A study of an incremental texture-based heuristic for the train routing and scheduling problem

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Outline

1. Rail traffic management
   - Scope
   - Problem description
   - Motivation

2. Constraint Based Scheduling model

3. Resolution methods

4. Experiments

5. Conclusion
## Rail Traffic management - Scope

### Rail Traffic management problems

<table>
<thead>
<tr>
<th>Off-line timetabling</th>
<th>→ high-quality timetables</th>
</tr>
</thead>
<tbody>
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<td>Real time traffic management</td>
<td>→ modify the timetables to reduce the impact traffic of incidents</td>
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Rail Traffi c management - Scope

Rail Traffic management problems

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Real time traffic management

Geographical organisation:
- National control center
- Regional control centers
- Local control centers (e.g. stations, ...)

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Real time traffic management

Geographical organisation:
- National control center
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Real time traffic management problem

A station traffic control center
Real time traffic management problem

- Events
  - Technical failures, disturbances,
  - Additional trains, track maintenance works, ...
  ⇒ primary delays

- Interaction between train runs may cause propagation of primary delays
  ⇒ secondary delays (knock-on delays)
Real time traffic management problem

- Solve the problem:
  \[
  \begin{aligned}
  \min & \left( \sum secondary \ delays \right) \\
  \text{s.t.} & \\
  \text{Satisfy the safety and operational constraints between train runs}
  \end{aligned}
  \]

- Dispatcher decisions to reduce/avoid propagation:
  - change **train routes**
  - change **train schedules**
# Resolution methods

<table>
<thead>
<tr>
<th>Two-phase approach</th>
<th>Incremental approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>With global decisions:</td>
<td>With local decisions:</td>
</tr>
<tr>
<td><strong>Train route allocation</strong></td>
<td><strong>Track section allocation</strong></td>
</tr>
<tr>
<td><strong>Train schedule</strong></td>
<td><strong>Track section movement schedule</strong></td>
</tr>
</tbody>
</table>
Rail traffic management - Motivation

Decision tree: two-phase approach

( train route allocations, train schedules)

Complete search space exploration
Rail traffic management

Decision tree: incremental approach

(\textit{partial train route allocations}, \textit{partial train schedules})

Complete search space exploration
Objectives

- New heuristic resolution method based on local decisions,
- Compare with a previous resolution method based on global decisions.
Our model is based on schedule theory:
The real time traffic management problem is a kind of «joint resource allocation and scheduling » problem.
A train is a «job», i.e. a sequence of «activities»,
Activities require track section «resources».
### Constraint Based Scheduling model

#### Model

<table>
<thead>
<tr>
<th>Train movements on track sections</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track sections</td>
<td>Unary Resources</td>
</tr>
<tr>
<td>Opposite direction conflicts</td>
<td>State Resources</td>
</tr>
<tr>
<td>Alternative routes</td>
<td>Resource constraints</td>
</tr>
<tr>
<td>Trains schedule, Block/ Interlocking system</td>
<td>Temporal constraints</td>
</tr>
</tbody>
</table>
Constraint Based Scheduling model

Time over distance diagram

Temporal constraints:
- Signal watching time,
- Clearing time,
- 2 aspects of signalling
Time over distance diagram

Temporal constraints:
- Signal watching time,
- Clearing time,
- 2,3, ... aspects signalling

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Constraint Based Scheduling model

Time over distance diagram

Temporal constraints:
- Signal watching time,
- Clearing time,
- 2,3,... aspects signalling
- Sectional route release (interlocking)
Solving a joint scheduling and resource allocation problem:

Two phases approach - TPH
1. Complete resource allocation
2. Complete scheduling

Incremental approach - INC
Repeat
(Partial resource allocation)
or (Partial scheduling)
Until a complete solution is found.
Resolution methods

Two phases approach - TPH

Algorithm:
1. Assign routes to all trains
2. Schedule all activities of trains («Rank» algorithm of Ilog Scheduler)
3. Set the time variables of activities of trains to the earliest value
Resolution methods

Incremental approach - INC

Algorithm:

1. Identifies a resource R with the **critical time point**, 
2. Let A, B two unsequenced activities which require R on the critical time point, 
3. Let C an activity which requires R on the critical time point and that still have alternative resources, 
4. Choose between:

   \[(A \prec B) \text{ or } (B \prec A) \text{ or } (\text{resource}(C) = R) \text{ or } (\text{resource}(C) \neq R)\]
Resolution methods - Critical time point

Example of calculation of the contention for a resource R:

- Individual demand of an activity A

![Diagram showing earliest start time, latest finish time, and activity duration.](image)
Resolution methods - Critical time point

Example of calculation of the contention for a resource $R$:

- Individual demand of an activity A, B and C

![Diagram showing time periods for activities A, B, and C with corresponding demand curves.](image-url)
Resolution methods - Critical time point

Example of calculation of the contention for a resource R:

- Individual demand of an activity A, B and C
- Aggregated demand as a measure of the contention for R
Resolution methods - Critical time point

Example of calculation of the contention for a resource R:

- Individual demand of an activity A, B and C
- Aggregated demand as a measure of the contention for R
- The curves are updated during search to get algorithms that implement dynamic analyses (»texture measurement»)
The layout of the Lille-Flandres station

7 lines, 17 platforms
Running distance $\approx 4$ kilometers.
Running time $\approx 6$ minutes.
Instance problems considered

Set of instance problems:

- Select a peak period with 40 trains,
- Alternative routes per train < 30,
- Instance L18: compress the train schedule from 3600s to 2300s,
- Generate L17-L1 by removing 2 trains.

<table>
<thead>
<tr>
<th>Inst.</th>
<th>$T$</th>
<th>nb var.</th>
<th>nb ct.</th>
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</thead>
<tbody>
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<td>2978</td>
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<tr>
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<td>22</td>
<td>13225</td>
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</table>

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<th>Inst.</th>
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<th>nb var.</th>
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<tbody>
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</table>
## Experiments

### Configurations considered in the study

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>NoSRCt + TPH</td>
<td>Model <strong>without</strong> the state resource constraints (NoSRCt) and the two-phase resolution method (TPH),</td>
</tr>
<tr>
<td>SRCt + TPH</td>
<td>Model <strong>with</strong> the state resource constraints (SRCt) and the two-phase resolution method,</td>
</tr>
<tr>
<td>SRCt + INC</td>
<td>Model <strong>with</strong> the state resource constraints (SRCt) and the incremental resolution method.</td>
</tr>
</tbody>
</table>

**Stop condition**: 180 s CPU time limit (including setup and preprocessing of data)
### Results

<table>
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<tr>
<th>inst.</th>
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<th>NoSRCt + TPH</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td>BS</td>
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<tr>
<td>L18</td>
<td>40</td>
<td>-</td>
<td>-</td>
<td>2133</td>
</tr>
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- (NoSRCt+TPH) improves the greedy solution for 7 instances and find no solution for the other instances.
- (SRCt+TPH) improves the greedy solution for 14 instances.
- (SRCt+INC) gives the best results.
Two-phase method (TPH) versus incremental method (INC)

Sum of delays

- **SRCit + TPH**
- **SRCit + INC**

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Experiments

The Gantt chart for a solution
A model of the train routing and scheduling problem,
Our model is able to consider a large number of technical and commercial characteristics drawn from real situations.
A two-phase method has been compared with an incremental method.
The incremental method shows very promising results.
Futur work:
- Apply the heuristic to local search methods,
- Link the model with a speed coordination module to consider train speed profiles.