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A three-level framework for performance-based railway timetabling

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Outline

- Timetable performance indicators
- Three-level timetabling framework
- Micro-macro iterations
- Corridor fine-tuning
- Conclusions

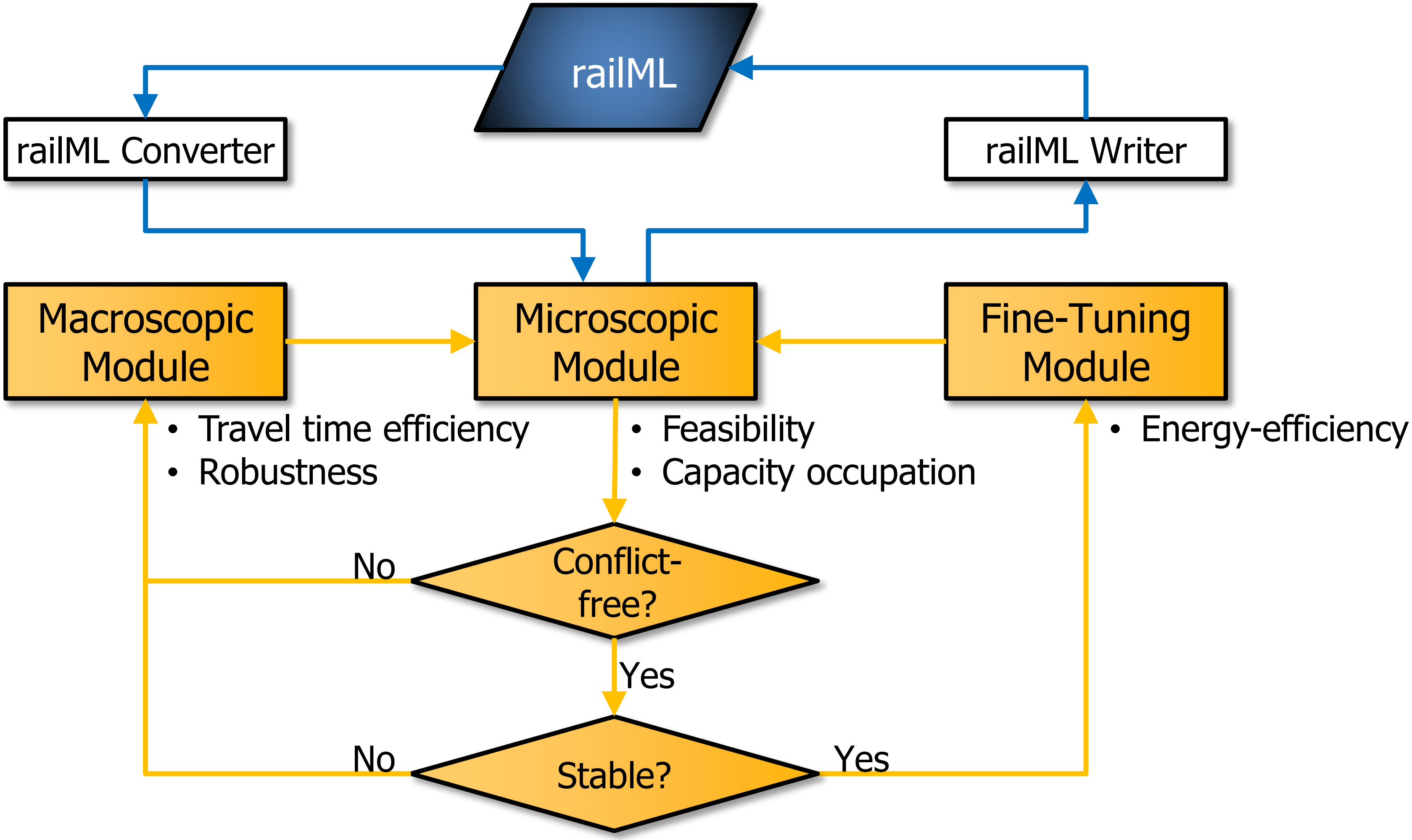
Introduction

Timetable performance indicators

- **Scheduled travel time**
    - Time scheduled between any OD incl. running, dwell and transfer times
- **Infrastructure occupation and stability**
    - Time required for a given timetable pattern on a given infrastructure
    - Sufficient time allowance to settle delays
- **Feasibility**
    - All processes realizable within their scheduled process times
    - Scheduled train paths are conflict free
- **Robustness**
    - Delay propagation behaviour kept within bounds
- **Energy-efficiency**
    - Timetable allows energy efficient train operations

