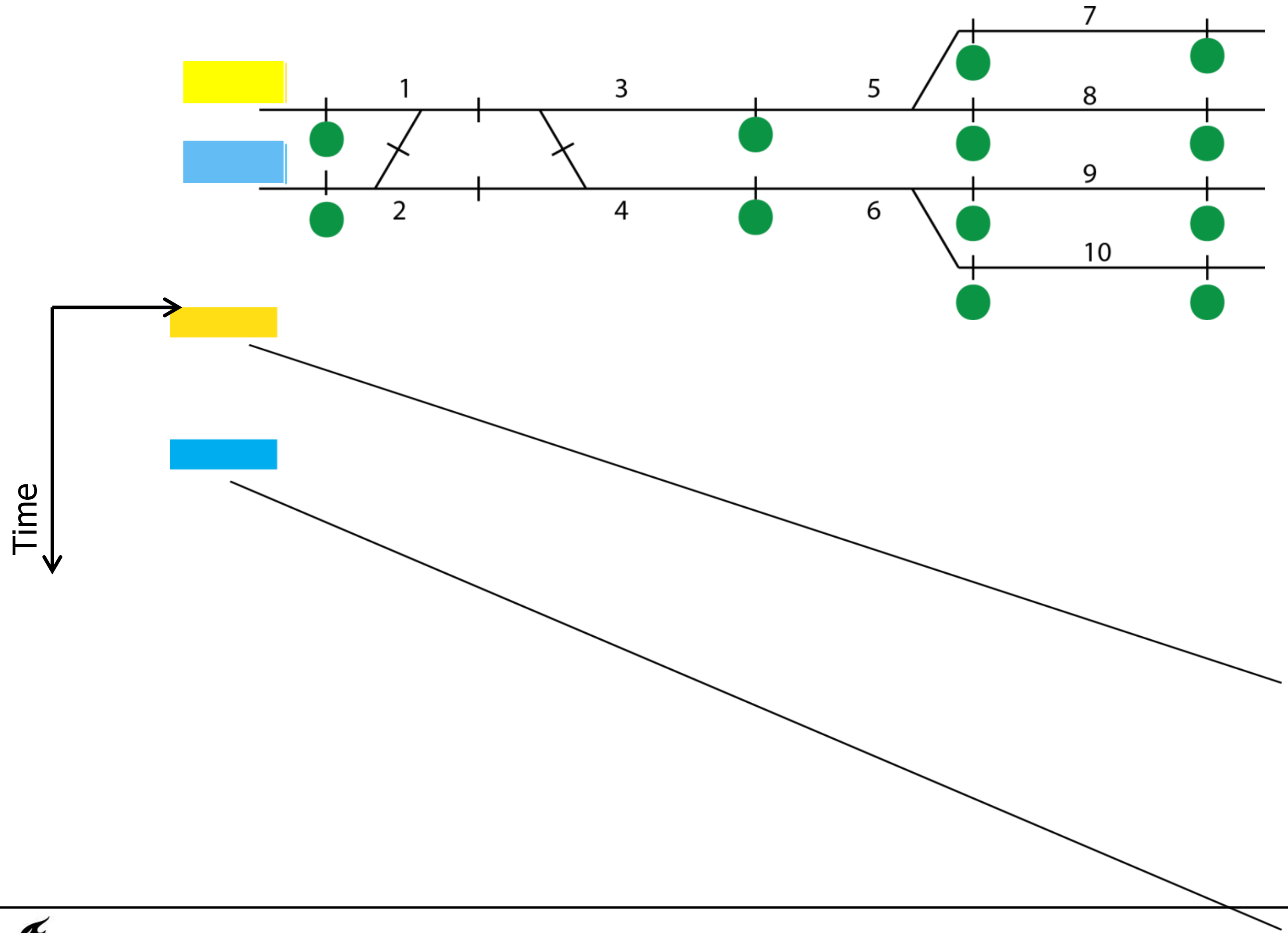




- Resource tree – acyclic graph that includes all alternative routes

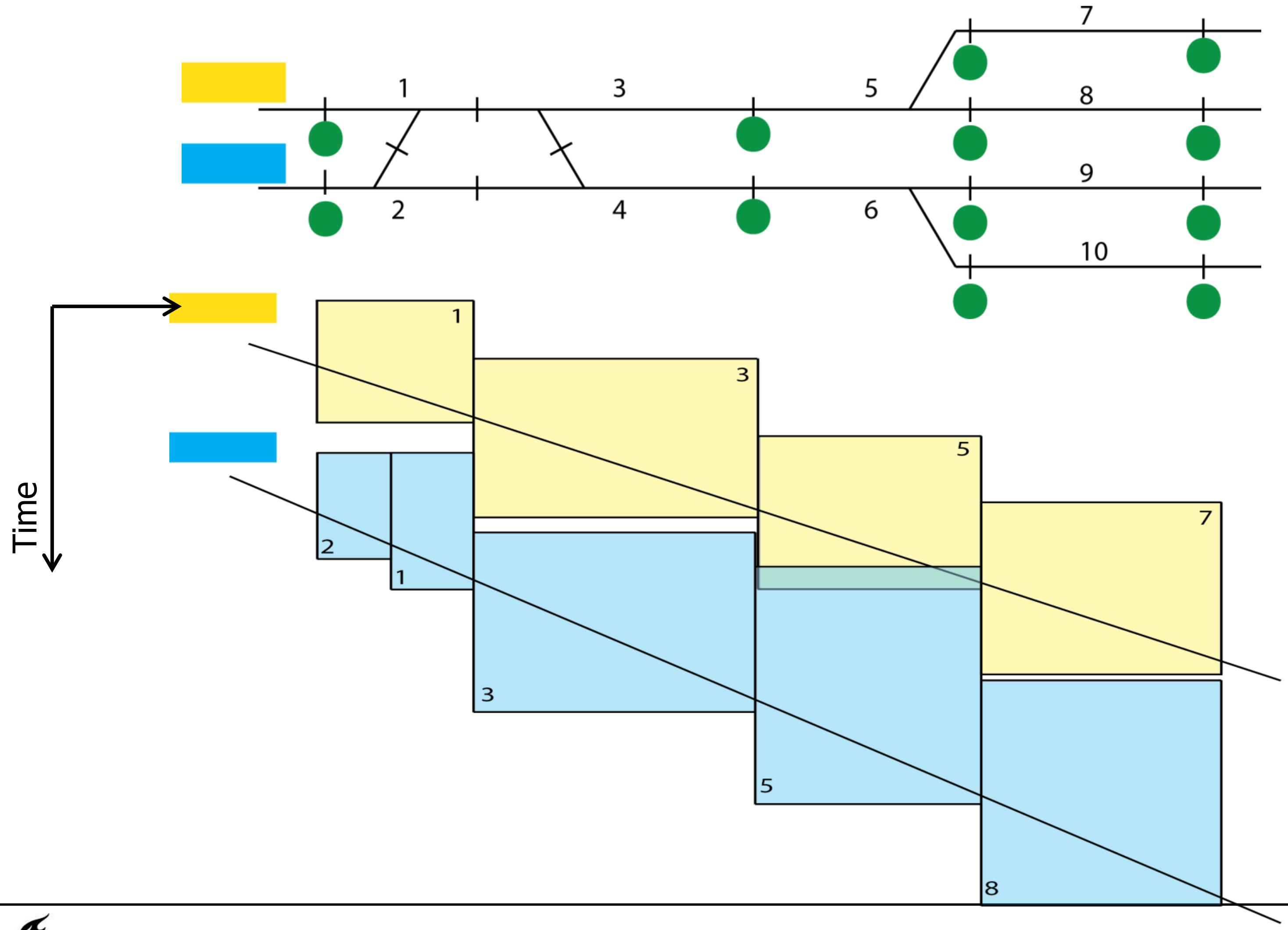
Preprocessing (2)

Resource trees
