A Rolling Horizon Based Framework for Rolling Stock Rescheduling

Lars Kjær Nielsen, Leo Kroon, Gábor Maróti

February 12, 2009
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Introduction

Reasons for unexpected disruptions

- Infrastructure malfunctions
  - Rails, switches, catenary, bridges
- Computer problems in control centers
- Rolling stock breakdowns
- Accidents with other traffic
- Weather conditions
- Crew no shows
- ...

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A Rolling Horizon Based Framework for...
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Numbers from 2007 for the Netherlands

<table>
<thead>
<tr>
<th>Disruptions</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>933</td>
</tr>
<tr>
<td>Medium</td>
<td>1011</td>
</tr>
<tr>
<td>Large</td>
<td>834</td>
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</tbody>
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The disruption management process

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2. Reschedule rolling stock to cover the new timetable.
3. Reschedule crew to operate the rolling stock.

The tasks are interdependent but are solved separately.

Our research focuses on the rolling stock.
Example
Example

Time-space diagram for a line.
Example

Updating the timetable

Hdr
Amr
Asd
Ut
Ah
Nm
Example

Rolling stock assignment

Hdr
Amr
Asd
Ut
Ah
Nm
Example

Train length is adjusted at certain stations
Example

Original rolling stock assignment is not feasible during disruption

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A Rolling Horizon Based Framework for...
Uncertainty related to the disruption

Disruption  Uncertainty
The Online Rolling Stock Rescheduling Problem (Online RSRP)

Input:

- Original timetable $\mathcal{T}_0$.
- Original rolling stock circulation $C_0$.
- Finite list of changes to the timetable, $\langle t_1, \mathcal{T}_1 \rangle, \ldots, \langle t_n, \mathcal{T}_n \rangle$. 
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Output at each step:
- Circulation $C_i$ which is feasible for $\mathcal{T}_i$ with rolling stock fixed until time $t_i$. 

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Output at each step:
- Circulation \( C_i \) which is feasible for \( T_i \) with rolling stock fixed until time \( t_i \).

Objective:
- Minimize the deviation of \( C_n \) from \( C_0 \).
Perspectives of the overall managerial objective:

**Service**
- Cancelled trips
- Capacity
- Travel time
- Connections

**Robustness**
- Shunting operations
- Trains / lines affected
- Propagation of disruption

**Process**
- Deviation from original schedule
- Return to original schedule

**Operational costs**
- Carriage kilometers
- Empty rides
- Shunting operations

**Objective**

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A model for RSRP at NS

Based on the MIP model by Fioole et al. (2006):

- The core of the model is the assignment of rolling stock compositions to trips.
A model for RSRP at NS

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- The core of the model is the assignment of *rolling stock compositions* to *trips*.

- For a trip $r$:

  \[
  \begin{align*}
  X_{r,0} & \\
  X_{r,c_1} & \\
  X_{r,c_2} & \\
  X_{r,c_3} & \\
  X_{r,c_4} & \\
  X_{r,c_5} & \\
  \in \{0, 1\}
  \end{align*}
  \]

Subject to

\[
\sum_c X_{r,c} = 1
\]
A model for RSRP at NS

Composition changes between trips

Trip $r$ from Asd to Amr

Composition change in Amr

Trip $r'$ from Amr to Hdr

$X_{r,c}$

$Z_{r',c,c'}$

$X_{r',c'}$
A model for RSRP at NS

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A model for RSRP at NS

- Variables $D_{s,m} \in \mathbb{Z}_+$ count the deviation from the target number of units of type $m$ at station $s$. 
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Objective:

$$\min \sum_r w_r X_{r,0} + \sum_{r,r'} \sum_{c,c'} \gamma_{r,r',c,c'} Z_{r,r',c,c'} + \sum_s \sum_m \beta_m D_{s,m}$$

- Cancellations
- Off balances
- Changed shunting operations
Observations:

- Computation time is a bottleneck.
- The uncertainty of the online version may lead to suboptimal decisions.
- In practice, only the most immediate decisions are executed.
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- The uncertainty of the online version may lead to suboptimal decisions.
- In practice, only the most immediate decisions are executed.

Rolling horizon approach:

- Only look $h$ timesteps ahead.
- Revise whenever new information becomes available.
- If no new information is revealed, revise after $p$ timesteps.
Rolling horizon approach
Accounting for off balances

- Off balances are counted at the end of the day.
- When only considering a horizon of $h$ timesteps, off balances cannot explicitly be accounted for.
Accounting for off balances

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- When only considering a horizon of $h$ timesteps, off balances cannot explicitly be accounted for.

Heuristic approach:
- Observation: The original circulation has no off balances.
- Use the intermediate balances of the original circulation as a guideline.
Accounting for off balances

- Arguably the accuracy of this approach increases over time.
- When rescheduling at time $t$, multiply the cost of off balances by a factor $\rho(t)$:

$$\sum_s \sum_m \rho(t) \beta_m D_{s,m}$$
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  \[ \sum_s \sum_m \rho(t) \beta_m D_{s,m} \]
- $\rho(t)$ depends on the time $t$ at which the horizon ends.
- Parameter $a$: When intermediate balances are taken into account.
- Parameter $b$: Off balances are taken into account with full cost.
Computational tests

Test instances:

- Several disruptions in rolling stock circulations at NS are used.
- Each instance contains several timetable updates.
Computational tests

Test instances:

- Several disruptions in rolling stock circulations at NS are used.
- Each instance contains several timetable updates.
- The presented results come from a number of instances involving the Noord-Oost lines.
Parameters for the intermediate balances

Objective vs. when intermediate balances are taken into account.
Parameters for the intermediate balances

Off balances/shunting operations vs. when intermediate balances are taken into account.

![Graph showing new shunting operations and off balances over time]

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Parameters for the horizon

Objective vs. horizon length.

![Chart showing objective value against horizon length in hours.](chart.png)
Computation time

Computation time vs. horizon length.

![Graph showing computation time vs. horizon length.](image_url)
Disruptions in the rolling stock schedules are modeled by the Online RSRP.

A rolling horizon approach is used to reduce problem size.

A model for generic rolling stock scheduling is adapted to the real time case at NS.

Off balances are dealt with heuristically by comparing with the original circulation.

The approach yields good results on instances from practice.

Computation time depends on horizon length.