Replanning in Advance for Instant Delay Recovery in Multi-Agent Applications

Rerouting Trains in a Railway Hub

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University of New Hampshire
TU Delft

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Single delayed agent in multi-agent setting

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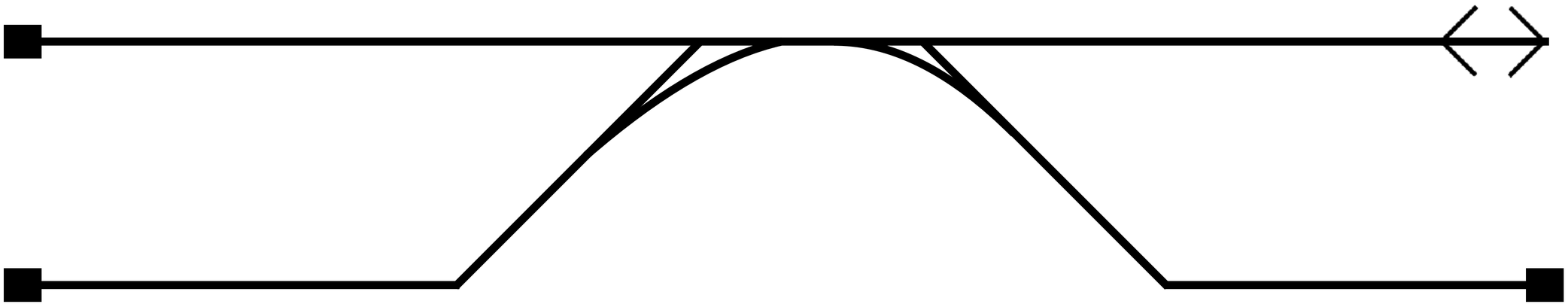

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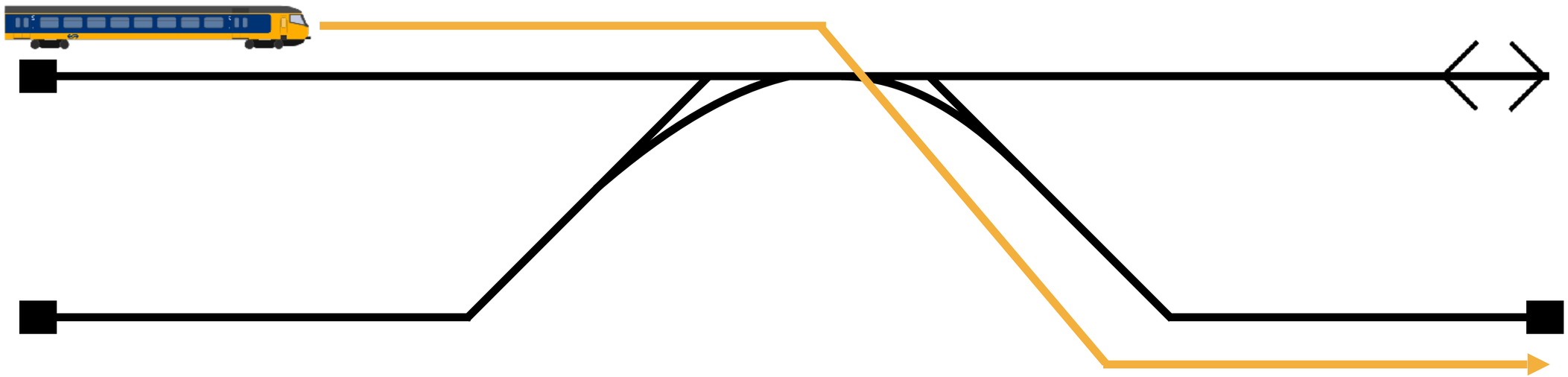

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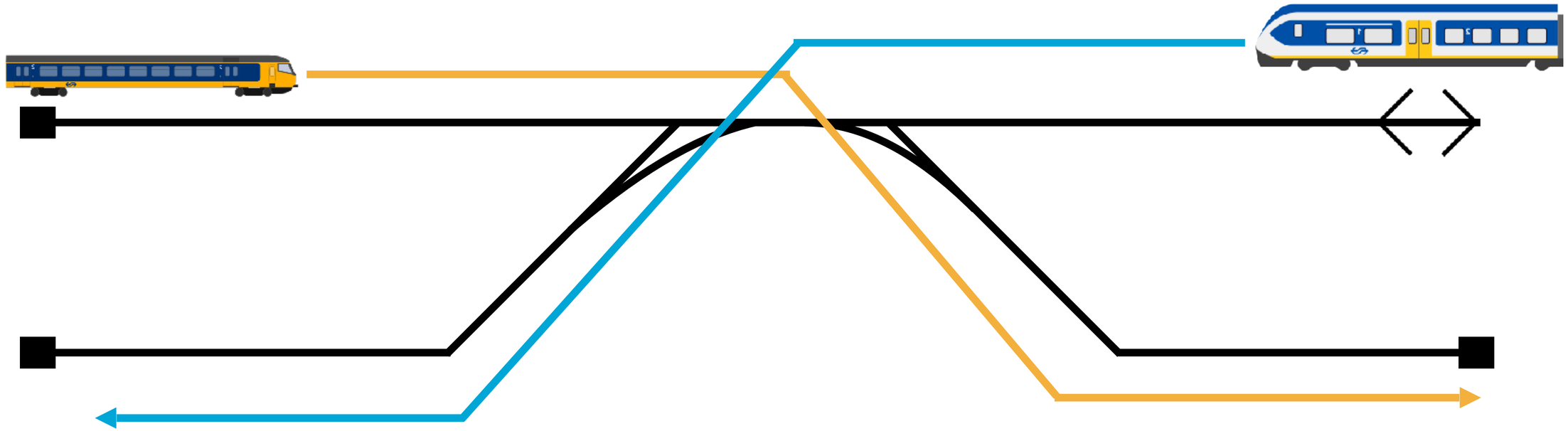

