Toward operationally feasible railway timetables (PPT)

Bešinović, Nikola; Goverde, Rob

Publication date
2016

Document Version
Final published version

Citation (APA)
Bešinović, N., & Goverde, R. (2016). *Toward operationally feasible railway timetables (PPT)*. 2016 INFORMS Annual Meeting, Nashville, United States.

Towards operationally feasible railway timetables

Nikola Bešinović, Rob M.P. Goverde

Delft University of Technology, The Netherlands

INFORMS 2016, Nashville, Tennessee

Outline

Current state in railway traffic

- Constant growth of demand for passenger and freight railway transport
- Heavily congested networks
- Reaching maximum available infrastructure capacity
- Experiencing delays

Current state in railway traffic

- Constant growth of demand for passenger and freight railway transport
- Heavily congested networks
- Reaching maximum available infrastructure capacity
- Experiencing delays

- *Existing need for better planning to satisfy a high level of service*

(ERA, UIC, IMs, RUs...)

Timetable planning

Infrastructure → Line plan → Timetable → Rollingstock → Crew

INPUT:

- Train line requests (OD, stops, frequencies, rolling stock)
- Track topology
- Rolling stock with dynamic characteristics
- Passenger connections and rolling stock turn-arounds

OUTPUT:

- Timetable: arrival, departure and passing times at timetable points

Timetable planning

Goals:

- **Efficiency** - short travel times and seamless connections
- **Realizability** - scheduled RT $>$ minimum RT
- **(Operational) Feasibility** - no conflicts
- **Stability** - acceptable capacity occupation in corridors and stations
- **Robustness** - cope with system stochasticity

Timetable planning

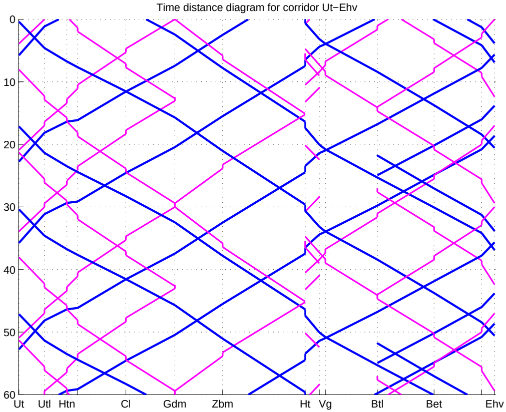
Goals:

- **Efficiency** - short travel times and seamless connections
- **Realizability** - scheduled RT > minimum RT
- **(Operational) Feasibility** - no conflicts
- **Stability** - acceptable capacity occupation in corridors and stations
- **Robustness** - cope with system stochasticity

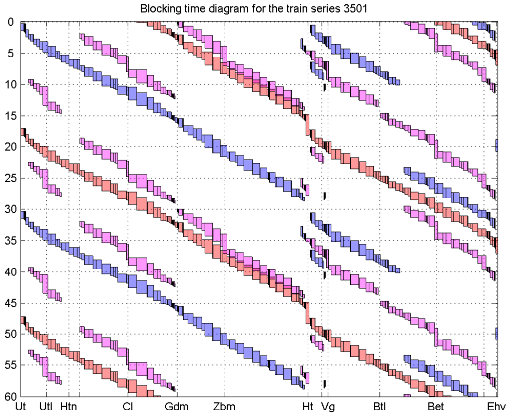
Operationally feasible timetable

An operationally feasible timetable has no conflicts on the microscopic level (block and track detection sections) between train's blocking times.

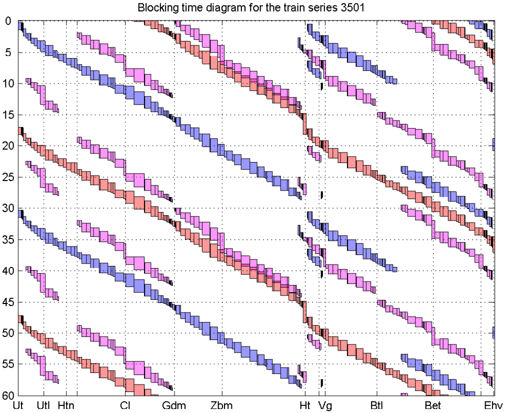
Time-distance diagram



Blocking time diagram



Blocking time diagram



Question:

- How to guarantee the operational feasibility in timetabling models?