Blocking times
Conflict constraints



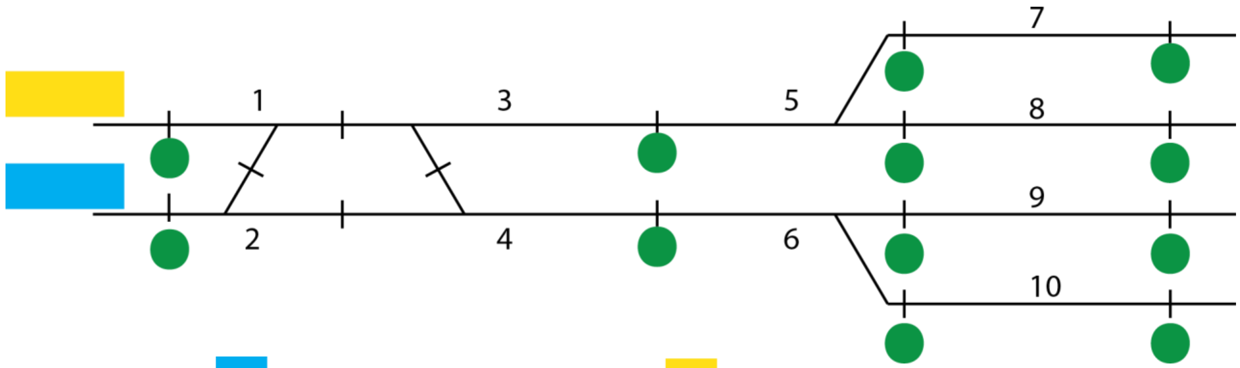
Preprocessing (2)

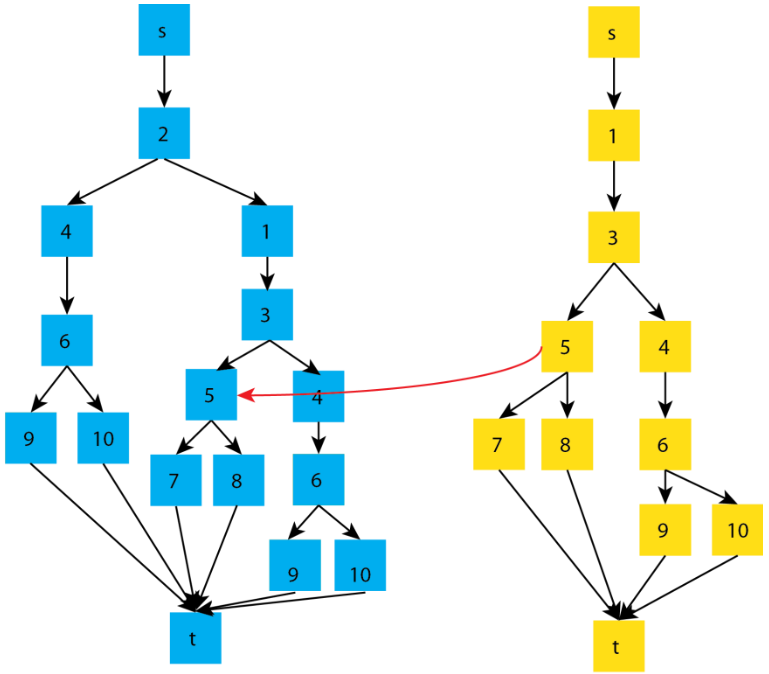
Resource trees
Blocking times
Conflict constraints



