The OpenTrack API - further Experiences

Case Study using OpenTrack for benchmarking automatically generated timetable scenarios specified by the transport service intention
1. Basics: Timetable Planning for construction intervals
   a. Interval planning application concept
   b. Timetabling process
   c. Use cases
   d. Service intention as functional requirement for automated scheduling service
   e. Performance indicators resulting from SII and MPPA
   f. Demonstration of lab environment

2. Case Study
   a. Relation between macroscopic timetabling and microscopic simulation
   b. Planning Cases for construction interval
   c. Evaluation of planning cases

3. Summary
Basics: Application concept: IP

Timetable Planning for construction intervals (IP),

Requirements:

• Fast, computer aided development of timetable scenarios
• Easy assessment of timetable scenario performance.
• Quality assessment of timetables with respect to:
  1. Customer convenience, of transport service offer (service intention, SI),
  2. Operational feasibility and stability of timetable scenario.
Basics: Timetabling process as iterative computer aided decision support*

Restrictions of the infrastructure
- macroscopic modelling of the infrastructure over nodes and links
- modelling of the safety system over headway times on lines, at stations and junctions
- minimal trip and dwell times for each train, line and station
- if desired minimal turnaround times

Functional Requirements
- description of train lines over a sequence of macroscopic nodes which are passed on their driving path and tracks used on the lines
- maximal trip and dwell times for each train line and station
- connections between train lines including a minimal and maximal time for transfers
- train frequencies and train separations in time
- fixation of train departure times to a given time interval

PESP: Periodic Event Scheduling Problem

Algorithms

hourly pattern for a macroscopic periodic timetable optimizing total passenger travel time

macroscopic timetable evaluation

manual input adaptations from planners

MaxPlus Algebra

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*Herrigel-Wiedersheim, S. (2015). Algorithmic decision support for the construction of periodic railway timetables, diss. ETH no. 22548,
Aim of Use Case 1: Handling of restricted infrastructure availability

In case of planned or unplanned restrictions of infrastructure, the system is required to (automatically) generate a service intention, which is customer oriented and operationally feasible.
Aim of Use Case 2a, Automated Timetabling:
Given valid service intentions for input, the system is required to (automatically) generate timetable scenarios which can be assessed quantitatively in terms of operational stability.
Aim of Use Case 2b, Simulative Validation of operational feasibility and stability:
Customer orientation and operational feasibility of automatically generated timetable scenarios should be validated on a microtopological resolution with the help of OpenTrack.
**Basics: Service Intention (SI) as Input for IBM TraMP**

**Functional Specification of Schedule**
- partial periodic service intention (short ppSI)

\[
\tilde{G} = (Z, C, D, \bar{\rho})
\]

- Single train run
  (Train type, stopping stations, dwelltimes, section trip times, \(\omega\) service slot, periodicity, number of repetitions)

\[
z = \left(\tilde{z}, \left( v_k, t_{dwell}^k, t_{dwell}^k, t_{trip}^k, t_{trip}^k, \omega_k^-, \omega_k^+ \right)_{k=0}^K, \rho, R \right)
\]

- Transfer times
  (Train runs, stopping station, \(r_i\)-th repetition of train run \(z_i\), \(\theta\) maximum connection time)

\[
c = (z_1, z_2, v, r_1, r_2, \theta^+) \]

## Basics: User Interface

### UI-Table Service (TrainRun)

<table>
<thead>
<tr>
<th>Service ID</th>
<th>Train RunNr</th>
<th>Sta_A</th>
<th>WN_A</th>
<th>Stp_A</th>
<th>Stp_AT</th>
<th>Stp_B</th>
<th>WN_B</th>
<th>Sta_B</th>
<th>LineType</th>
<th>Rolling Stock</th>
<th>Periodicity</th>
<th>Repeat</th>
<th>Periode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>00:31</td>
<td>00:32</td>
<td>00:45</td>
<td>00:56</td>
<td></td>
<td></td>
<td></td>
<td>SB</td>
<td>1x DPZ</td>
<td>60</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
<td>01:24</td>
<td>01:21</td>
<td>01:10</td>
<td>00:59</td>
<td></td>
<td></td>
<td></td>
<td>SB</td>
<td>1x DPZ</td>
<td>60</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>00:29</td>
<td>00:26</td>
<td></td>
<td>00:01</td>
<td>00</td>
<td>IR</td>
<td></td>
<td>IC 2000</td>
<td>259m</td>
<td>60</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>00:30</td>
<td>00:31</td>
<td></td>
<td>00:56</td>
<td>00:59</td>
<td>IR</td>
<td></td>
<td>IC 2000</td>
<td>259m</td>
<td>60</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td>00:29</td>
<td>00:02</td>
<td>00:01</td>
<td>SB</td>
<td>1x DPZ</td>
<td>60</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
<td>00:31</td>
<td>00:56</td>
<td>00:59</td>
<td>SB</td>
<td>1x DPZ</td>
<td>60</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### UI-Tabelle Turnarounds (Transition of TrainRuns)