Minimum headway time

Minimum headway time (Hansen and Pachl, 2014)

A minimum headway time is the time separation between two trains at certain positions that enable conflict-free operation of trains.

Minimum headway time

Minimum headway time (Hansen and Pachl, 2014)

A minimum headway time is the time separation between two trains at certain positions that enable conflict-free operation of trains.

Minimum headway time L_{ij} depends on:

- infrastructure characteristics: block lengths
- signalling system
- train engine characteristics
- (scheduled) train running times

Minimum headway time

Minimum headway time (Hansen and Pachl, 2014)

A minimum headway time is the time separation between two trains at certain positions that enable conflict-free operation of trains.

Minimum headway time L_{ij} depends on:

- infrastructure characteristics: block lengths
- signalling system
- train engine characteristics
- (scheduled) train running times
- **not a single value**

State-of-the-art

So far:

- **Efficiency** ☺
- **Realizability** ☺
- **(Operational) Feasibility** ☹
- **Stability** - ☺ ☹
- **Robustness** - ☺

Periodic event scheduling problem (PESP)

Serafini & Ukovich (1989)
Periodic timetable with cycle time T
Periodic events: arrival & departure times $\pi_i \in [0, T)$

Periodic event scheduling problem (PESP)

Serafini & Ukovich (1989)
Periodic timetable with cycle time T
Periodic events: arrival & departure times $\pi_i \in [0, T)$
Constraints:

$$lowerBound_{ij} \leq \pi_j - \pi_i + z_{ij} T \leq upperBound_{ij}$$

Periodic event scheduling problem (PESP)

Serafini & Ukovich (1989)
Periodic timetable with cycle time T
Periodic events: arrival & departure times $\pi_i \in [0, T)$
Constraints:

$$lowerBound_{ij} \leq \pi_j - \pi_i + z_{ij} T \leq upperBound_{ij}$$

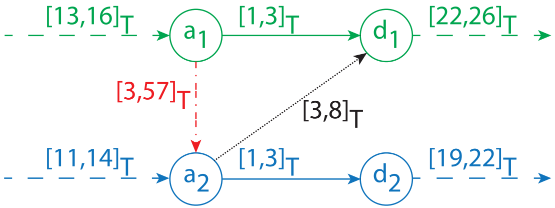
Period shift: z_{ij} - define the order of trains

Periodic event scheduling problem (PESP)

Serafini & Ukovich (1989)
Periodic timetable with cycle time T
Periodic events: arrival & departure times $\pi_i \in [0, T)$
Constraints:

$$lowerBound_{ij} \leq \pi_j - \pi_i + z_{ij} T \leq upperBound_{ij}$$

Period shift: z_{ij} - define the order of trains



Solving PESP

$$(PESP - N) \quad \text{Min } f(\pi, z)$$

such that

$$l_{ij} \leq \pi_j - \pi_i + z_{ij} T \leq u_{ij} \qquad \forall (i,j) \in A$$

$$0 \leq \pi_i < T, \quad \forall i$$

$$z_{ij} \ \textit{binary}$$

Computing operationally feasible timetables

Solving PESP-N:

- Fixed minimum headways
- Can be violated when scheduled running time increases

Computing operationally feasible timetables

Solving PESP-N:

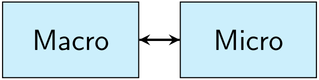
- Fixed minimum headways
- Can be violated when scheduled running time increases

How to include microscopic details in timetable planning models?