Preprocessing (3)

Resource trees
Blocking times
Conflict constraints

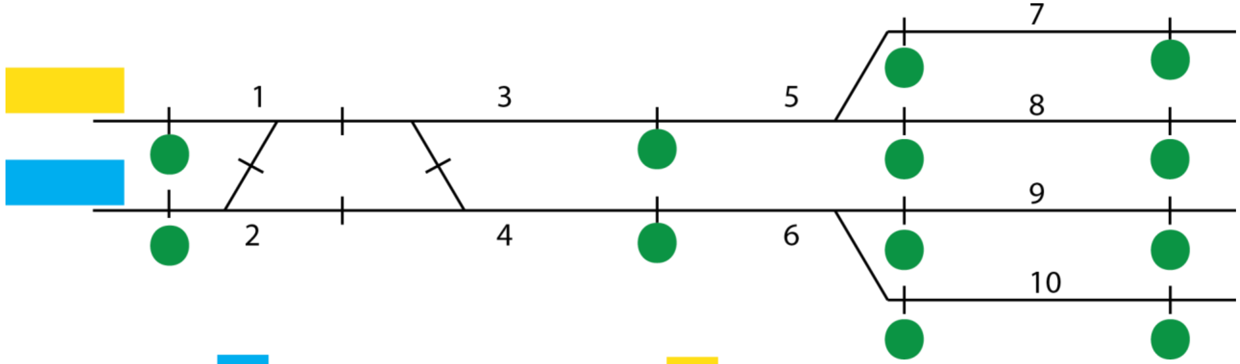


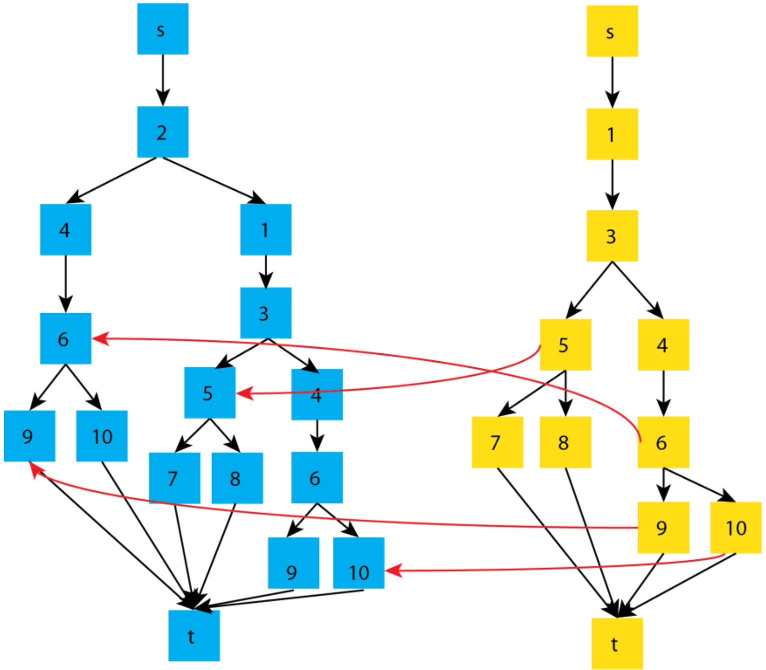


$$x_{blue,5} + x_{yellow,5} \leq 1$$

Preprocessing (3)

Resource trees
Blocking times
Conflict constraints





Conflict arcs:

$$x_{zr} + x_{yq} \leq 1$$

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  - RTRP model
  - RTRP heuristics
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TRP model

- Multi-commodity flow problem
- Train = commodity

- Objective
  - Max quality of chosen routes (short running times)

$$Maximize \sum \sum w_{zr} x_{zr}$$

- Constraints
  - Capacity constraints
  - Flow conservation
  - Conflict constraints

$$\sum_{x_{zr} \in s_z} x_{zr} = -1 \qquad \sum_{x_{zr} \in t_z} x_{zr} = 1$$

Caimi (2009)

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RTRP model

- Extension of TRP model
  1. robustness
  2. capacity occupation

- Robustness = increase buffers between train routes (Caprara et al. 2011)
- For two train routes

$$Buffer\ cost = \begin{cases} big\ M, & \text{independent routes,} \\ minimum\ headway, & \text{otherwise.} \end{cases}$$

