Towards operationally feasible railway timetables

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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...)

N.Besinovic (n.besinovic@tudelft.nl)
Timetable planning

**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

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**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

Time distance diagram for corridor Ut–Ehv

N.Besinovic (n.besinovic@tudelft.nl)
How to guarantee the operational feasibility in timetabling models?
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.
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Minimum headway time $L_{ij}$ depends on:

- infrastructure characteristics: block lengths
- signalling system
- train engine characteristics
- (scheduled) train running times
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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 $\pi_i \in [0, T)$
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Constraints:

$$\text{lowerBound}_{ij} \leq \pi_j - \pi_i + z_{ij} T \leq \text{upperBound}_{ij}$$
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\[
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Period shift: $z_{ij}$ - define the order of trains
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Period shift: $z_{ij}$ - define the order of trains

![Diagram showing periodic event scheduling]

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Solving PESP

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

such that

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

\[0 \leq \pi_i < T, \ \forall i\]

\[z_{ij} \text{ binary}\]
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

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

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

\[0 \leq \pi_i < T, \quad \forall i\]

\[z_{ij} \text{ binary}\]
Integrated approach

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

such that

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

\[L_{ij} \leq \pi_j - \pi_i + z_{ij} \cdot T \leq U_{ij} \quad \forall (i, j) \in A_{\text{headway}}\]

\[0 \leq \pi_i < T, \quad \forall i\]

\[z_{ij} \text{ binary}\]

\[L_{ij} = F(\text{running times of two trains})\]
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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 \( \rightarrow L_{ij} \)
\[ L_{ij} = F(\text{running times of two trains}) \]

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
\[ L_{ij} = F(\text{running times of two trains}) \]

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

\[
R_{ij} = \text{run}_{ik} - \text{run}_{jl}
\]
$L_{ij} = F(\text{running times of two trains})$

- $run_{ik}$ - 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 %)

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

$$run_{ik} = r_{ik}/\bar{r}_{ik} - 1 \quad run_{jl} = r_{jl}/\bar{r}_{jl} - 1$$
\[ L_{ij} = F(\text{running times of two trains}) \]

Headway relation for train lines 6001 and 16001 at station CI

\[ \text{run}_{ik} - \text{run}_{jl} > 0: \text{ the first train is faster}^* \]
\[ \text{run}_{ik} - \text{run}_{jl} < 0: \text{ the second train is faster}^* \]

* Assuming the same category trains
\[ L_{ij} = F(\text{running times of two trains}) \]

**Headway relation for train lines 6001 and 16001 at station CI**

- \( \text{run}_1 - \text{run}_2 > 0 \): the first train is faster*
- \( \text{run}_1 - \text{run}_2 < 0 \): the second train is faster*

* Assuming the same category trains
\[ L_{ij} = F(\text{running times of two trains}) \]

Linear dependency between \( \text{run}_{ik} \) and \( \text{run}_{jl} \)

\[ L_{ij} = \alpha_{ij} \cdot R_{ij} + l_0 \]

\( \alpha_{ij} \) - slope of \( L_{ij} \)
\( R_{ij} \) - relative difference between time supplements of two trains (in \%) 
\( l_0 \) - minimum headway time for \( \text{run}_{ik} = \text{run}_{jl} \)
Integrated approach

\[(PESP - FlexHeadways) \text{ Min } f(\pi, z)\]

such that

\[l_{ij} \leq \pi_j - \pi_i + z_{ij} \cdot T \leq u_{ij}\]

\[\alpha_{ij} \cdot R_{ij} + l_0 \leq \pi_j - \pi_i + z_{ij} \cdot T \leq u_{ij}\]

\[R_{ij} = run_{ik} - run_{jl}\]

\[0 \leq \pi_i < T, \quad \forall i\]

\[z_{ij} \text{ binary}\]

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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

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<th>Model</th>
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*After first iteration
Computed timetables

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*After first iteration
Iterative micro-macro framework finished after 10 iterations
Committed timetables

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Iterative micro-macro framework finished after 10 iterations
PESP-FlexHeadway allocated more time supplements to satisfy new headways
**Computed timetables**

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*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
Iterative micro-macro framework

Time distance diagram for corridor Ut–Ehv

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Iterative micro-macro framework

Blocking time diagram for the train series 3501
Integrated framework: PESP-FlexHeadway

Time distance diagram for corridor Ut−Ehv

Integrated framework: PESP-FlexHeadway

Time distance diagram for corridor Ut−Ehv

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Integrated framework: PESP-FlexHeadway
Some more headways...

Headway relation for train lines 3501 and 801 at station Htn

Headway relation for train lines 800 and 3500 at station Btl

Headway relation for train lines 800 and 6000 at station Htn
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:

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- 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
Thank you for your attention
Iterative micro-macro framework

Figure: Micro-macro iterations