- Iterative approach
- Integrated approach

TU Delft Delft University of Technology

Iterative micro-macro framework (*Transp. Res. B*, 2016)



Micro model (*Comp-aided Civil and Inf. Eng.*, 2016):

- Compute operational train speed profiles
- Conflict detection
- Update headways

Integrated approach

Can we add microscopic details directly to the macroscopic level?

Integrated approach

Can we add microscopic details directly to the macroscopic level? Yes.

Integrated approach

Can we add microscopic details directly to the macroscopic level? Yes.

Introduce flexible minimum headways in PESP

Integrated approach

$$(PESP - N) \ \ \text{Min} \ f(\pi, z)$$

such that

$$l_{ij} \leq \pi_j - \pi_i + z_{ij} \cdot T \leq u_{ij} \qquad \forall (i,j) \in A$$

$$0 \leq \pi_i < T, \quad \forall i$$

$$z_{ij} \ \ binary$$

Integrated approach

$$(PESP - FlexHeadways) \quad \text{Min } f(\pi, z)$$

such that

$$l_{ij} \leq \pi_j - \pi_i + z_{ij} \cdot T \leq u_{ij} \qquad \forall (i,j) \in A_{run} \cup A_{dwell}$$

$$L_{ij} \leq \pi_j - \pi_i + z_{ij} \cdot T \leq U_{ij} \qquad \forall (i,j) \in A_{headway}$$

$$0 \leq \pi_i < T, \quad \forall i$$

$$z_{ij} \ binary$$

L_{ij} = F(running times of two trains)

$L_{ij} = F(running\ times\ of\ two\ trains)$

For each train pair at each timetable point:

- vary running speeds = amount of time supplements
- compute minimum headway time for each trains-speeds variations
- get functional relationship between given time supplements and minimum headways → L_{ij}

$L_{ij} = F(running\ times\ of\ two\ trains)$

For each train pair at each timetable point:

- vary running speeds = amount of time supplements
- compute minimum headway time for each trains-speeds variations
- get functional relationship between given time supplements and minimum headways $\rightarrow L_{ij}$

Expected: bigger speed difference $\rightarrow$ bigger minimum headway time

- more homogenized running times $\rightarrow$ smaller minimum headway time
- second train faster $\rightarrow$ minimum headway increases

TU Delft Delft University of Technology

$L_{ij} = F(running\ times\ of\ two\ trains)$

run_{ik} - running time supplement of the first train (in %)
run_{jl} - running time supplement of the second train (in %)
R_{ij} - relative difference between time supplements of two trains (in %)

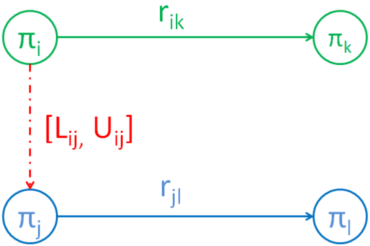
$$R_{ij} = run_{ik} - run_{jl}$$

$L_{ij} = F(running\ times\ of\ two\ trains)$

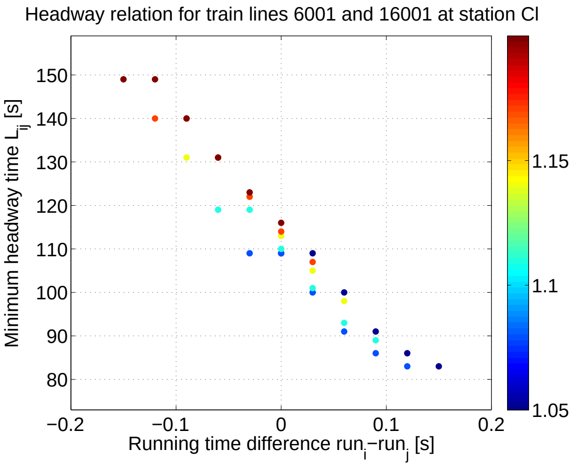
run_{ik} - running time supplement of the first train (in %)
run_{jl} - running time supplement of the second train (in %)
R_{ij} - relative difference between time supplements of two trains (in %)

$$R_{ij} = run_{ik} - run_{jl}$$

$$run_{ik} = r_{ik}/\overline{r}_{ik} - 1 \qquad run_{jl} = r_{jl}/\overline{r}_{jl} - 1$$