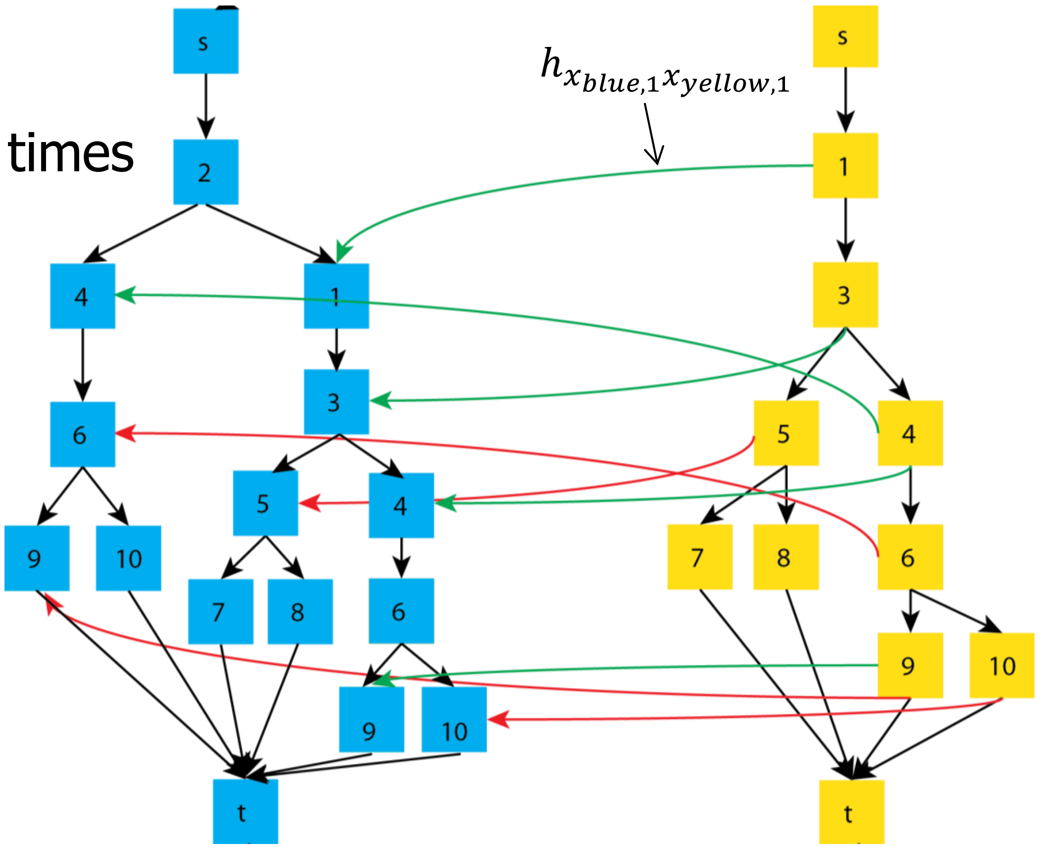
- Buffer costs are assigned between leaves of resource trees

RTRP model

- Capacity occupation is a summation of critical processes as minimum headways, scheduled running or dwell times
- Capacity occupation = critical (longest) path over *chosen* routes
- Lower capacity occupation provides more time allowances (i.e., better stability)
- To evaluate capacity occupation minimum headways are needed
- Add arcs with weights that correspond to minimum headways