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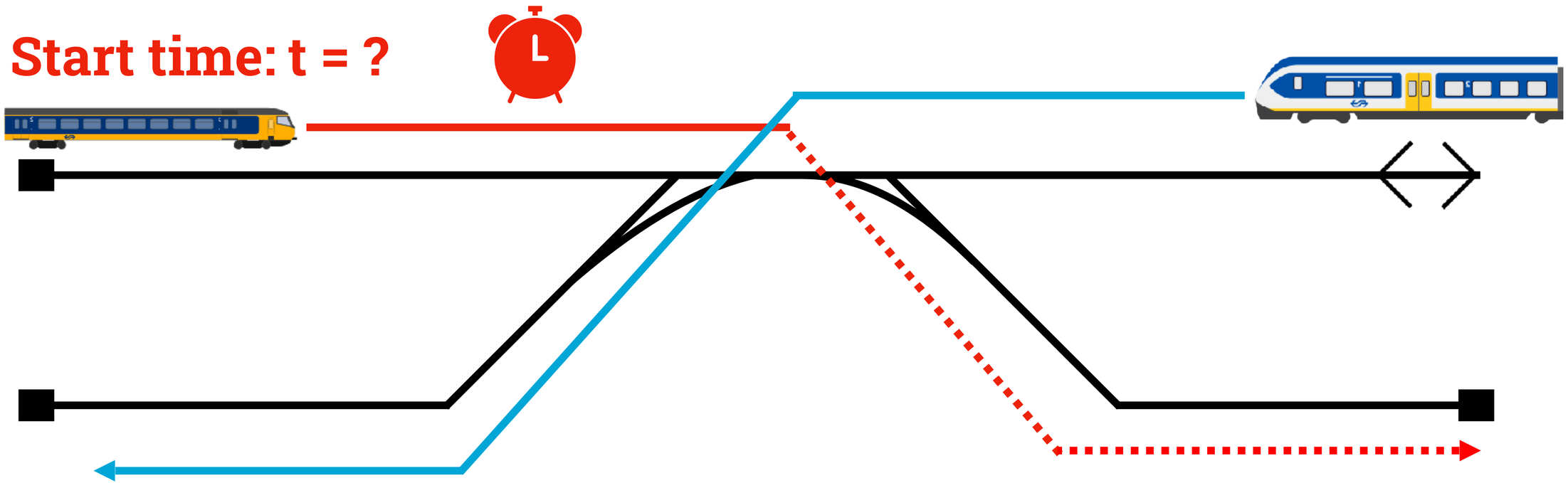

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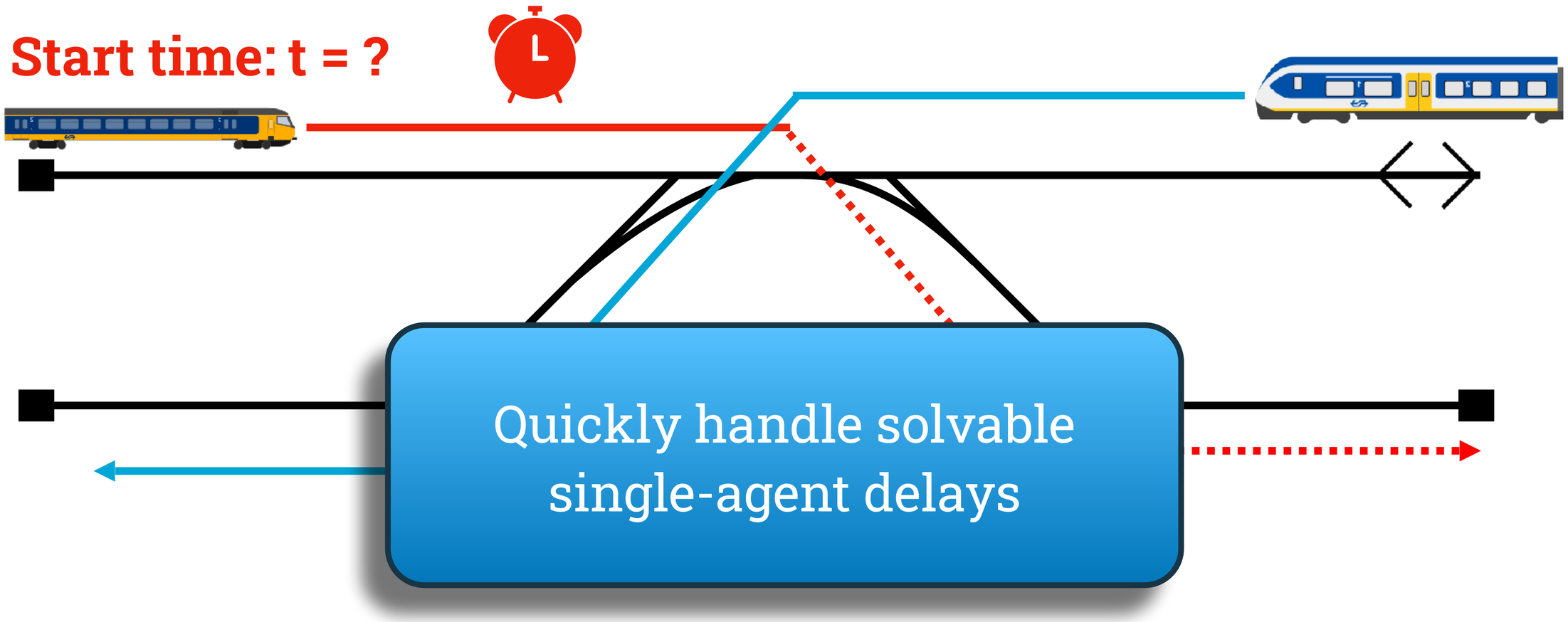