$L_{ij} = F(running\ times\ of\ two\ trains)$

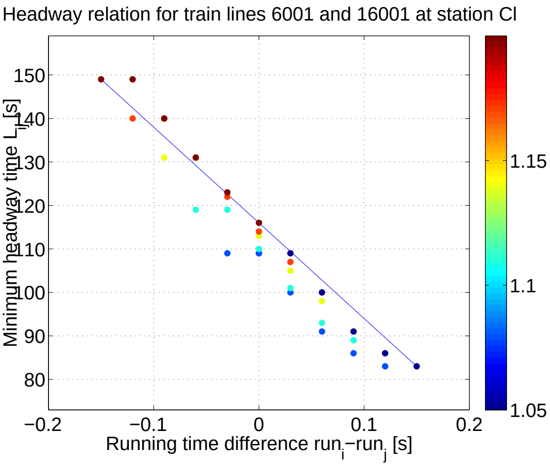


$run_{ik} - run_{jl} > 0$: the first train is faster*

$run_{ik} - run_{jl} < 0$: the second train is faster*

* Assuming the same category trains

$L_{ij} = F(running\ times\ of\ two\ trains)$



$run_1 - run_2 > 0$: the first train is faster*

$run_1 - run_2 < 0$: the second train is faster*

* Assuming the same category trains

$L_{ij} = F(running\ times\ of\ two\ trains)$

Linear dependency between run_{ik} and run_{jl}

$$L_{ij} = \alpha_{ij} \cdot R_{ij} + l_0$$

α_{ij} - slope of L_{ij}
R_{ij} - relative difference between time supplements of two trains (in %)
l_0 - minimum headway time for $run_{ik} = run_{jl}$

Integrated approach

$$(PESP - FlexHeadways) \quad \text{Min } f(\pi, z)$$

such that

$$l_{ij} \leq \pi_j - \pi_i + z_{ij} \cdot T \leq u_{ij} \qquad \forall (i,j) \in A_{run} \cup A_{dwell}$$

$$\alpha_{ij} \cdot R_{ij} + l_0 \leq \pi_j - \pi_i + z_{ij} \cdot T \leq u_{ij} \qquad \forall (i,j) \in A_{headway}$$

$$R_{ij} = run_{ik} - run_{jl}$$

$$0 \leq \pi_i < T, \quad \forall i$$

$$z_{ij} \; binary$$

Case studies

Case network: Utrecht - Eindhoven network (two intersecting corridors)

- 15 stations and junctions
- 40 trains/h
- 96 events and 148 activities

Minimum running time supplement: 5%
Maximum running time supplement: 20%
Minimum dwell times: 60-120 s

Test: Iterative micro-macro and integrated PESP-FlexHeadway models

Case 1: Utrecht-Eindhoven network

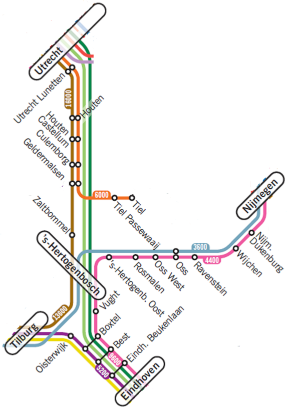


Figure: Line plan

Computed timetables

Table: Solutions obtained after the first iteration

Model	# of conflicts [train pairs]	Total time in conflicts [s]	Scheduled time supplements [s]
Iterative micro-macro*	4	160	10
Integrated PESP-FlexHeadway	0	0	382

*After first iteration

Computed timetables

Table: Solutions obtained after the first iteration

Model	# of conflicts [train pairs]	Total time in conflicts [s]	Scheduled time supplements [s]
Iterative micro-macro*	4	160	10
Integrated PESP-FlexHeadway	0	0	382