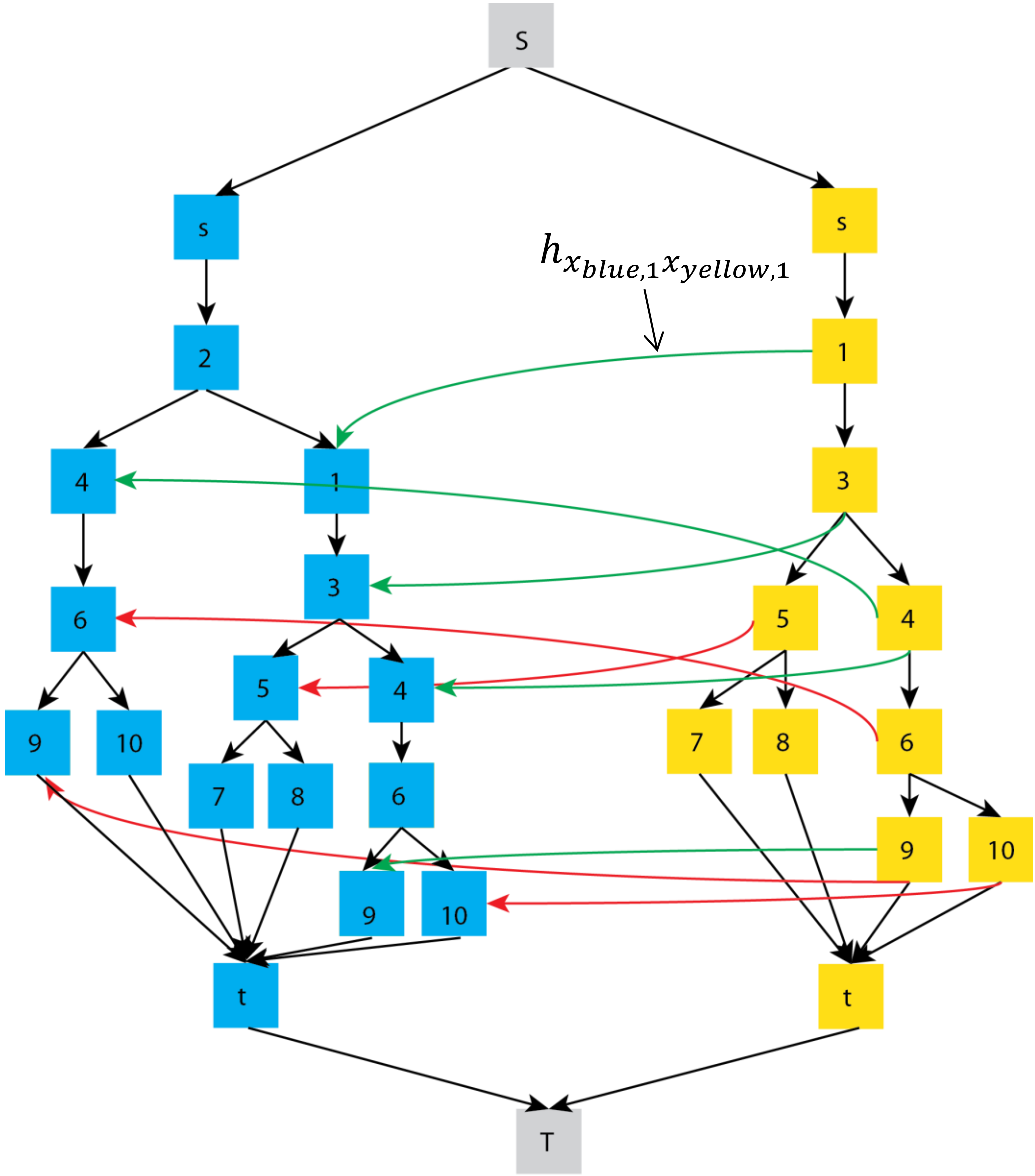
RTRP model

- Headway arcs $h_{x_{ir}x_{jr}}$
- Computed based on blocking times



RTRP model

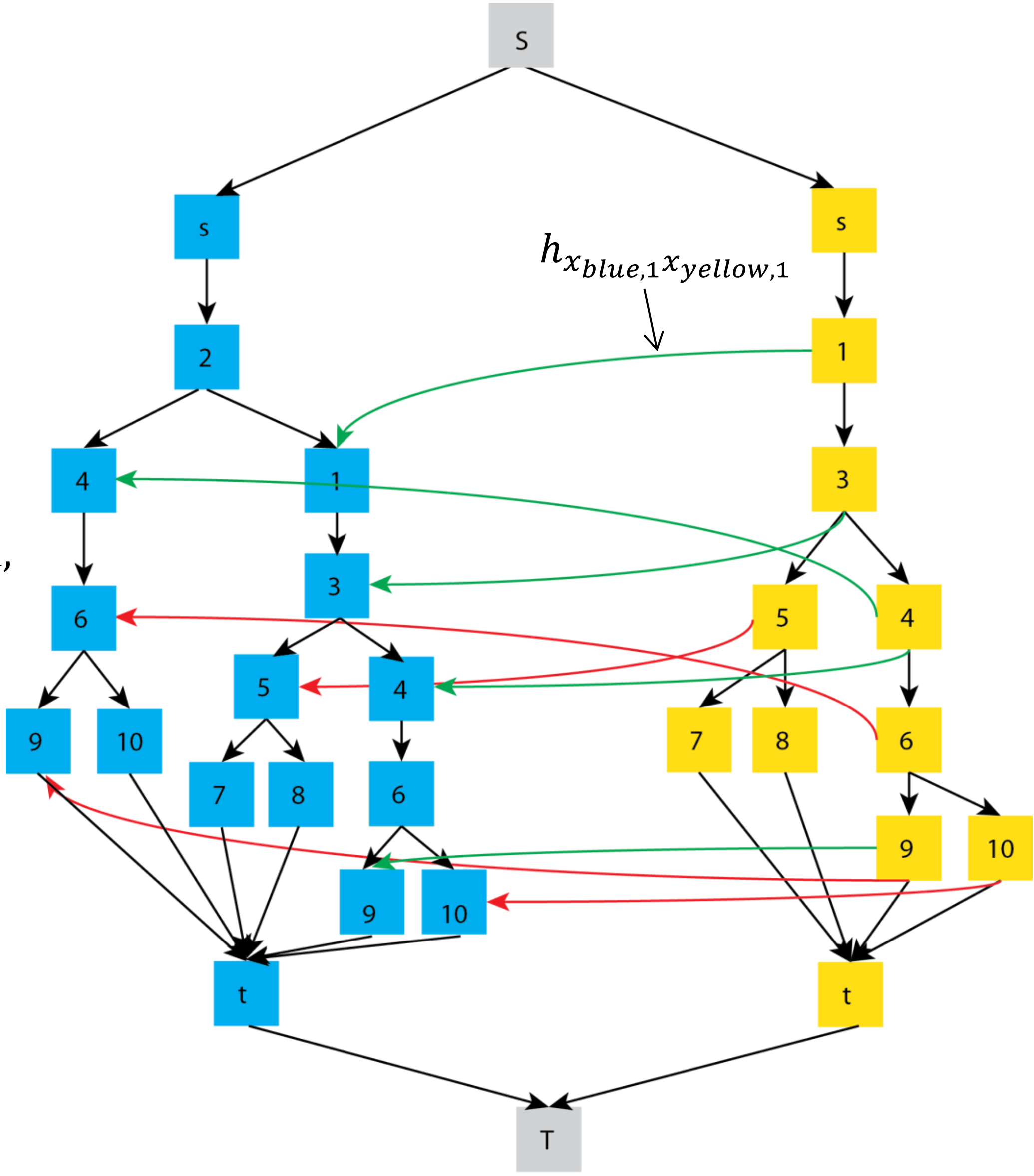
- Headway arcs $h_{x_{ir}x_{jr}}$
- Add source and sink nodes