Motivation

Motivation


Depart
To/Via
Platform
19:19
19:07 Dordrecht
+20 via Blaak
6
Intercity
19:12 Dordrecht
+20 via Blaak, Rotterdam Zuid, Lombardijen
7
Sprinter
19:14 Eindhoven Centraal
+15 via Breda, Tilburg
4
Intercity
19:18 Den Haag Centraal
via Delft, Den Haag HS
12
Intercity
19:20 Utrecht Centraal
via Alexander, Gouda
13
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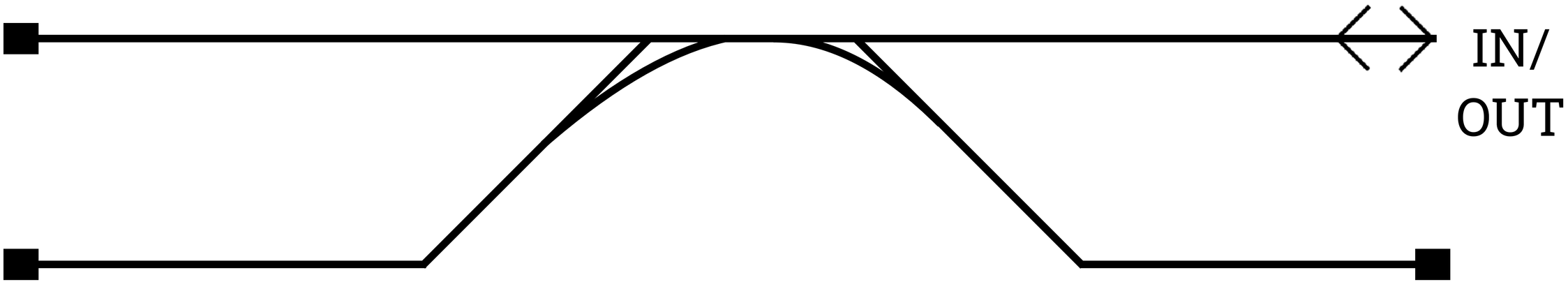
Utrecht Centraal
Cancelled
09:10 Berlin Ostbahnhof
Platform has been changed
09:11 Brussel-Zuid Midi → Paris-Nord
Cancelled
09:11 Zandvoort aan Zee
Platform has been changed
9:13 Amersfoort Vathorst
Cancelled

Motivation

Our method can instantly recover from a single delayed train without affecting other trains

Railway Hub setting



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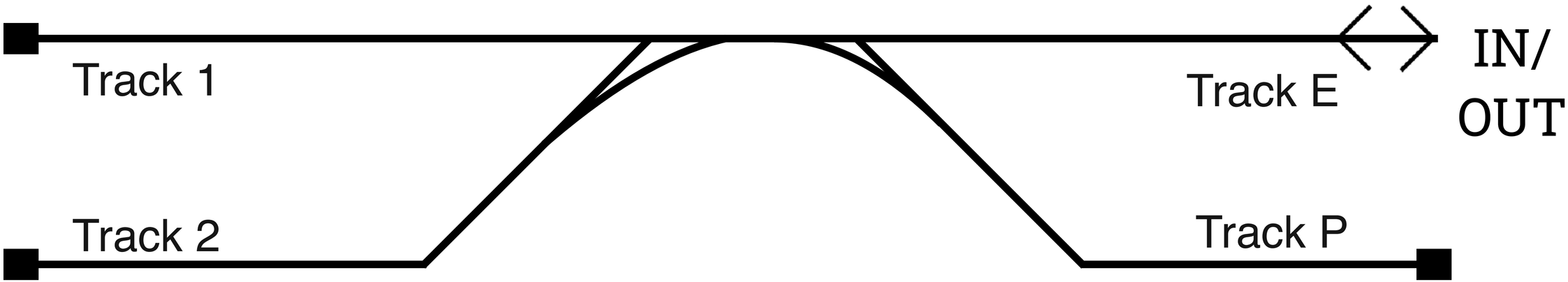

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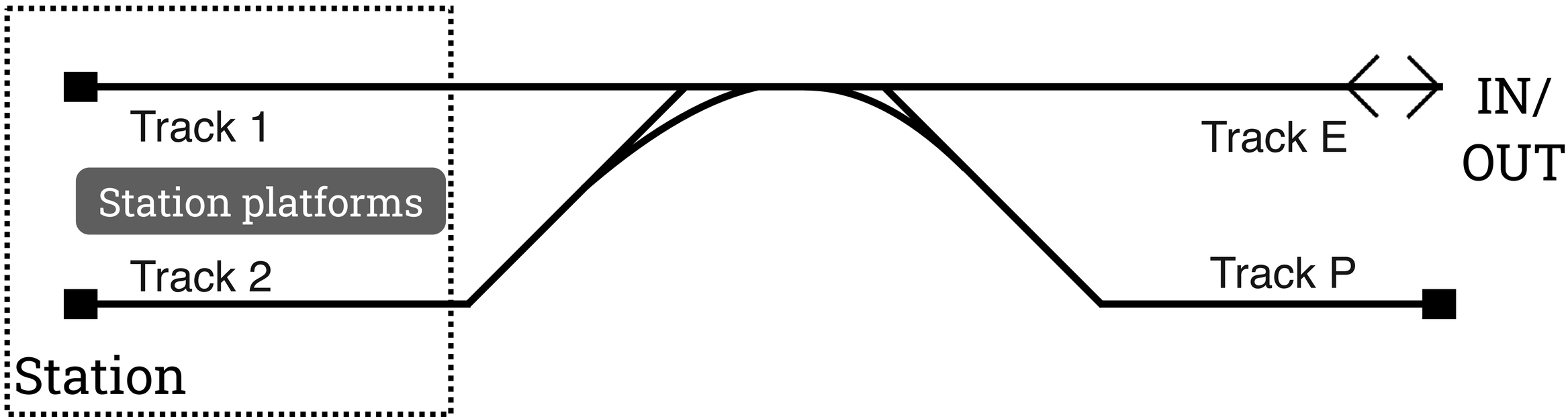