Three-level timetabling framework

Performance-based timetabling



Three-level timetabling framework

Timetabling levels

Microscopic (track section level)

- Speed and running time computations incl. time supplements
- Conflict detection using blocking times
- Infrastructure occupation & stability tests by compression method
- Precision of 1 s

Macroscopic (network level)

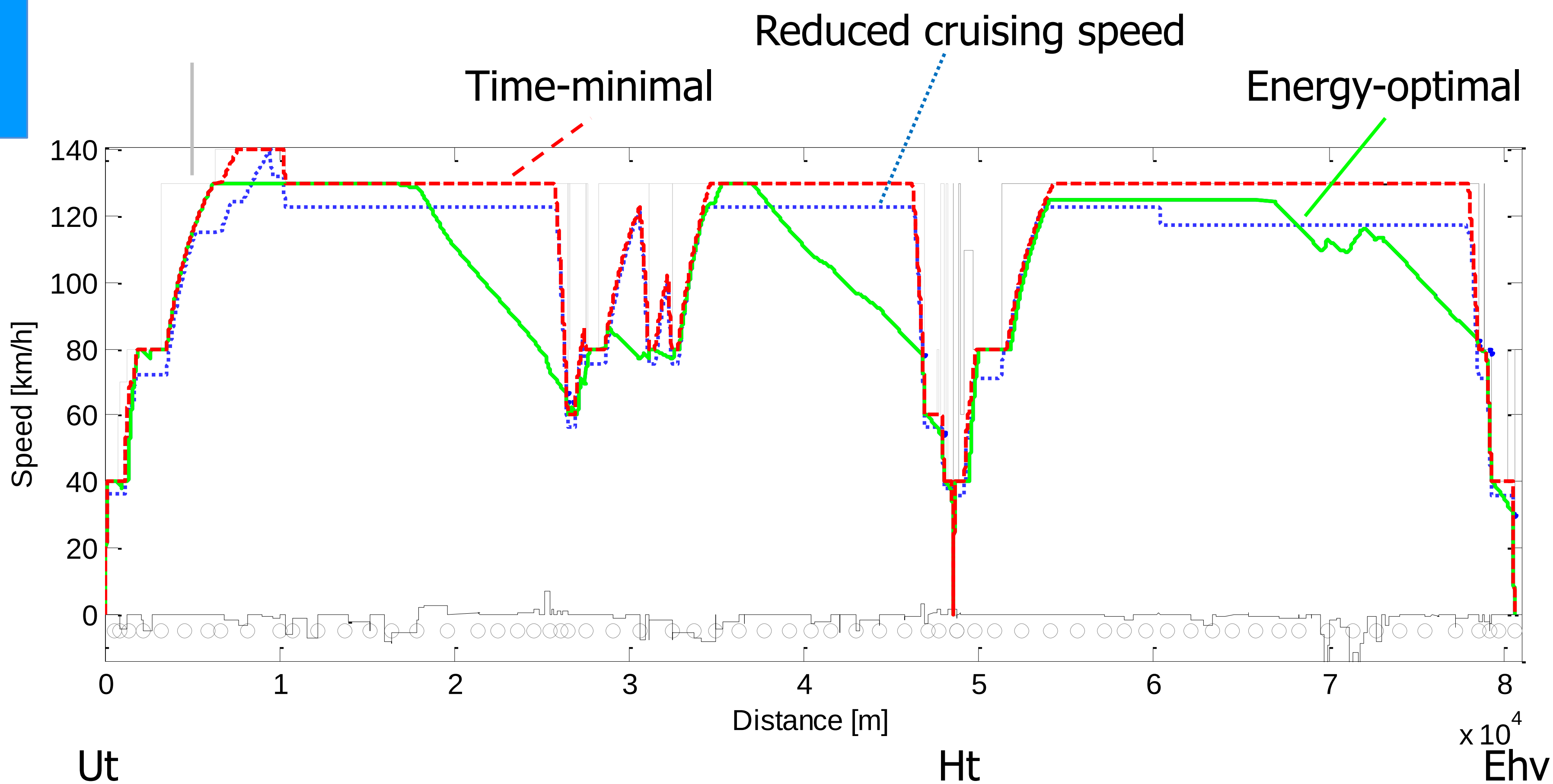
- Network timetable optimization of journey times, transfer times, missed connections, cancelled trains, and settling times (ILP)
- Stochastic robustness analysis using Monte Carlo simulation
- Timetable precision of 5 s minimizing capacity waste