RTRP model

- Active headways depend on selected routes
- Active headway arcs

$$Active\ hw = \begin{cases} 1, & \text{both resources selected,} \\ 0, & \text{otherwise.} \end{cases}$$

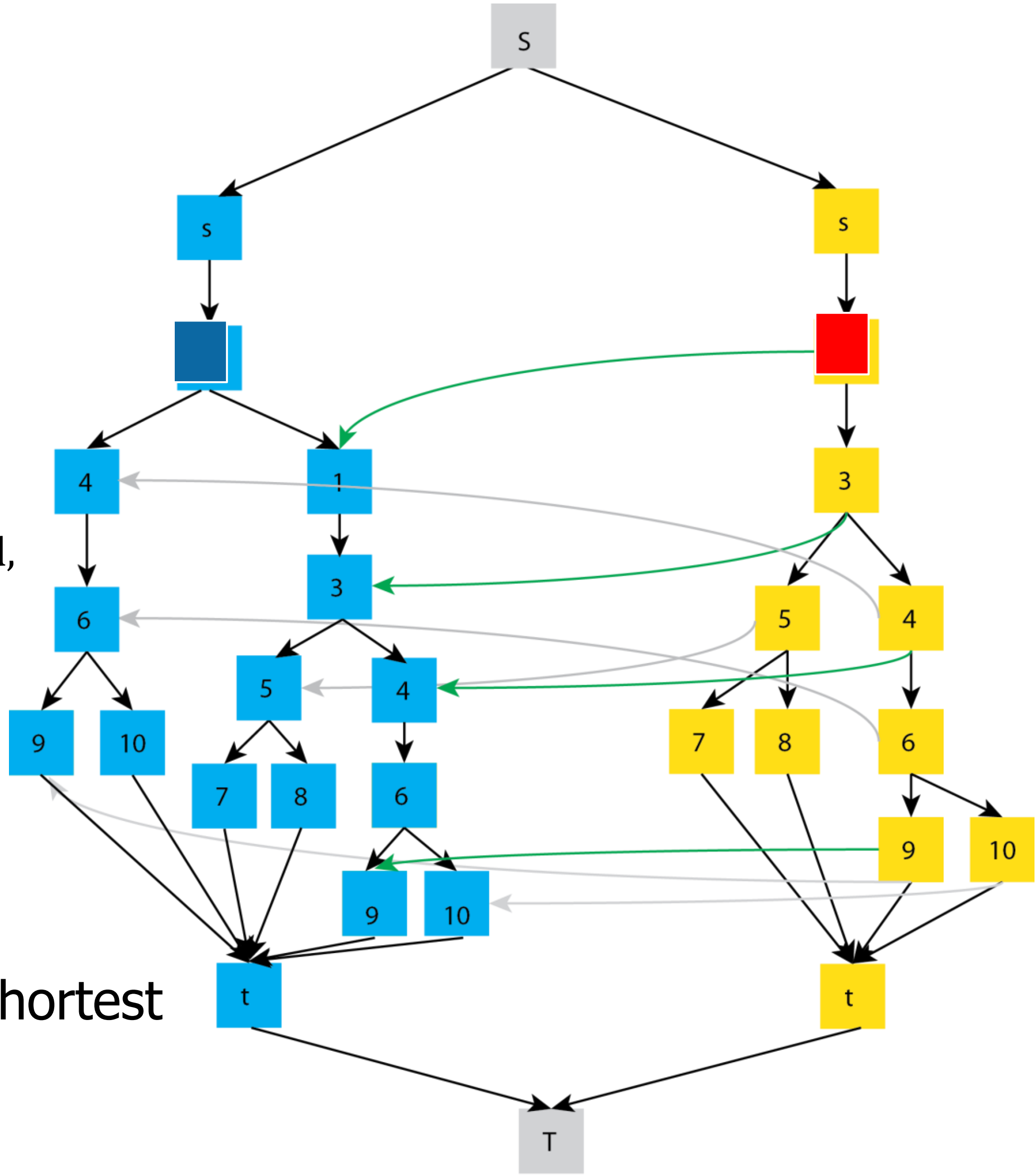


RTRP model

- Active headways depend on selected routes
- Active headway arcs

$$Active\ hw = \begin{cases} 1, & \text{both resources selected,} \\ 0, & \text{otherwise.} \end{cases}$$

- Directed acyclic graph
- Find the critical path
- Adjusted LP formulation for shortest path problem



RTRP model

- Objectives
  - Max quality of chosen routes
  - **Max robustness**
  - **Min capacity occupation (critical path)**
- Constraints
  - Capacity constraints
  - Flow conversation
  - Conflict constraints
  - **Active headways**
  - **Shortest path constraints**
  - **Maximum permitted capacity occupation**
- Developed heuristics for solving RTRP