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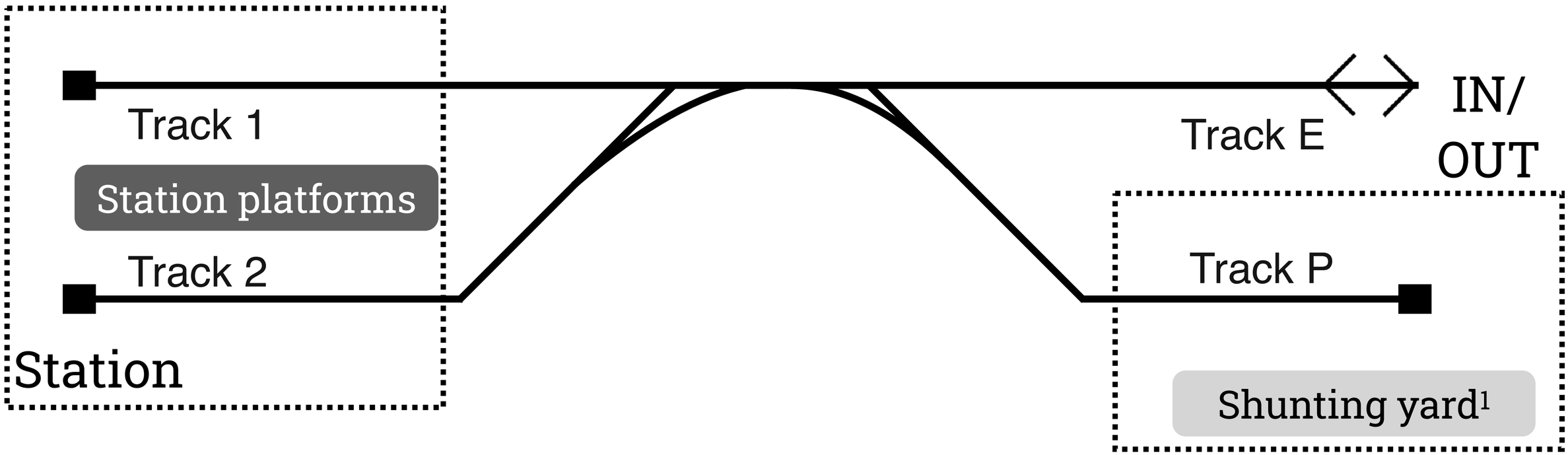

[1]Shunting yard is place to park and service (e.g., clean) trains, for example, overnight or outside of rush hour.

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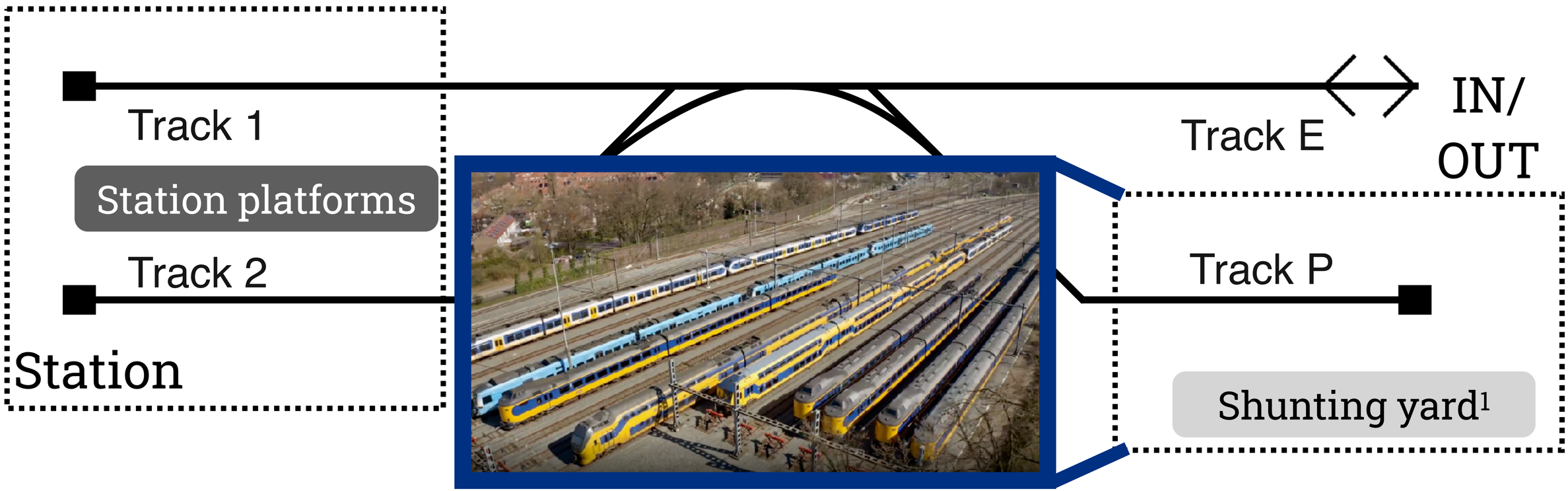