*After first iteration

Iterative micro-macro framework finished after 10 iterations

Computed timetables

Table: Solutions obtained after the first iteration

Model	# of conflicts [train pairs]	Total time in conflicts [s]	Scheduled time supplements [s]
Iterative micro-macro*	4	160	10
Integrated PESP-FlexHeadway	0	0	382

*After first iteration

Iterative micro-macro framework finished after 10 iterations

PESP-FlexHeadway allocated more time supplements to satisfy new headways

Computed timetables

Table: Solutions obtained after the first iteration

Model	# of conflicts [train pairs]	Total time in conflicts [s]	Scheduled time supplements [s]
Iterative micro-macro*	4	160	10
Integrated PESP-FlexHeadway	0	0	382

*After first iteration

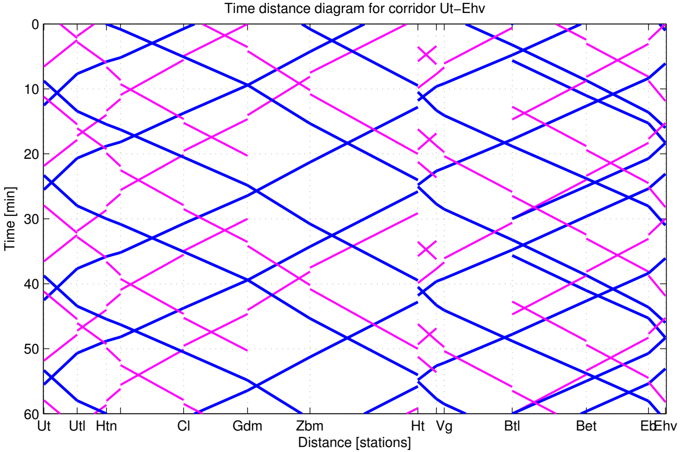
Iterative micro-macro framework finished after 10 iterations

