Determining and Evaluating Alternative Line Plans in (Near) Out-of-Control Situations

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Introduction
Introduction

- Railway systems are susceptible to disruptions
- In 2018 on average 14 disruptions per day in the Dutch railway network
- For the average, well-defined disruption, disruption management models are available
Disruption management strategies for *average* disruptions cannot be applied in *extreme* situations

- Size of the disruption
- Lack of complete information
Out-of-Control

Disruption management strategies for average disruptions cannot be applied in extreme situations

- Size of the disruption
- Lack of complete information

Dekker et al. (2018) define the state of out–of–control as a situation:

*where dispatchers cease to have an overview of the system and consequently decide to terminate all railway traffic in the affected region, even though the required resources (infrastructure, rolling stock and crew) might be available.*
Goal: develop new disruption management strategies for avoiding or reducing the impact of out-of-control situations
Main idea 1: isolation

Figure 3: Disrupted region
Main idea 1: isolation

Figure 3: Disrupted region
Main idea 1: isolation

**Figure 3:** Disrupted region
Main idea 1: isolation

Figure 3: Disrupted region
Main idea 2: decentralized decision making

- Central dispatchers need to gather information from local agents before they can make a decision.
- In out-of-control situations, communication channels are disrupted and information is often inaccurate or already outdated.

⇒ Use self-organizing, local principles to schedule the disrupted region.
How to modify the line plan in the disrupted region?
Method: mathematical programming

How to operate the new line plan in the disrupted region without an explicit timetable?
Use self-organizing, local principles.
Method: simulation
Research Questions and Methodology

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Line Planning
Why modify the line plan?

Figure 4: Modification of a line plan. Relative frequencies are indicated by the line thickness.
To ensure that the line plan can be operated, we have to consider timetabling and rolling stock scheduling while determining the line plan.
(Partial) Integration is Required

To ensure that the line plan can be operated, we have to consider timetabling and rolling stock scheduling while determining the line plan.

We use a novel approach based on Bender’s decomposition.
Input:

- Disrupted region
- Line pool
- Original line plan (reference)
- Origin destination matrix

Output:

- Line plan that minimizes passenger inconvenience and is "feasible"
Master Problem

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- Disrupted region
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- Original line plan (reference)
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Output:

- Line plan that minimizes passenger inconvenience and is "feasible"
Objective

Minimize passenger discomfort \textit{in a fair way}

(a) Original line plan

(b) Alt. line plan 1

(c) Alt. line plan 2
Minimize passenger discomfort in a fair way

(a) Original line plan

(b) Alt. line plan 1

(c) Alt. line plan 2

⇒ measure passenger inconvenience using relative decreases in OD-frequency

Alt. line plan 1 has penalty of \( \frac{0}{4} + \frac{1}{2} = \frac{1}{2} \)

Alt. line plan 2 has penalty of \( \frac{1}{4} + \frac{0}{2} = \frac{1}{4} \)
Objective

(a) Original line plan
(b) Alt. line plan 1
(c) Alt. line plan 2

⇒ square the relative decreases

Alt. line plan 1 has penalty of $(2^2 + 0^2) = 4$

Alt. line plan 2 has penalty of $(1^2 + 1^2) = 2$
Objective

- **Amsterdam**
- **Rotterdam**
- **Den Haag**

**(a)** Original line plan

- Amsterdam to Den Haag: 4/h
- Amsterdam to Rotterdam: 4/h

**(b)** Alt. line plan 1

- Amsterdam to Den Haag: 2/h
- Amsterdam to Rotterdam: 4/h

**(c)** Alt. line plan 2

- Amsterdam to Den Haag: 3/h
- Amsterdam to Rotterdam: 3/h

⇒ square the relative decreases

Alt. line plan 1 has penalty of \((\frac{2}{4})^2 + (\frac{0}{2})^2 = \frac{1}{4}\)

Alt. line plan 2 has penalty of \((\frac{1}{4})^2 + (\frac{1}{4})^2 = \frac{1}{8}\)
Ensure that we do not ask too much from the infrastructure

- Lines ‘consume’ platform time at stations (dwelling, turning, headway time)
- Total consumption cannot exceed the capacity
Rolling Stock Constraints

Ensure that within the disrupted area there are enough trains to operate the selected lines.

- **Fixed** rolling stock circulations keep the same vehicle to the same line throughout operations.
- **Flexible** circulations allow trains to switch to different lines and turn sooner. Computationally more challenging, so we only consider combinations of two lines.
Slave Problem

The line plan produced by the master serves as input for the slave problem, which checks whether the line plan admits feasible *partial* timetables.

Why consider partial timetables?

1. Complete timetable not required
2. Tractability
3. Stronger cuts
4. Multiple cuts per identified inconsistency
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(a) Solution of the master problem.
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(a) Solution of the master problem.

(b) Line plan with the same timetabling problem at station C.
Test case: Power Outage in Amersfoort
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**Proposed Line Plans**

(a) No R.S. Constraints
Objective 0.033

(b) Fixed R.S. Constraints
Objective 0.447

(c) Flexible R.S. Constraints
Objective 0.351
Dispatching Strategies
Dispatching Strategies

When does a train depart?

- **ASAP**: as soon as possible
- **SYNC**: in a regular pattern

Where does a train go upon arriving at the terminal station?

- **STAT**: back and forth, fixed to a line
- **DYN**: reassign trains to lines at the terminals
The dispatching strategies are evaluated by means of simulation.
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Operational measures:
- Frequency
- Train Delay
- Regularity

Travel measures:
- Travel Time
- Realized Objective
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Operational measures:
- Frequency
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Travel measures:
- Travel Time
- Realized Objective
Simulation Results (Operational)

(a) Fixed R.S. Constraints
Simulation Results (Operational)

(a) Fixed R.S. Constraints

(b) Flexible R.S. Constraints
In the undisrupted situation, the average travel time is about 18 minutes.

<table>
<thead>
<tr>
<th></th>
<th>Fixed RS constraints</th>
<th>Flexible RS constraints</th>
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<tbody>
<tr>
<td></td>
<td>Real. Obj.</td>
<td>Travel Time (min.)</td>
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<tr>
<td>ASAP-STAT</td>
<td>0.388</td>
<td>28.1</td>
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<tr>
<td>SYNC-STAT</td>
<td>0.478</td>
<td>31.1</td>
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<tr>
<td>ASAP-DYN</td>
<td>0.388</td>
<td>27.9</td>
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<tr>
<td>SYNC-DYN</td>
<td>0.486</td>
<td>30.9</td>
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• We can generate passenger-oriented and practicable line plans for disrupted regions in real-time
• It is possible to operate railway traffic in a disrupted region using self-organizing, local principles
• Further research: schedule the train drivers and conductors
### Algorithmic Performance Large Instance

**Table 1:** Results of the line planning algorithm on the large disrupted region using the three types of rolling stock constraints.

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<th>RS constraints</th>
<th>Objective</th>
<th>Lines</th>
<th>Iterations</th>
<th>Cuts</th>
<th>Master CPU (s)</th>
<th>Total CPU (s)</th>
<th>Max Total CPU (s)</th>
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<tr>
<td>None</td>
<td>0.074</td>
<td>36</td>
<td>4</td>
<td>371</td>
<td>480.1</td>
<td>501.5</td>
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<tr>
<td>Fixed</td>
<td>0.162</td>
<td>22.0</td>
<td>2.0</td>
<td>160.0</td>
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