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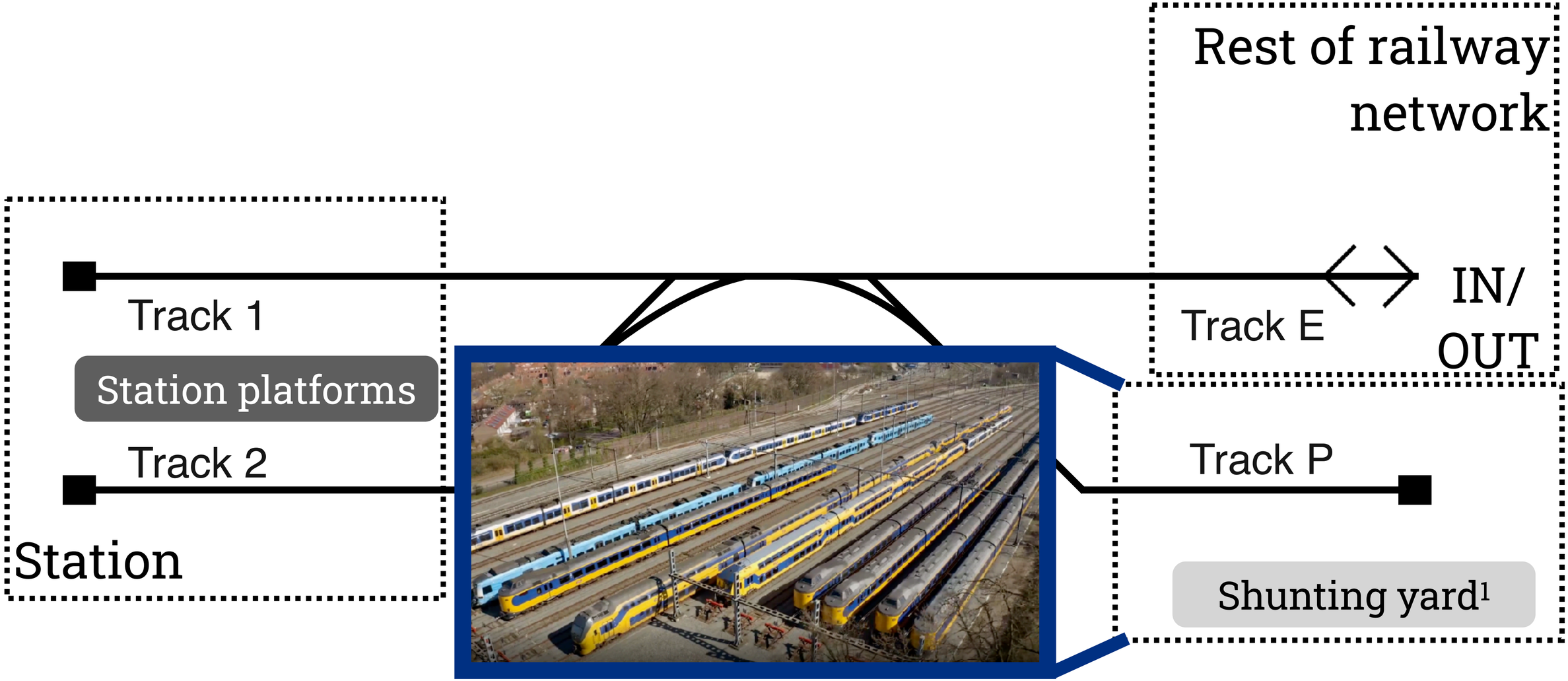

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Problem definition (MAEDeR)

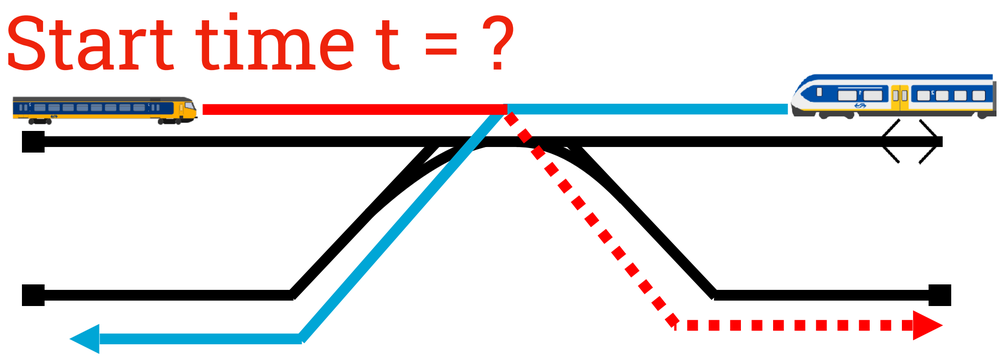
Given a graph with:

- Multiple moving agents
- Single delayed agent

Objective: Minimize the interval of uncertainty

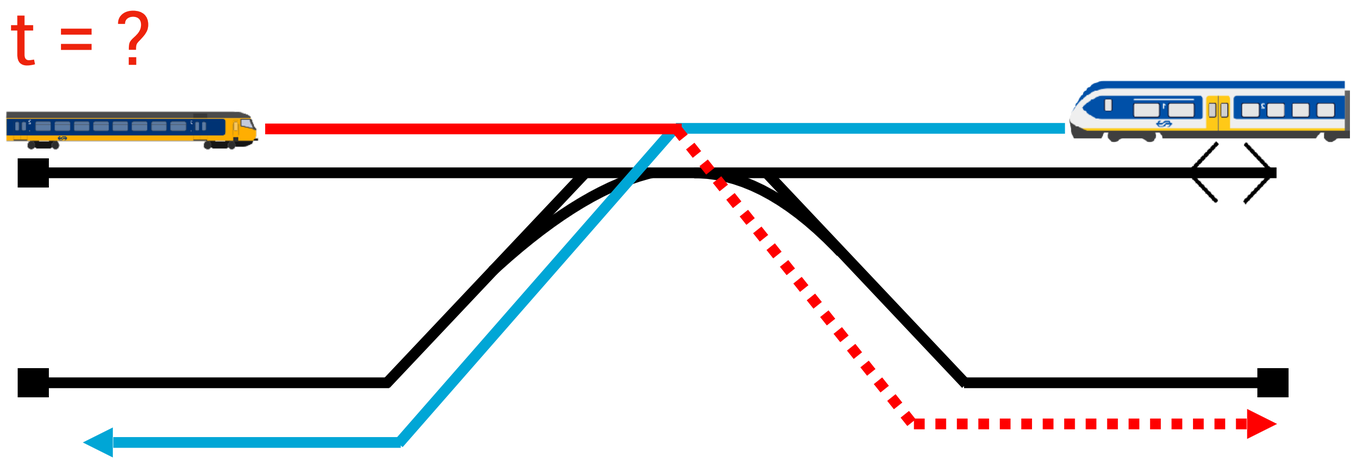
Returning a function that:

- For an agent and delayed start time
- Returns a shortest safe plan



Replanning for MAEDeR

- Intuitively: replan on delay using Safe Interval Path Planning (SIPP)
  - Join consecutive safe states into safe intervals
  - Run A*, earliest arrival dominates (Phillips & Likhachev, ICRA, 2011)
- Minimize Interval-of-Uncertainty
- Online: cannot pause world
  - Trains cannot stop
  - Many trains involved



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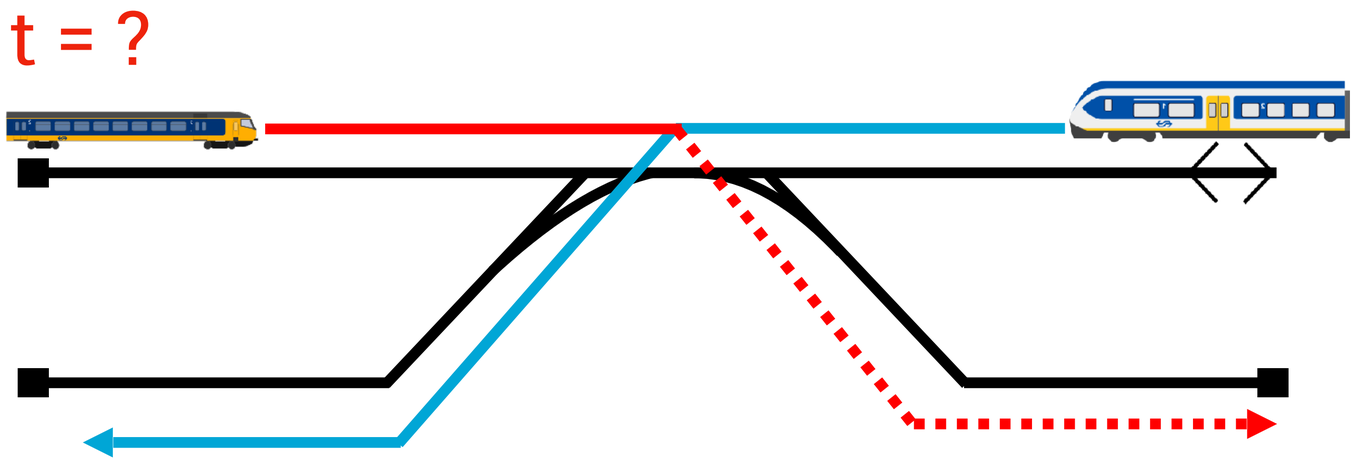
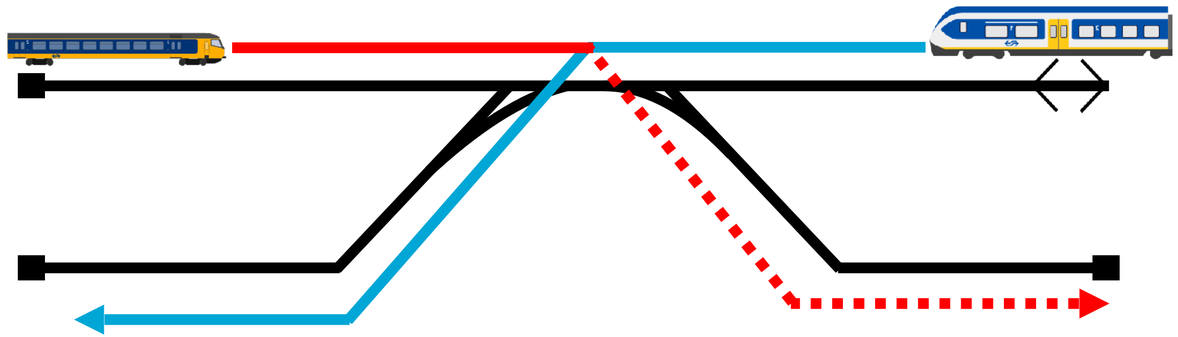


Any-start-time MAEDeR (@MAEDeR)

- Precompute any-start-time plans for each agent (Thomas et al., HSDIP, 2023)
  - Each agent only needs to plan for its own delays
- On delay: lookup plan
  - Binary search on a time-ordered array of plans
- Precomputation scales quadratically with number of trains
  - Any-start-time planning: linear in problem size (per agent)



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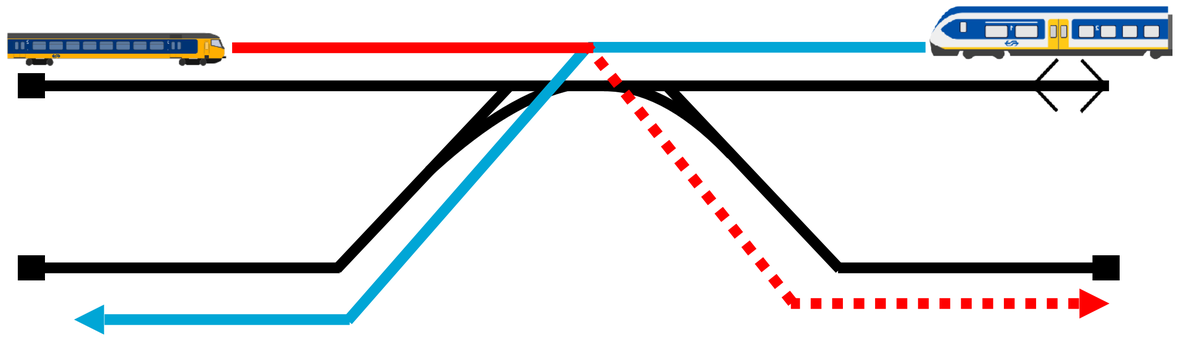