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RTRP heuristics

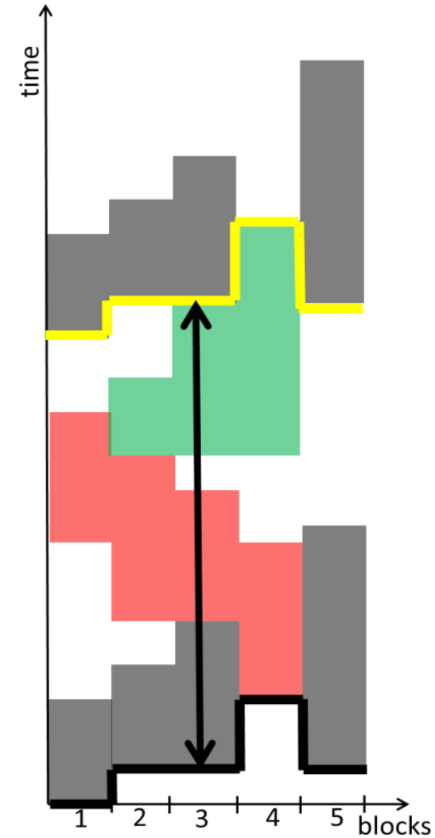
- Local search algorithm
- Main components
  - Capacity assessment (CA)
  - Robustness evaluation (RE)
  - Improvement rules (IR)

- Algorithm of the RTRP heuristics

Input: route plan RP
Initialize $bestRP \coloneqq RP$
While $iter < maxIter$ OR $not\ converged$
    Compute capacity occupation CA
    Compute delay propagation RE
    $totalCost(RP) := cost(CA) + cost(RE)$
    if $totalCost(RP) < totalCost(\text{bestRP})$
        $bestRP \coloneqq RP$
    end if
    vary routes in RP (IR)
End while

RTRP heuristics

- Capacity assessment
  - Compression method (UIC 406)
  - Microscopic model
  - Algebraic approach = *Max-plus automaton*
  - All train dependencies naturally considered
  - Output: capacity occupation, resources at the critical path, occupation of each resource



- Robustness evaluation
  - Delay propagation model
  - Input: set of delay realisations R
  - Output: average delay D

Methodology

Route permutations

- Substitute *bad* train routes
- Exclusion (E) and inclusion (I) rules for alternating routes in the route plan
- *E-rules.* Choose a route that:
  - has a resource is on the critical path
  - uses a platform with the highest occupation
  - generates the most delays
- *I-rules.* Choose a route that:
  - Does not use a resource on a critical path
  - Does not use the highest utilised platform
  - Is not conflicting with existing routes in the route plan

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Case study

- Station Den Bosch
- 14 trains lines with periodicity of 2 trains/h
- Input: computed timetable

Besinovic et al. 2015

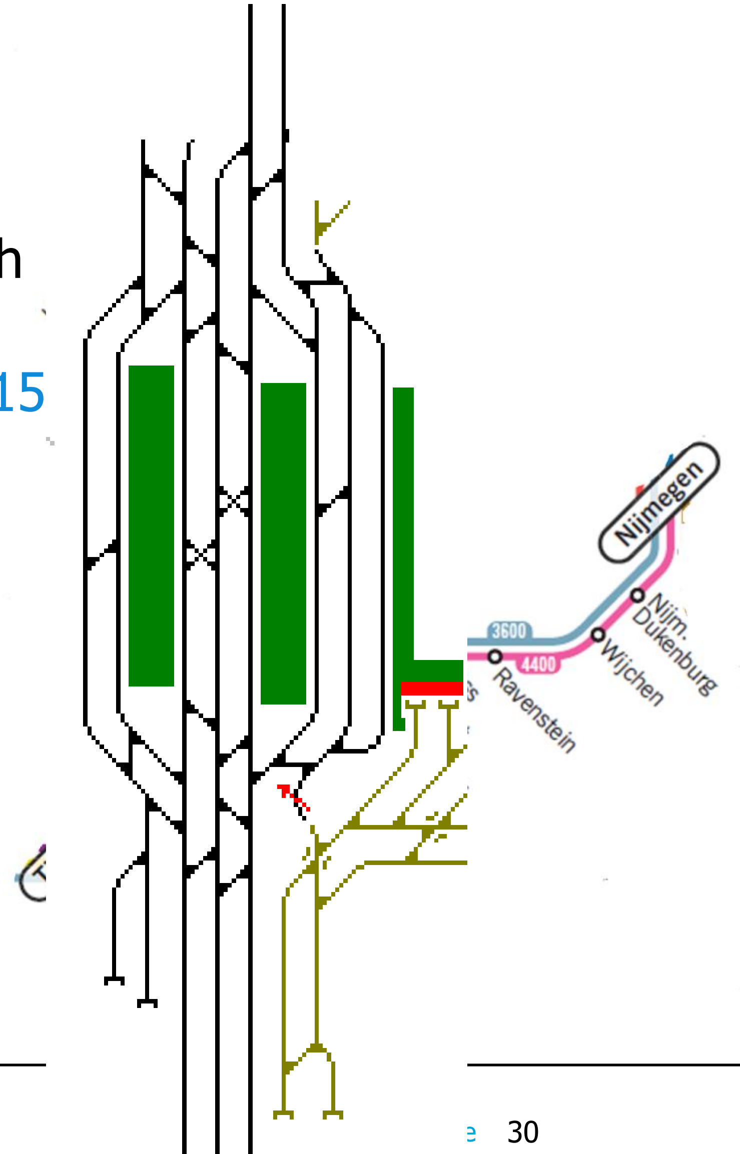

Table 1. Input parameters

Period (s)	1800
# of platforms	6
# of routes	91
maxIter	500
convIter (iterations without improvement)	100