<table>
<thead>
<tr>
<th>Turnaround ID</th>
<th>OperationPoints</th>
<th>TrainRunNr</th>
<th>MinTurnaround Time</th>
<th>r1</th>
<th>r2</th>
<th>cyclic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stp_AT</td>
<td>10</td>
<td>11</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Sta_A</td>
<td>20</td>
<td>21</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Stp_B</td>
<td>30</td>
<td>31</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Sta_A</td>
<td>11</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Sta_B</td>
<td>21</td>
<td>20</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>Sta_B</td>
<td>31</td>
<td>30</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Basics: Service Intention (SI) in graphical timetable

Example SI-timeslot for corridor Zürich Airport – Winterthur
Service Quality: SI-Index (SII)
Performance Indicator, referring to the Service Time Spent per Period \( STSpP \) of the transport service:

\[
SII = \frac{STSpP^{\text{Plan}}}{STSpP^{\text{Dispo}}} , SII \in [0,1]
\]

SI-Index (SII), number between 0 and 1, indicating the relative distance to the original service intention.

Planned Service Time Spent per Period (\( STSpP^{\text{Plan}} \)),
The originally planned SI-travel time per (timetable-) period in \([\text{eight}^{\text{th}}\text{’s of hours}]\)

Realized Service Time Spent per Period (\( STSpP^{\text{Dispo}} \)),
The SI-travel time per (timetable-) period in \([\text{eight}^{\text{th}}\text{’s of hours}]\) for the IP scenario
### Basics: Case Study STSpPlan

Case Study: Result of Calculation $STSpP_{Plan} (Tot) = 136$

<table>
<thead>
<tr>
<th>Accesspoint</th>
<th>ZugNr / Connection</th>
<th>Segment Nr</th>
<th>Accesspoint Arrival</th>
<th>STSpP (ZP)</th>
<th>STSpP (Tot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sta_A</td>
<td>10</td>
<td></td>
<td>Sta_A 0 3 4</td>
<td>7</td>
<td>136</td>
</tr>
<tr>
<td>Sta_A</td>
<td>21</td>
<td></td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Sta_A</td>
<td>A4</td>
<td></td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Sta_B</td>
<td>20</td>
<td></td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Sta_B</td>
<td>A2</td>
<td></td>
<td>7 8 0</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Sta_B</td>
<td>30</td>
<td></td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Stp_A</td>
<td>10</td>
<td></td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Stp_A</td>
<td>A1</td>
<td></td>
<td>12 0</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Stp_AT</td>
<td>11</td>
<td></td>
<td>5 0 2</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Stp_AT</td>
<td>A1</td>
<td></td>
<td>0</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Stp_AT</td>
<td>A1-A4</td>
<td></td>
<td>13 0</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Stp_B</td>
<td>31</td>
<td></td>
<td>0</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Stp_B</td>
<td>A3</td>
<td></td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Stp_B</td>
<td>A3-A2</td>
<td></td>
<td>0 12 13 0</td>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>
Basics: Modeling of Timetable

Timetable generation
Defined by periodic timetable vector (result of TraMP) \(d_i^0\).

\(d_i^0\) indicates the timestamp of event \(i\) in period \(k\), with \(d_i^0 \in [0, T)\).

Required solution: timestamp of event \(i\) in an arbitrary period \(k = 0, 1, \ldots\) is calculated as follows:

\[
d_i(k) = d_i^0 + k \cdot T
\]

Restrictions

a. Process event and timetable event
Any event \(i\) should not occur before the time of the corresponding timetable event:

\[
x_i(k) \geq d_i(k)
\]
b. Consideration of preceding events

Considering the minimal process time of a process \((j, i)\) given the timestamp of it’s start event \(x_j\) the following condition must be satisfied:

\[
x_i(k) \geq a_{ij} + x_j(k - \mu_{ij}),
\]

The period shift \(\mu_{ij}\) is defined through the initial timetable event time \(d_0\), the minimal process time duration \(a_{ij}\) between events \(i, j\) and the timetable period \(T\) by the following equation:

\[
\mu_{ij} = \frac{a_{ij}^0 + d_j^0 - d_i^0}{T} \in \mathbb{N}_0
\]

\(\mu_{ij}\) indicates, if between event \(j\) and \(i\) occurs (one or several) period transitions. Index 0 represents the first occurance.
c. Critical cycle

Based on the periodicity of a discrete event system, there exists at least one cycle, which is defined by a sequence of events, which leads backwards from any event \( i \) to its (periodically) originating event \( i - T \).