Fine-tuning (corridor level)

- Energy-efficient speed profiles using optimal control
- Stochastic optimization of time allowances for local trains

Micro-macro iterations

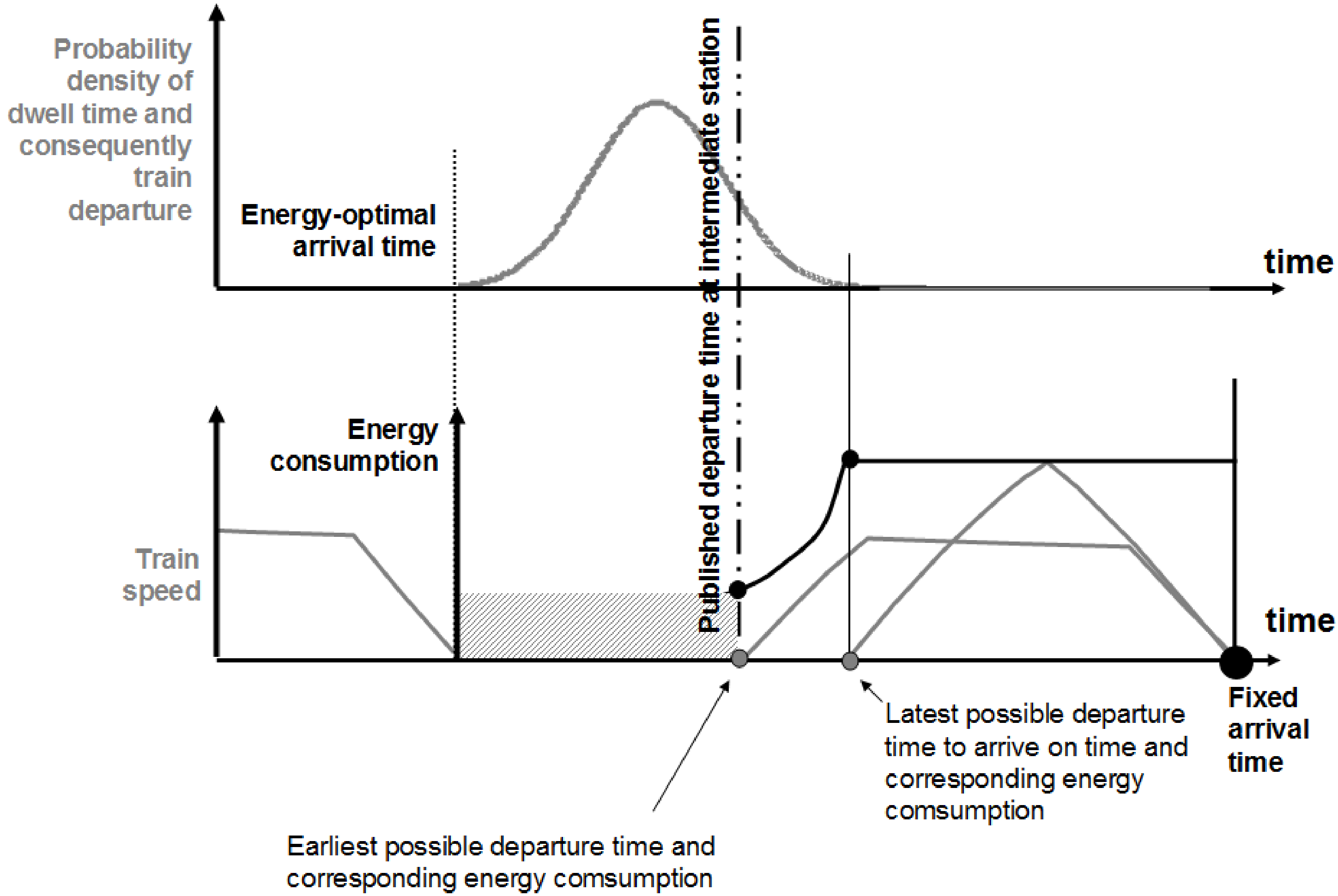
Dealing with running time supplements



- Fastest, non-coasting and energy-efficient speed profiles

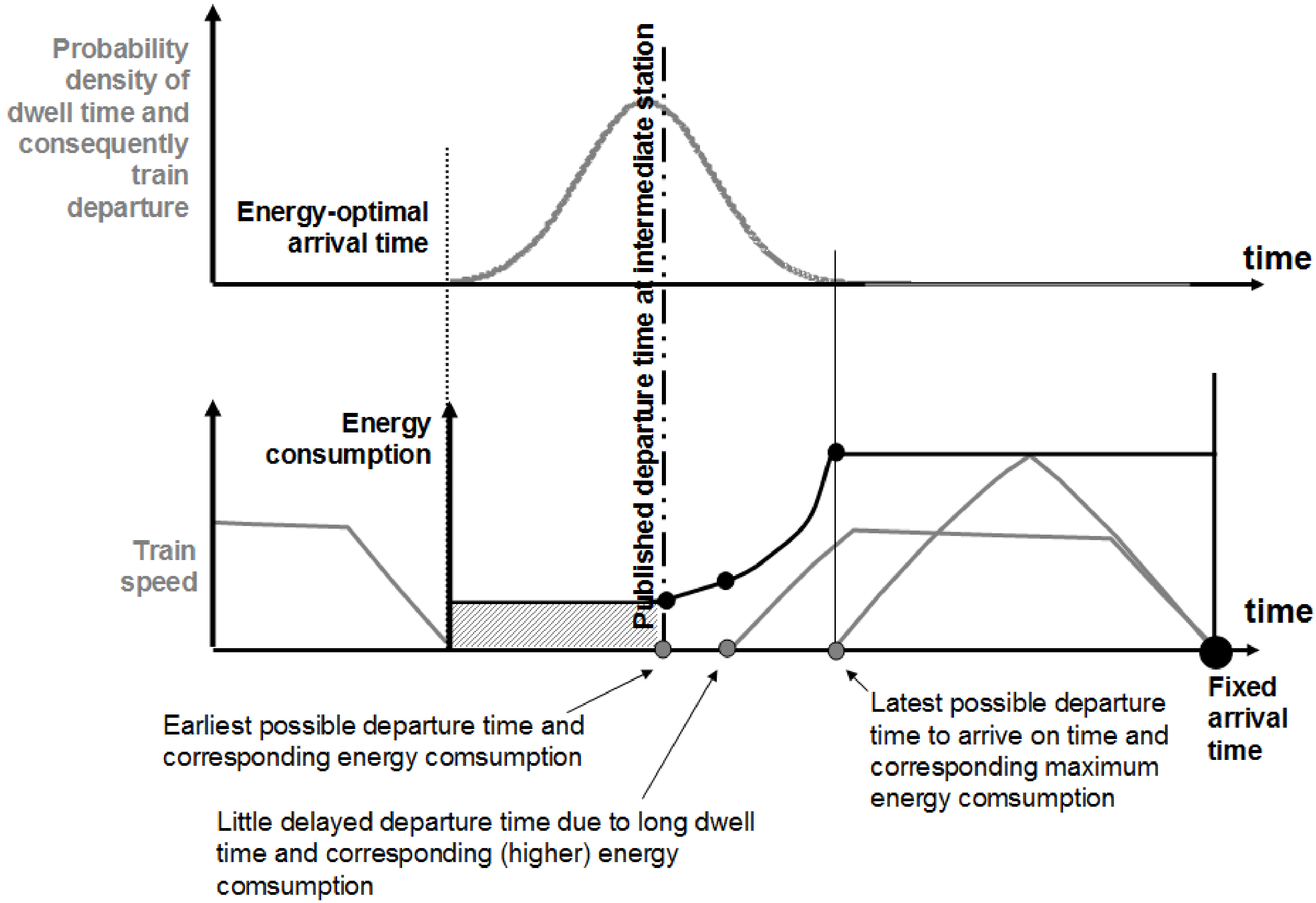
Corridor fine-tuning

