Automatically and Quickly Planning Platform and Route of Trains in Railway Stations

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Business Problem

Task

Belgian Infrastructure Management Company: Infrabel:
"Train Platforming Problem (TPP): platform and route as many trains as possible"

Objectives:
no conflicts in planning in stations, check robustness

Fixed:
infrastructure, train lines, halting pattern, arrival & departure times

Specifics:
- one busy day, morning peak hours, periodic/non-periodic
- (check current platforming +) create new ('optimised') one
Platforming = Mapping Trains on Infrastructure
In objective function:

- Minimize penalties
  - of assigning to fictive a platform and
  - of moving assignment from preferred (real) to non-preferred (real) platforms,
for both initial $O_{INI}$ and for supplementary $O_{SUP}$ train sets

$$
g(op_o,p) = \sum_{o \in O_{INI}} CF_{INI} \cdot f_o + CR_{INI} \cdot cr_o + \sum_{o \in O_{SUP}} CF_{SUP} \cdot f_o + CR_{SUP} \cdot cr_o. \quad (1)$$

where

- $\forall o \in O : f_o \equiv (o2p_o,p = pFICT)$
- $\forall o \in O : cr_o \equiv (o2p_o,p \neq pORIG_o)$

- uses fictive platform at a higher cost than real platform
- conservative optimisation $(CF_{INI}, CF_{SUP}, CR_{INI}, CR_{SUP}) = (8, 4, 2, 1)$
- progressive optimisation $(CF_{INI}, CF_{SUP}, CR_{INI}, CR_{SUP}) = (1, 1, 0, 0)$
Not in objective function:

- weighting of trains by importance (e.g. number of passengers)
- important (e.g. number of passengers) transfer concerns, placing two trains close together
- robustness against delays
Definitions: Movement & Occupation

Movement Definition:
- Train ‘IN/OUT movement’ specifies:
  - IN/OUT line
  - platform arrival time
  - platform departure time
- IN route: connects IN line to platform,
- OUT route: connects platform to OUT line.

Occupation Definition:
- platform ‘occupation’ specifies (bundles):
  - (list of) IN movement(s)
  - (list of) OUT movement(s)
  - e.g.: 1 IN movement, 2 OUT movements = train split
  - e.g.: 2 IN movements, 1 OUT movement = train merge
In / Not In Variability

In Variability:
- per occupation
  - one platform choice
- per movement
  - one route choice
  - (indirectly) one platform choice

Not in Variability:
- per line-platform combination: only 1 default routing allowed for now
- only fixed platform arrival/departure times
Constraints Requiring total Assignment

Per-Movement, Per-Occupation and Compatibility Constraints:

- For each occupation, exactly one platform has to be chosen:
  \[ \forall o \in O : \sum_{p \in P} op_{o,p} = 1 \]  (2)

- For each movement, exactly one route has to be chosen:
  \[ \forall o \in O : \forall m \in M_o : \sum_{r \in R} mr_{o,m,r} = 1 \]  (3)

- All movements in 1 occupation need to come together on 1 platform track
  \[ \forall o \in O : \forall m \in M_o : mr_{o,m,r} \implies op_{m2o_m,r2p_r} \]  (4)

- Via \( m2o_m \) function, movement-occupation membership is respected
- Via \( r2p_r \) function, route-platform connectivity is respected
Constraints Avoiding Conflicts

Inter-Occupation Constraints:

- no 2 extended occupations use equal platform tracks at any time

∀ \( o_0, o_1 \in O : \forall_{p_0=p_1} (p_0, p_1) \in (P_{o_0}, P_{o_1}) : \)

\[ \text{o}_{o_0, p_0} \land \text{o}_{o_1, p_1} \implies \text{o}_{\text{sep}, o_0, o_1} \]  \hspace{1cm} (5)

Inter-Movement Constraints:

- no 2 extended movements use dependent (equal or crossing) routings at any time

∀ \( m_0, m_1 \in M : \forall_{\text{dep}_{r_0, r_1}} (r_0, r_1) \in (R_{m_0}, R_{m_1}) : \)

\[ \text{m}_{o_0, m_0, r_0} \land \text{m}_{o_1, m_1, r_1} \implies \text{m}_{\text{sep}, m_0, m_1} \]  \hspace{1cm} (6)
Separation boolean definitions

Occupation Separation boolean definition:

\[
\forall o_0 \prec o_1 \quad [otLoLbC_{o_0}, otHiUbC_{o_0}) \cap [otLoLbC_{o_1}, otHiUbC_{o_1}) \neq \varnothing
\]

\[
o_0, o_1 \in O : obef_{o_0, o_1} \equiv (otHiV_{o_0} + dtS \leq otLoV_{o_1}) \quad (7)
\]

\[
obeo_{o_1, o_0} \equiv (otHiV_{o_1} + dtS \leq otLoV_{o_0})
\]

\[
osep_{o_0, o_1} \equiv (obeo_{o_0, o_1} \lor obef_{o_1, o_0}).
\]

Movement separation boolean definition:

\[
\forall m_0 \prec m_1 \quad [mtLoLbC_{m_0}, mtHiUbC_{m_0}) \cap [mtLoLbC_{m_1}, mtHiUbC_{m_1}) \neq \varnothing
\]

\[
m_0, m_1 \in M : mbef_{m_0, m_1} \equiv (mtHiV_{o_0} + dtS \leq mtLoV_{m_1})
\]

\[
mbef_{m_1, m_0} \equiv (mtHiV_{o_1} + dtS \leq mtLoV_{m_0})
\]

\[
msep_{m_0, m_1} \equiv (mbef_{m_0, m_1} \lor mbef_{m_1, m_0}),
\]

\[
(8)
\]
User Interface Parameters

![Leopard GUI: LEan Optimiser of Platforms And Routings including routing Dependencies](image)

- **Date**: 16/04/2013
- **From Hour**: 07:10
- **Up To Hour**: 08:50
- **Extract Macro Infrastructure From**: a371
- **Select Station**: BRUGGE[210]
- **Fix Station Movements**: fix
- **Mirror unmatched movements by turn-around time**: 5.0
- **Avoid routing conflicts also for Mirrored movements**: checked
- **Fixed train length in meter (-1 for actual length)**: 400
- **Draw Long Text for Movements**: unchecked
- **Mark and name times in occupations**: unchecked
- **Warn for (Real, Real)-dependent Route low reuse times**: Overlap, Too close, Quite close, Robust
- **Define warning level Upper Times (min)**: 0.0, 1.0, 2.0, 5.0
- **Warn for (Real,Fictive)-Route time overlaps**: Potential conflict
- **Popup Platfoming Plan for**: Original, Optimised, Both

**FINAL Station Connectivity** that Luks Routes will be checked against and rejected against in case of no match.
Table: Solver running times on a Xeon CPU E31240 Quad Core 3.3 GHz, comparing CPLEX v12.5.0.0 32 bit, XPRESS BCL v4.6.1 64 bit and Gurobi v5.6.3 64 bit

<table>
<thead>
<tr>
<th>Solver</th>
<th># Stations Optimally Solved in</th>
<th># Stations Suboptimally Solved in</th>
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<tr>
<td></td>
<td>&lt; 1s</td>
<td>&lt; 10s</td>
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<td>5</td>
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<tr>
<td>Gurobi</td>
<td>533</td>
<td>3</td>
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</tbody>
</table>
Figure: Antwerp-Central original Assignment: 3 levels, some conflicts
Results

Antwerp-Central Optimised, Non-Periodic

Optimised Assignment, Non-Periodic

**Figure:** Antwerp-Central Opt. assignment, non-periodic: no conflicts, some unplaced trains
Automatically and Quickly Planning Platform and Route of Trains in Railway Stations