The critical cycle is exactly that cycle of the system which has the maximum mean duration, which corresponds in the mathematical sense to the highest eigenvalue of the system (e.g. Goverde 2010).

The maximal average cycle time \( \lambda \) is calculated as follows:

\[
\lambda = \max_{\xi \in C} \frac{w(\xi)}{\mu(\xi)}
\]

\( C \) represents the set of all cycles of the DE system, \( \xi \) indicates one of these cycles, \( w(\xi) = \sum_{(j,i) \in \xi} a_{ij} \) represents the sum of all process times \( a_{ij} \) (between events \( j \) and \( i \)) belonging to that cycle and \( \mu(\xi) = \sum_{(j,i) \in \xi} \mu_{ij} \).
d. Eigenvalue and Eigenvector of DE System and Stability

Solving the Eigenvalue problem with respect to the quadratic state matrix $A \in \mathbb{R}_{\text{max}}^{n \times n}$ results in the scalar value $\lambda \in \mathbb{R}_{\text{max}}$ also as well as a corresponding vector $v \in \mathbb{R}_{\text{max}}^{n} \setminus \{\epsilon\}$, satisfying (in Max-Plus-Notation) the following equation:

$$A \otimes v = \lambda \otimes v$$

$\lambda = \lambda(A)$ refers to the eigenvalue and $v$ to the corresponding (right) eigenvector. Based on the Eigenvalue $\lambda_0$ of the critical cycle, the stability of the system can be characterised quantitatively by three different cases:

- $\lambda_0 < T \rightarrow$ the system is \textbf{stable}
- $\lambda_0 \approx T \rightarrow$ the system is \textbf{critical}
- $\lambda_0 > T \rightarrow$ the system is \textbf{instable}
Case Study: «MaxplusHausen»*
Macro topological representation

Case Study: reference case A and micro topological representation
Case study: comparison of four scenarios

Case A: Reference timetable
Case B: Reference timetable with restrictions of interval
Case C: SI-Solution for interval with broken connection
Case D: SI-Solution for interval with shifted turnaround, no service of Stop AT
Case Study: Case B
situation of construction interval

Interval situation
Simulation snapshot of original timetable with reduced trackspeed in section between Stop A and Stop AT.
Case Study: Case B
situation of construction interval

Critical cycles: base plan with interval (case B)
Case Study: Case C
scenario with broken line connection

Service Table: Adaptation of SI-Departure timeslots for services 10 and 11 of Line 1 in order to reflect the situation with reduced track speed between operation points Stop_A and Stop_AT.

Connection table: broken connection from Line 1 to Line 2 in Station A (Sta_A) by setting the ‘deleted’-Flag in the row for ConnectionID = 1.
Case Study: Case D
scenario with shifted turnaround

Critical cycle: intervalplan (case D)

Turnaround table: The entry for the corresponding turnaround of the line 1 is transferred from operation point Stop_AT to operation point Stop_A.
## Case study: summary of different cases

<table>
<thead>
<tr>
<th>Case</th>
<th>Assessment from operational point of view</th>
<th>Assessment from point of view of customer convenience</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Eigenvalues of critical cycles</td>
<td>Stability</td>
</tr>
<tr>
<td></td>
<td>$\lambda_1$</td>
<td>$\lambda_2$</td>
</tr>
<tr>
<td>A</td>
<td>58 Min.</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>62 Min.</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>61 Min.</td>
<td>58 Min.</td>
</tr>
<tr>
<td>D</td>
<td>58 Min.</td>
<td>-</td>
</tr>
</tbody>
</table>

**Case A:** Reference timetable

**Case B:** Reference timetable with restrictions of interval

**Case C:** SI-Solution for interval with broken connection

**Case D:** SI-Solution for interval with shifted turnaround, no service of Stop AT
Summary

• The introduced methods are suitable for timetable planning with computer aided decision support.

• The introduced methods allow for quick and easy quality assessment of timetables with respect to:
  – Customer convenience of transport offer (service intention, SI),
  – Operational feasibility and stability of timetable scenario.

• There exists a clear mapping between macroscopic timetable modelling and microscopic simulation modelling.