Case study

Initial results

- Heuristics performance
- 30 repeated runs of RTRP heuristics
- Weights for CA and RE are equal

Table 1. Heuristics convergence

Parameters	Mean (s)	Standard deviation (%)
Total cost (s)	1135	0.73
# of iterations	165	34.57

Case study

Initial results

- Test single submodels CA and RE vs CA+RE
- CA = original TRP

Table 2. Results of individual submodels

	Capacity occupation (s)	Average delay (s)	Total cost (s)	Number of resources used
Only CA	**801**	796	1597	72
Only RE	956	**301**	1257	58
CA & RE	821	314	**1135**	**70**

Conclusion

- New multiobjective MILP formulation for robust train routing problem
- Promising heuristics for solving RTRP
- Optimized route plan fulfils
  - Proven feasibility (at microscopic level)
  - Capacity consumption reduced
  - Improved robustness
  - More even resource usage => less frequent maintenance
- Future work
  - Compare results with the optimal solution
  - Flexible event times
  - Evaluate the effect of different weights for CA and RE

Thank you for your kind attention

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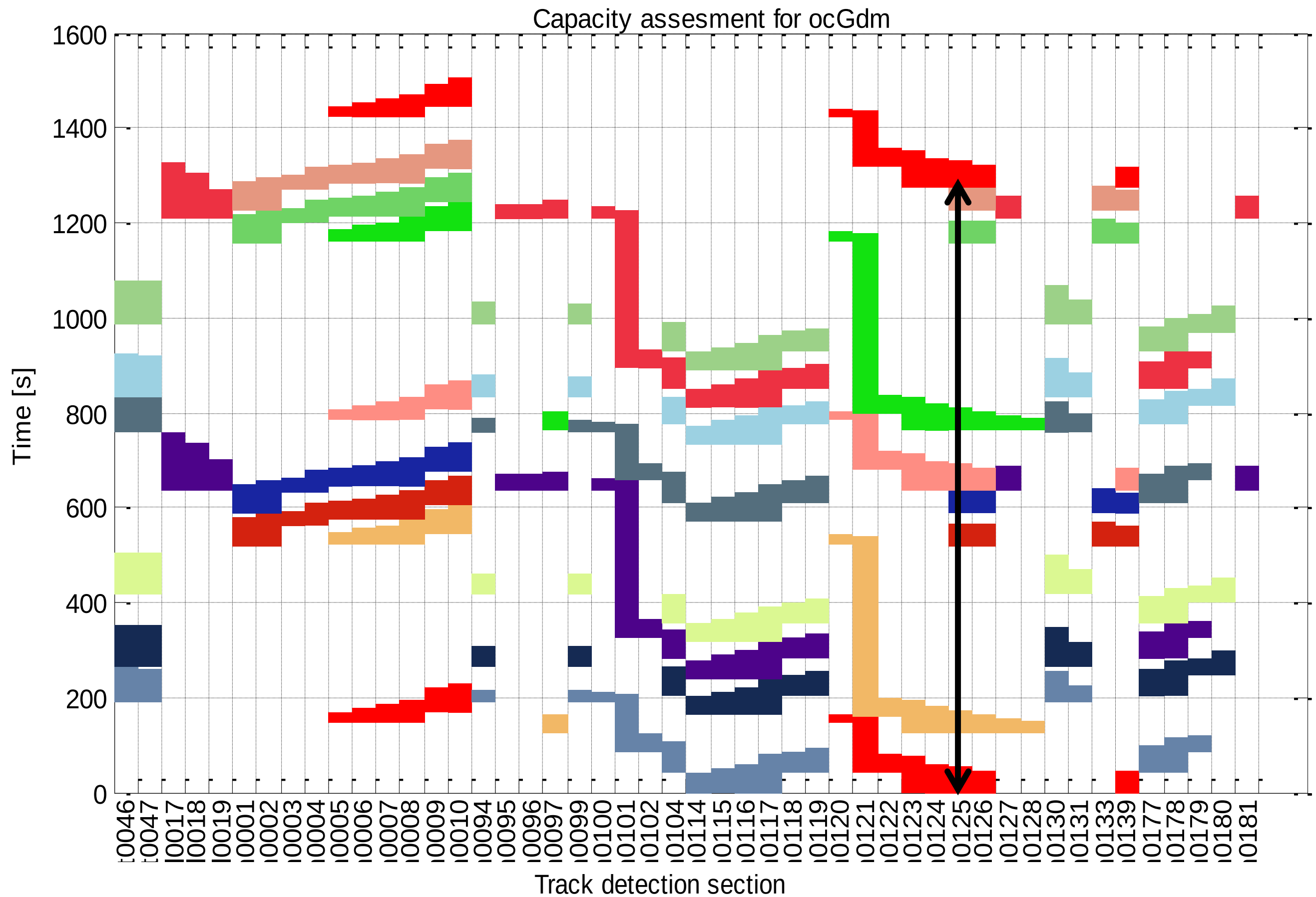
Case study

Optimized route plan



*red train route is repeated from the next period