Trade-off: time allowance in dwell or running time



Corridor fine-tuning

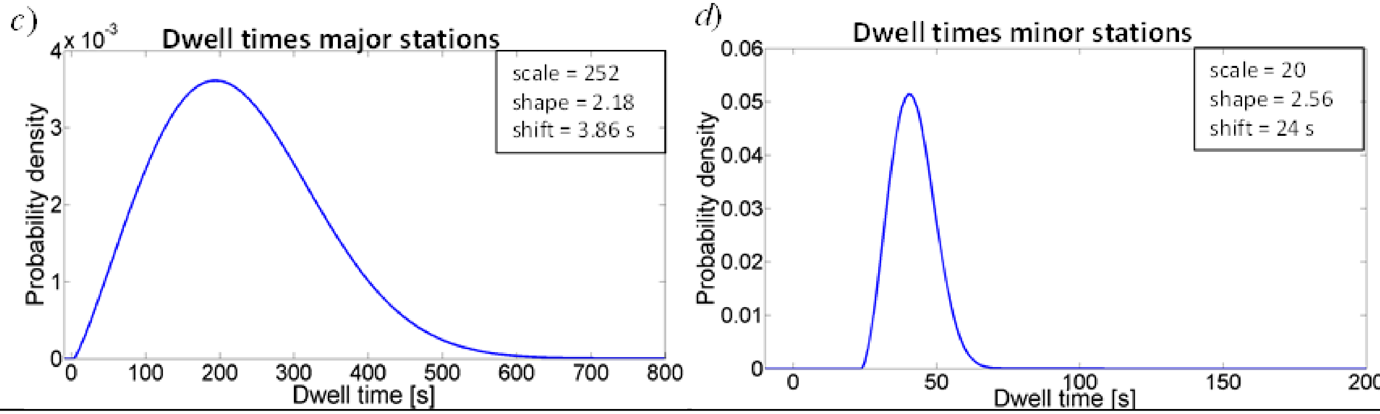
Trade-off: time allowance in dwell or running time



Corridor fine-tuning

Generic model

- For each corridor between main stations (IC stops or overtaking)
- Distribute time allowances of local trains over intermediate stops with respect to stochastic dwell time distributions
- Start and end time fixed at main stations bounding the corridor
    - Total allowance time on corridor fixed
- Bandwidth of train trajectory defined by surrounding (intercity) trains
- Given empirical distributions of dwell times (stations and short stops)
    - Weibull 3-parameter distributions based on Dutch empirical data