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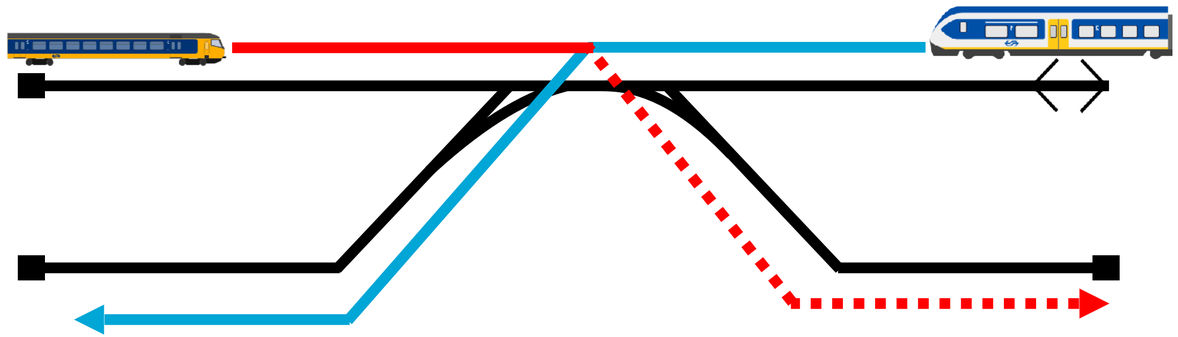

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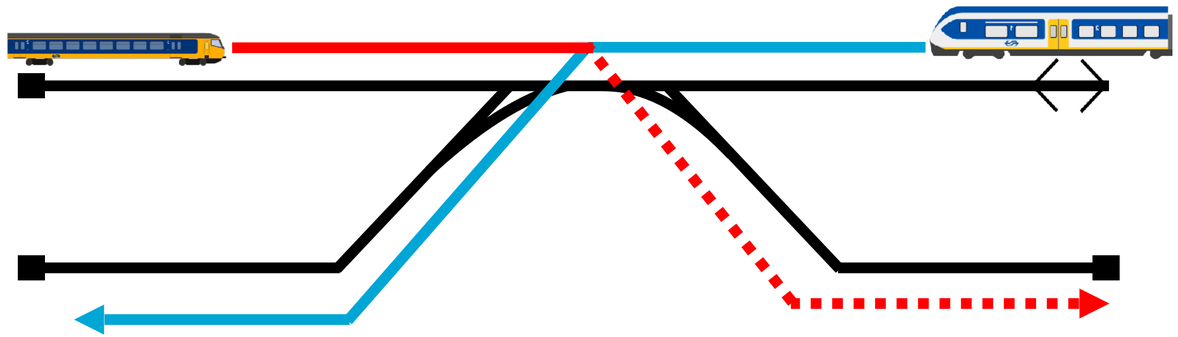
Any-start-time plan( **)**

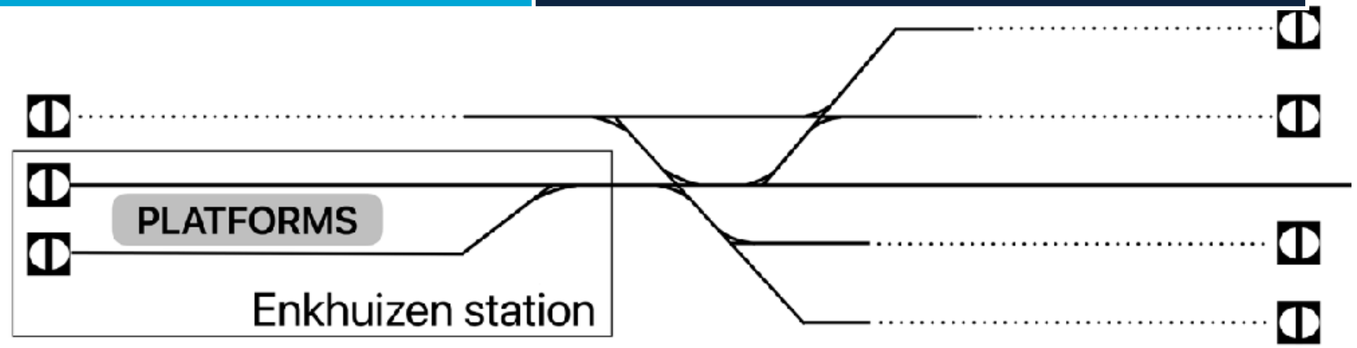
```
Before  crossing:
  Pass in front
Otherwise:
  Wait for other to pass
```