PESP-FlexHeadway allocated more time supplements to satisfy new headways

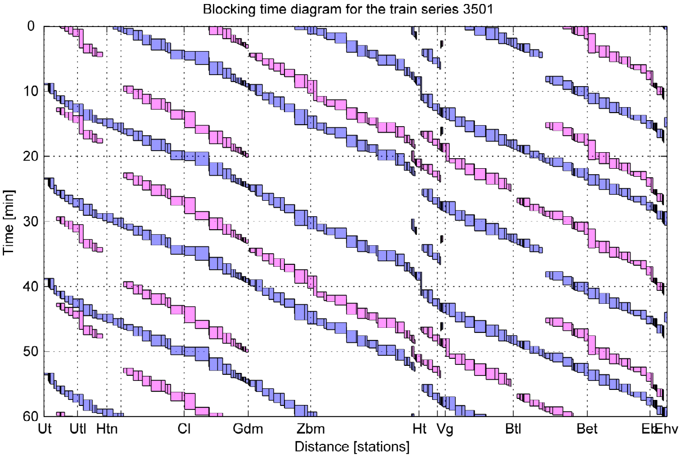
CPU times are comparable

TU Delft Delft University of Technology

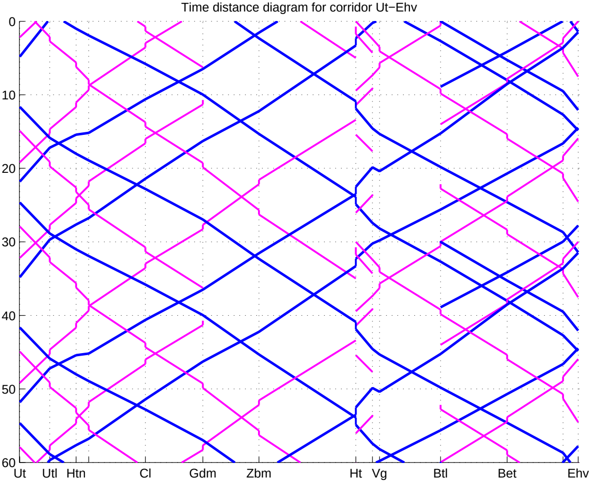
Iterative micro-macro framework



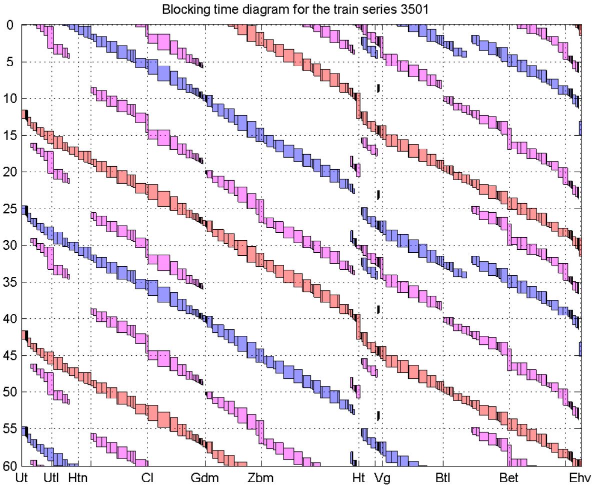
Iterative micro-macro framework



Integrated framework: PESP-FlexHeadway

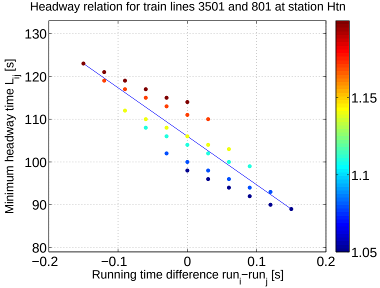


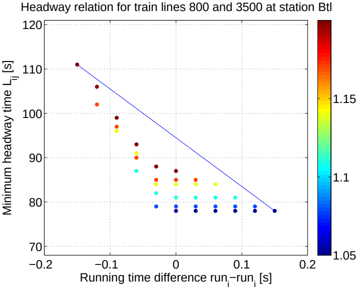
Integrated framework: PESP-FlexHeadway

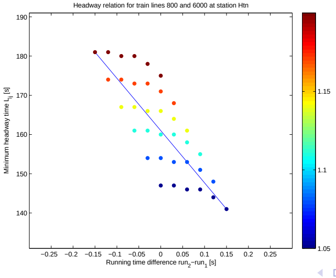


TU Delft Delft University of Technology

Some more headways...







Conclusions

Main observations:

- We can compute operationally feasible timetables
- Iterative approach solves within a limited number of iterations
- Minimum headway times as a function of running times
- Macroscopic Flexible minimum headway model formulation generates (almost) operationally feasible solutions

Conclusions

Main observations:

- We can compute operationally feasible timetables
- Iterative approach solves within a limited number of iterations
- Minimum headway times as a function of running times
- Macroscopic Flexible minimum headway model formulation generates (almost) operationally feasible solutions

Pursuing the (passenger) happiness

- Is linear approximation always good? Piecewise linear?
- Include stability and robustness in the objective function
- Test the model on bigger instances

TU Delft Delft University of Technology

Thank you for your attention

Iterative micro-macro framework

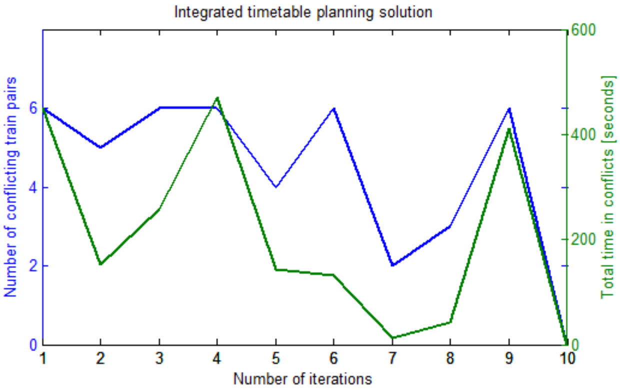


Figure: Micro-macro iterations