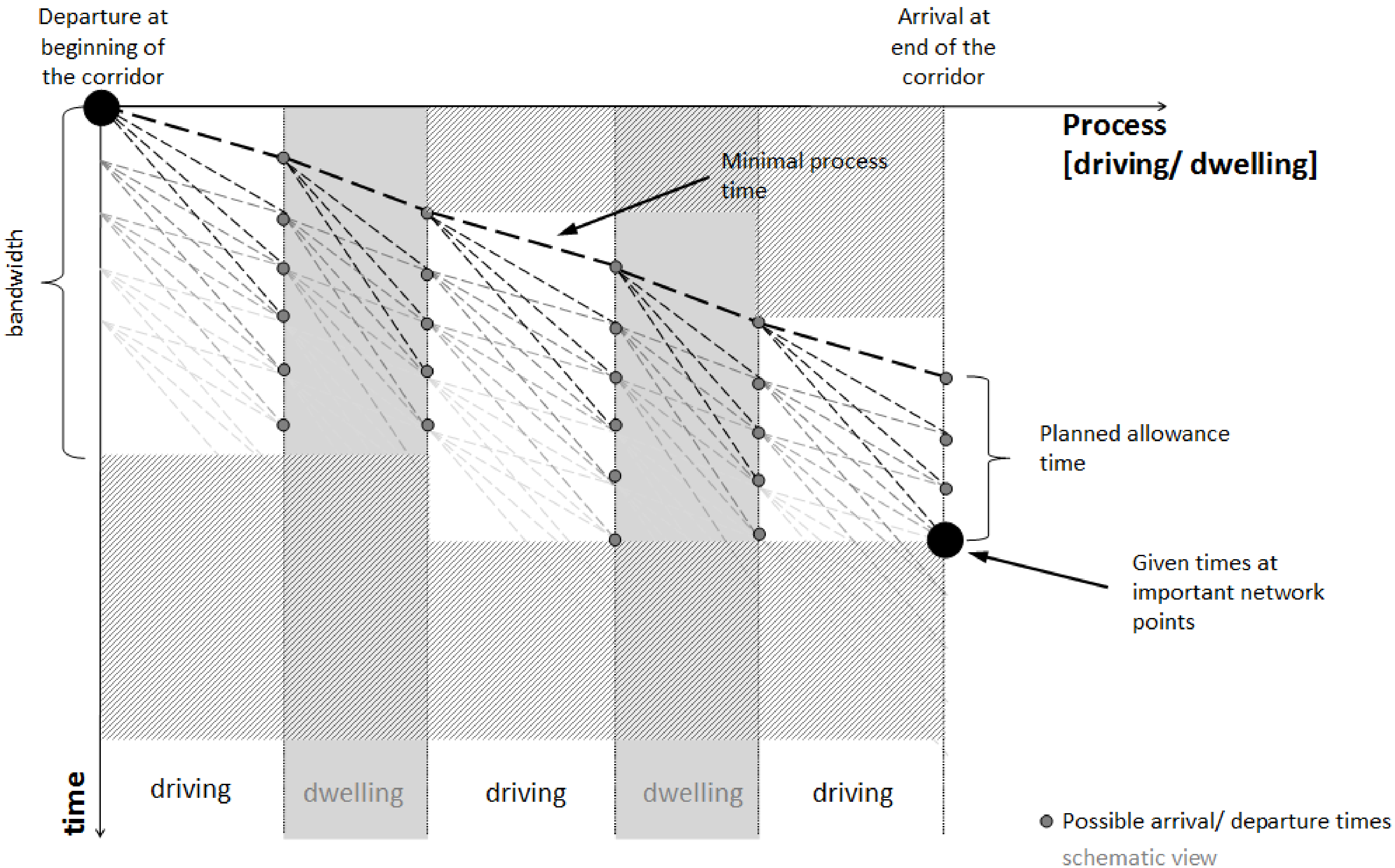
Corridor fine-tuning

Multi-stage multi-objective optimization

- Decision variables
  - Scheduled arrival and departure times at intermediate stops in minutes
- Driving stage
  - Each departure/arrival time pair defines running time supplement
  - Optimal energy consumption computed using optimal control
- Dwelling stage
  - Each arrival/departure time pair defines scheduled dwell time
  - Convolution of all possible arrival times and dwell time distribution gives all possible departure times and their probability
- Cost function: weighted sum of expected arrival delays and energy
- Pre-processing
  - Generate all possible timetables within given bandwidth
  - Compute optimal speed profiles for all possible scheduled running times and the associated energy consumptions

Corridor fine-tuning

Multi-stage multi-objective optimization



Corridor fine-tuning

Multi-stage multi-objective optimization

Cost criteria at each stop (arrival/departure stage) i

- Expected energy consumption until target station at stage i
- Expected delay at target station from stage i
- Expected total delay at intermediate stops from stage i

- Each cost at stage i depends on the time allowance decision at stage i
- Each cost at stage i is a recursive equation in the cost at stage $i + 1$