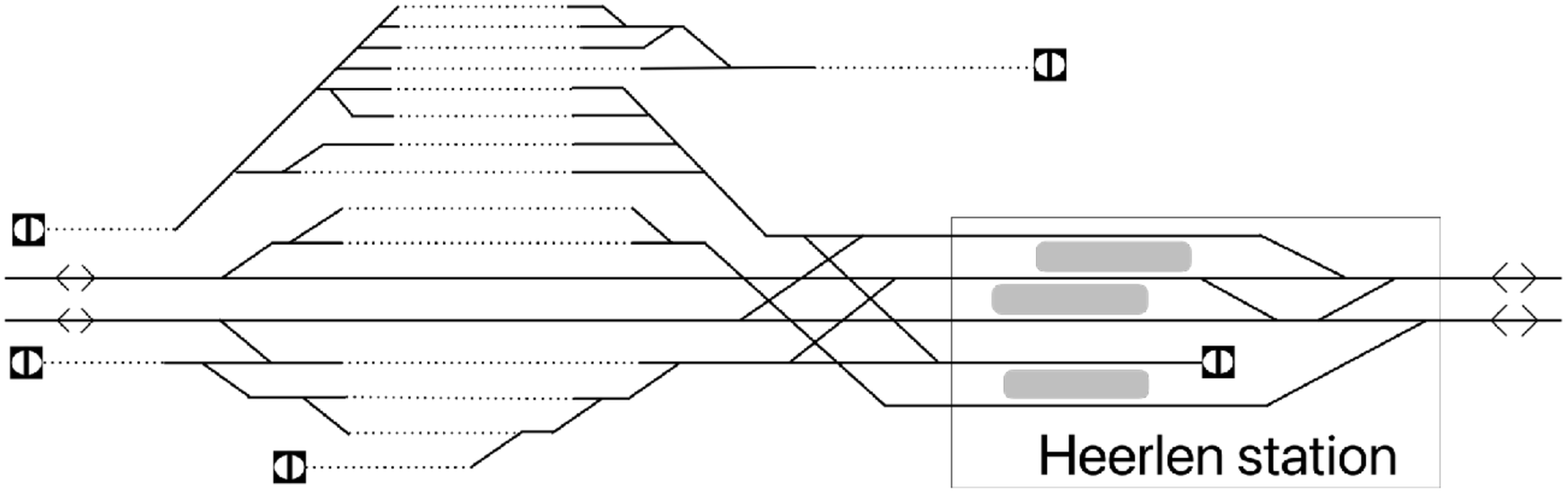
Experimental setup

Experimental setup

- Two railway hub layouts



- Different size scenarios in number of trains (varying from 6 to 50)



End of track — Track ···· Parking track Platforms

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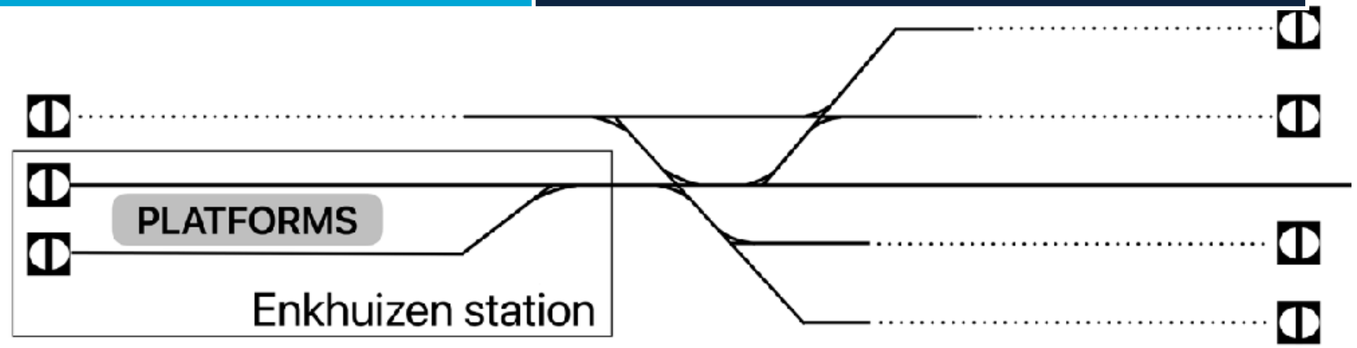


- Two railway hub layouts
- Different size scenarios in number of trains (varying from 6 to 50)
- Compare our method @MAEDeR
  - to Replanning Safe Interval Path Planning (rSIPP)

End of track — Track ···· Parking track Platforms

Results

Real-world scenario: Tuesday morning October 2023

Heerlen has 29 tracks, more than 50 trains would not be realistic

	Enkhuizen station – 13 trains		Heerlen station – 50 trains	
	rSIPP	@MAEDeR	rSIPP	@MAEDeR
Reaching safe state	600 μs	**6 ns**	3 ms	**6 ns**
Partial recovered state	-	0.01 s	-	0.27 s
Fully recovered state	0.01 s	0.01 s	0.27 s	0.28 s

➢ 80% of delays resolved by maintaining same route but later start time

More results in the paper

Where does MAEDeR apply?

When you want to handle delays in a multi agent system where:

- States and actions are either safe or unsafe (SIPP)

For example:

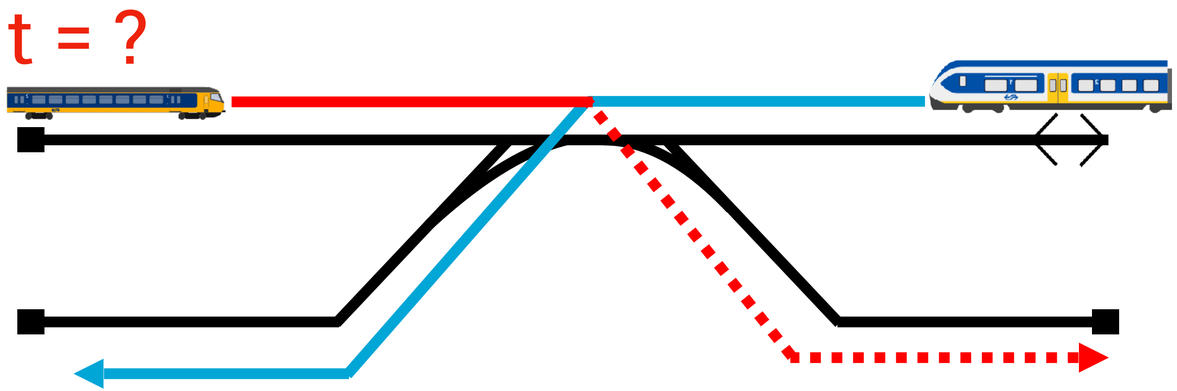
- Warehouses
- Drones
- Container terminals
- etc…

Example application for railways detailed in paper

Conclusion

Instantly recover from a single delayed train without affecting other trains

- Instant delay recovery
- Shift replanning to (fast) precomputation
- First application of any-start-time planning
- Trains as example of other multi-agent applications



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Link to paper

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