Results

Antwerp-Central Optimised, Periodic

Optimised Assignment, Periodic

Figure: Antwerp-Central Opt. assignment, periodic: no conflicts, some unplaced trains
Both Assignments, Non-Periodic

Figure: Antwerp-Central: comparing original and optimised assignments
Automatically and Quickly Planning Platform and Route of Trains in Railway Stations

Results
Antwerp-Central Both, Non-Periodic

Antwerp Station

Figure: Antwerp Station
Automatically and Quickly Planning Platform and Route of Trains in Railway Stations

Results

Ghent Sint-Pieters Original

Original Assignment

![Figure: Ghent Sint-Pieters original Assignment: some conflicts](image)
Automatically and Quickly Planning Platform and Route of Trains in Railway Stations

Results

Ghent Sint-Pieters Optimised, Non-Periodic

Optimised Assignment, Non-Periodic

Figure: Ghent Sint-Pieters Opt. assignment, non-periodic: no conflicts, some unplaced trains
Results

Ghent Sint-Pieters Both, Non-Periodic

Both Assignments, Non-Periodic

Figure: Ghent Sint-Pieters: comparing original and optimised assignments
Results

Ghent Sint-Pieters Both, Non-Periodic

**Ghent Station**

*Figure: Ghent Station*
### Results

#### Comparative Overview

Comparing Original and Optimised Assignment KPIs

| #platform | #UnplatformedOrig | #blueLine | #darkOrn | #lightOrn | #greenLin | RobustnessSc | #platformed | #Unplatformed | Opt | #blueLine | #darkOrn | #lightOrn | #greenLin | RobustnessSc | Both |
|-----------|-------------------|-----------|----------|----------|-----------|--------------|-------------|--------------|------|-----------|----------|----------|-----------|--------------|------|-----------|
| 20        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 23        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 9         | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 10        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 23        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 3         | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 13        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 21        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 28        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 46        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 14        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 17        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 16        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 7         | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 24        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 23        | 1                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 6         | 12                 | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 14        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 11        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 10        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 12        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 34        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 9         | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 15        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 33        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 33        | 1                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 87        | 7                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 36        | 0                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |
| 34        | 1                  | 0         | 0        | 0        | 0         | 0            | 0           | 0            | 0    | 0         | 0        | 0        | 0         | 0            | 0    | Both      |

| 12241     | 813                | 752       | 1524     | 2245     | -8123      | 12894       | 4.75%       | 95.25%     | 1.65%     | 98.35%     | 253      | 0         | 707       | 1578      | 2409     | -4406     |

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## TPP Research and Integration

<table>
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<tr>
<th>publication</th>
<th>integrated: company</th>
<th>in tool(s)</th>
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<tbody>
<tr>
<td>[De Luca Cardillo(1998)]</td>
<td></td>
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<tr>
<td>[Delorme and Rodriguez(2001)]</td>
<td>SNCF</td>
<td>RECIFE FR</td>
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<td>[Billionnet(2003)]</td>
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<td>[Carey and Carville(2003)]</td>
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<tr>
<td>[Caprara et al.(2011)Caprara, Galli, and Toth]</td>
<td>RFI, IT</td>
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<td>[Lusby et al.(2011)Lusby, Larsen, Ryan, and Ehrgott]</td>
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<tr>
<td>[Sels et al.(2014)Sels, Dewilde, Cattrysse, and Vansteenwegen]</td>
<td>Infrabel</td>
<td>Ocapı Leopard</td>
</tr>
</tbody>
</table>

**Table: Comparing TPP Research & Integration**
Conclusions & Future Work

Conclusions

- Leopard usable as check of current platform assignment
  - indicates all conflicts
  - indicates all robustness issues
- Leopard usable as generator of correct platform assignment
  - guarantees no conflicts
  - can have robustness issues, indicates them
- fast as a Leopard

Further Work

- roll-out with Infrabel planners
- avoid robustness issues
- weight trains per # passengers
- allow some variability of platform times
- allow multiple routes per line-platform combination
Questions

- Questions?
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