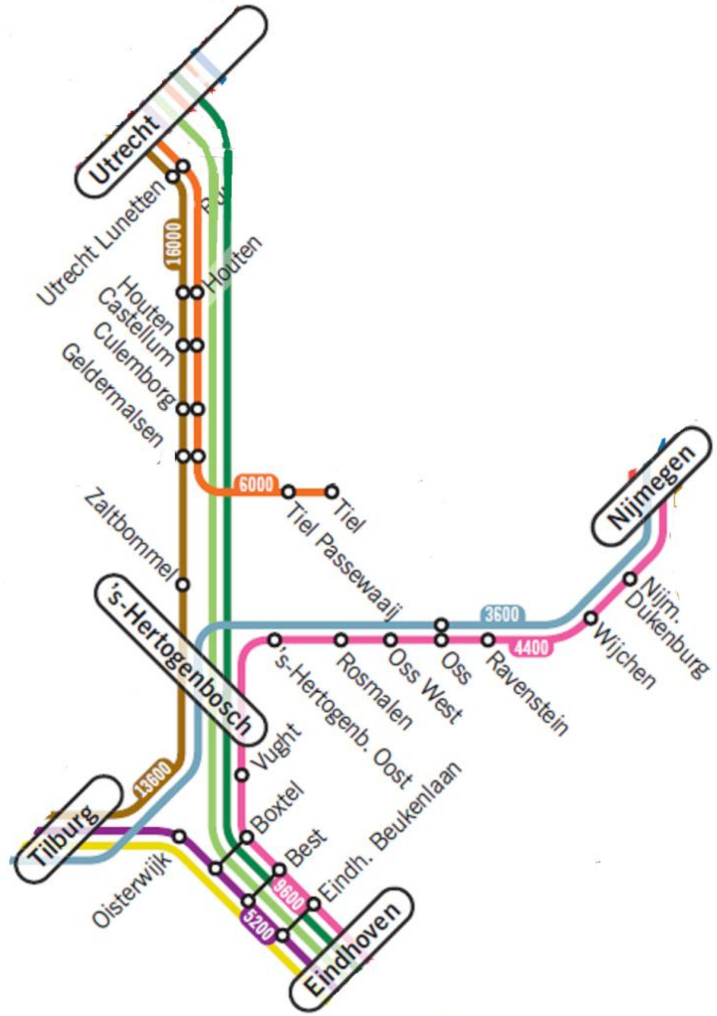
Dynamic programming solution approach

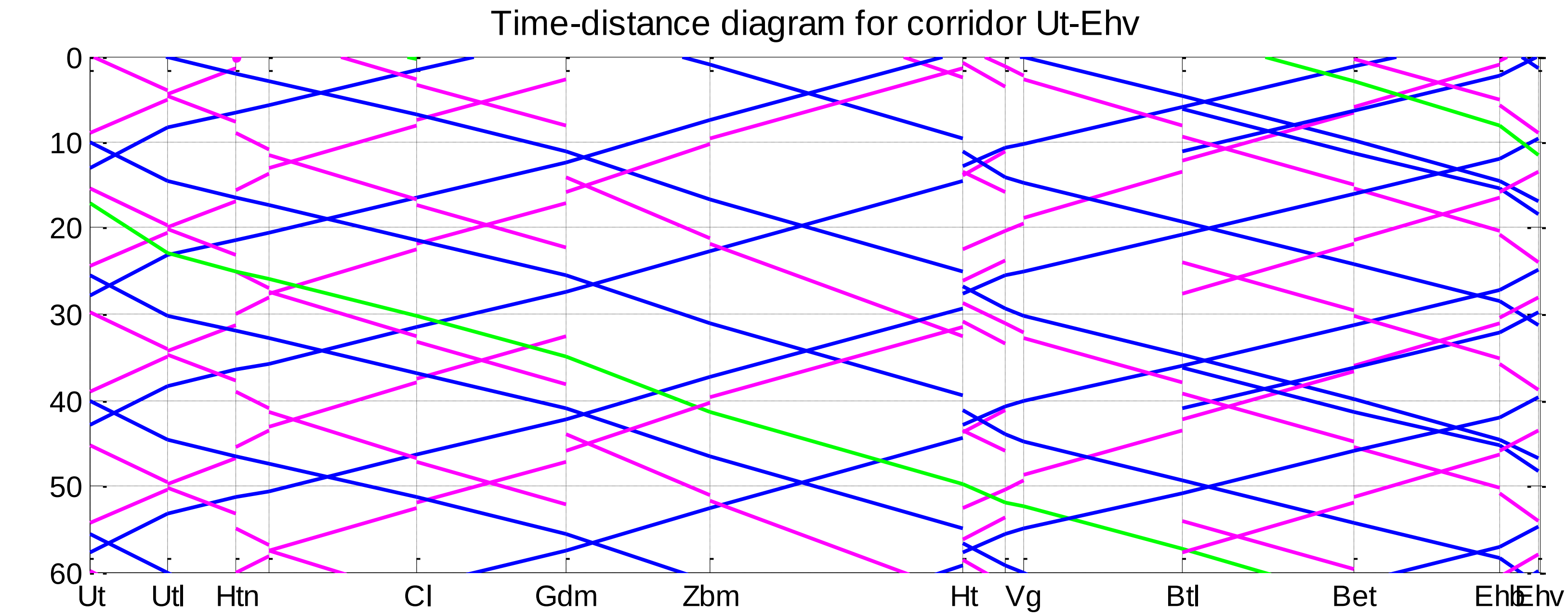
- Solve recursions backwards from target station back to begin
- At each stage find the optimal time allowance at that stage that minimizes a weighted squared sum of the three cost criteria at that stage

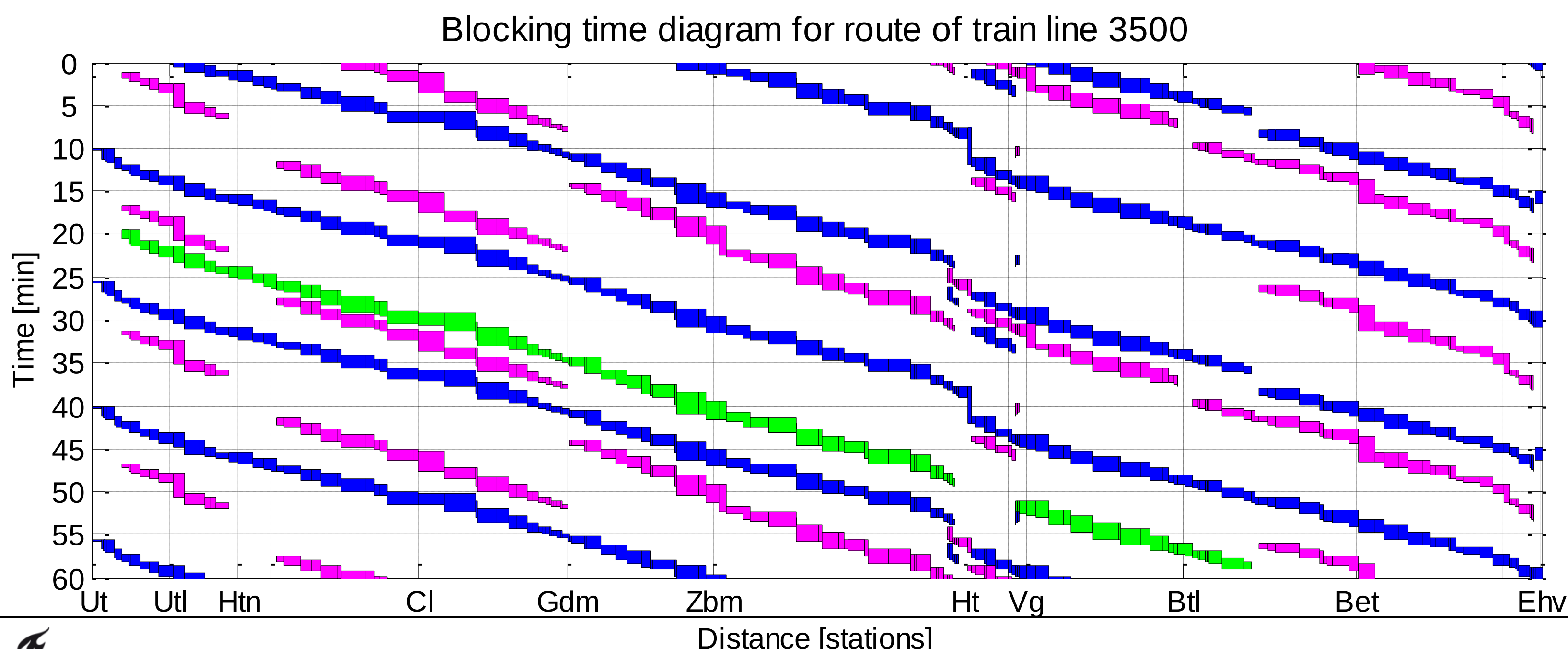
Case study

Dutch network around ‘s Hertogenbosch

- Infrastructure and line plan 2012
- Two intersecting corridors
  - Utrecht-Eindhoven and
  - Tilburg-Nijmegen
- Hourly timetable pattern with
  - 2 x 8 ICs per hr
  - 2 x 10 local trains per hr
  - One freight path (Ut-Ehv)
  - Many transfers in ‘s Hertogenbosch (and elsewhere)




Time-distance diagram for corridor Ut-Ehv
0
10
20
30
40
50
60
Ut Utl Htn Cl Gdm Zbm Ht Vg Btl Bet Ehb Ehv


Blocking time diagram for route of train line 3500
Time [min]
0
5
10
15
20
25
30
35
40
45
50
55
60
Ut Utl Htn Cl Gdm Zbm Ht Vg Btl Bet Ehv
Distance [stations]

Case study

Performance measure results

Maximum capacity consumption			
		Infrastructure occupation time [min]	Infrastructure occupation ratio [%]
Corridor	Ut-Ht	34.7	57.8
Station	Ht	35.0	58.3

Journey time			
	Minimum journey time [min]	Scheduled journey time [min]	Supplement [%]
Ut-Ehv	44.9	48.2	7.3
Ehv-Ut	47.6	51.3	7.8

Energy consumption		
	Energy consumption [kWh]	Energy saving [%]
Minimal-Time	64 395	-
Reduced cruising speed	58 800	8.7
Energy-optimal	41 667	35.3

Case study

Computation time results

		Iterations	Mean time [s]	Total [s]
Initial microscopic computations		1	35	35
Micro-macro iterations				1080
	Macro (1000 macro iterations)	9	80	
	Micro computations	9	40	
Finetuning*				215
	Micro computations	1	5	
	Energy-efficient speed profiles	1	210	
Total				1330
*Excluding stochastic optimization of local trains				

Conclusions

Performance-based railway timetabling

- Integrated method for computing optimal, stable, robust, conflict-free and energy-efficient railway timetables
- Modular implementation of three-level timetabling approach
- Standardized RailML input data (Infrastructure, Rolling Stock, Interlocking, Timetable)
- Output in (extended) standardized RailML Timetable file with scheduled train paths and speed profiles at section level