Robust Railway Operations
- A big data challenge
David Pisinger, professor DTU Management
5 May 2015
Robust Railway Operations
Robust Railway Operations

‘Hello, love, I’ll be late home, I’ve caught the train’
RobustRailS

Vision

Trains provide an environmentally friendly way of transportation.

If we want more people to use the trains, then the transportation system must be more timely, reliable, high-frequent, and comfortable.

• January 2012 – December 2015
• DTU Management, DTU Transport, DTU Compute, DTU Fotonik
Robustness

• A robust system can
  - absorb small disruptions
  - quickly recover from larger disruptions

Depends on
• Capacity utilization
• Symmetry
• Average speed
• Tightness / optimality

Robustness ≠ inefficient (use slack where contributes to robustness)
Robustness – Verbal definitions

• “The ability of the railway system to operate normally despite disturbing influences” (Michiel Vromans, 2005)

• “Robustness is the ability to avoid delay propagation as much as possible” (V. Cacchiani et al, 2009)

• “A railway system is robust whenever the average travel time is as small as possible” (Dewilde et al, 2013)
How to increase robustness

- Infrastructure robustness
- Robust operational process
- Perceived robustness
Operations Planning

- Lineplanning – where the trains should stop
- Timetabling – when should trains arrive at stations
- Rolling stock – composition of trains
- Crew – union rules
- Depot – how to perform shunting operations

Solved sequentially, but may lead to infeasible solutions
Important in disruption situations to cover all parts
Data from many sources

- Trains
- Robustness
- Crew
- Signaling system
- Passengers
Disruption

- Infrastructure damage
- Rollings stock breakdown
- Signal problems
- Weather
- Passenger incidence

- Disruptions can cascade
Integrated Disruption Management of Passenger Railway Transport

How does one optimally recover the timetable, rolling stock, depot schedules in a disrupted environment?

Currently done manually
Data from many sources

Diagram showing connections between stations with time intervals:
- HTA to FS
- FS to KH
- KH to HI
- HI to BA

Time intervals:
- 100 (HTA to FS)
- 200 (KH to HI)
- 80, 75, 85, 210, 150 (connections)

Images of people and trains at stations and on tracks.
Multi-criteria problem

Minimize

- Cancellations
- Seat shortage
- Depot balance
- Operational costs
- Lack of robustness
Robustness

Minimize couplings/decouplings
Slack time to couple/decouple
Correct number of seats
(to avoid passenger congestions)
Mathematical model

$$\sum_{p \in \mathcal{P}_d^u} \lambda_p = inv_d^u$$

$$\forall u \in \mathcal{U}, d \in \mathcal{D}$$

$$\sum_{p \in \mathcal{P}} \alpha_p^t \lambda_p \geq 1 - y_t$$

$$\forall t \in \mathcal{T}$$

$$\sum_{u \in \mathcal{U}} s_u \sum_{d \in \mathcal{D}} \sum_{p \in \mathcal{P}_d^u} \alpha_p^t \lambda_p \geq demand_t - z_t$$

$$\forall t \in \mathcal{T}$$

$$\sum_{p \in \mathcal{P}} \beta_p^d \lambda_p \geq eod_d^u - w_d^u$$

$$\forall u \in \mathcal{U}, d \in \mathcal{D}$$

$$\sum_{u \in \mathcal{U}} l_u \sum_{d \in \mathcal{D}} \sum_{p \in \mathcal{P}_d^u} \alpha_p^t \lambda_p \leq length_t$$

$$\forall t \in \mathcal{T}$$

$$\sum_{u \in \mathcal{U}} l_u \sum_{d \in \mathcal{D}} \sum_{p \in \mathcal{P}_d^u} \gamma_p^{depot(a),a} \lambda_p \leq track_{depot(a)}$$

$$\forall a \in \mathcal{A}$$

$$\lambda_p \in \{0, 1\} \quad y_t \in [0, 1] \quad z_t, w_d^u \in \mathbb{Z}_0^+$$
Solution method

1. Initialize master with initial columns
2. Generate heuristic columns
3. Insert columns
4. Solve restricted master as LP
5. Send duals
6. Solve subproblem(s)
7. Found reduced cost columns?
   - Yes
   - Go to next candidate
   - No
   - Is solution feasible?
     - Yes
     - Has unprocessed nodes
     - No
     - Done
   - No
8. Go to next candidate
9. Make branch nodes

4 May 2015
New solution framework

- Lineplanning
- (Timetabling) – easier to choose emergency plan
- Rolling stock
- (Crew) – since trains end at same depot as planned
- Depot

- Can be solved in a few minutes
- Much better at handling certain families of constraints
  (train milage, bike compartments, commercials)

Only difference between normal planning and disruption planning is
timetable and objective weights
Test case: S-tog

Copenhagen S-train Diagram

Symbols at stations:
- service always stops here
- service never stops here
- when more than one service stops, you are always able to transfer
- occasional terminus

Diagram showing the S-tog network in Copenhagen, with various stations and lines indicated.
Test case: S-tog

| Date     | Name | Stops | |T|   | Active Lines          |
|----------|------|-------|----|-----------------------|
| 2014-03-07 | Fri  | 28 719 | 1 086 | A,B,Bx,C,E,F&H         |
| 2014-03-08 | Sat  | 20 474 |  706 | A,B,C&F               |
| 2014-03-09 | Sun  | 19 919 |  690 | A,B,C&F               |
| 2014-03-10 | Mon  | 28 017 | 1 074 | A,B,Bx,C,E,F&H         |

- Four representative days
- Around 130 train units
- Should be solved quickly (within 1 hour, preferably minutes)
Test case: Scenario #1

<table>
<thead>
<tr>
<th>Scenario #1 - Leg Segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contingency Plan</td>
</tr>
<tr>
<td>Description</td>
</tr>
<tr>
<td>Cancelled lines</td>
</tr>
<tr>
<td>Turned lines</td>
</tr>
<tr>
<td>Unchanged</td>
</tr>
</tbody>
</table>
Test case: Scenario #1

<table>
<thead>
<tr>
<th>Disruption</th>
<th>#</th>
<th>Time</th>
<th>Cols</th>
<th>Gap</th>
<th>Root</th>
<th>Cover</th>
<th>Seat</th>
<th>Mileage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fri</td>
<td>9:00-10:00</td>
<td>823</td>
<td>5</td>
<td>2563</td>
<td>0.9%</td>
<td>3.4%</td>
<td>100.0%</td>
<td>99.0%</td>
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<tr>
<td>Fri</td>
<td>9:00-13:00</td>
<td>814</td>
<td>6</td>
<td>2608</td>
<td>0.0%</td>
<td>3.2%</td>
<td>100.0%</td>
<td>99.4%</td>
</tr>
<tr>
<td>Fri</td>
<td>11:00-12:00</td>
<td>703</td>
<td>5</td>
<td>2234</td>
<td>0.3%</td>
<td>3.8%</td>
<td>100.0%</td>
<td>99.1%</td>
</tr>
<tr>
<td>Fri</td>
<td>11:00-15:00</td>
<td>692</td>
<td>5</td>
<td>2483</td>
<td>0.3%</td>
<td>2.1%</td>
<td>100.0%</td>
<td>99.0%</td>
</tr>
<tr>
<td>Fri</td>
<td>15:00-16:00</td>
<td>456</td>
<td>3</td>
<td>1456</td>
<td>0.0%</td>
<td>0.8%</td>
<td>100.0%</td>
<td>98.9%</td>
</tr>
<tr>
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<td>15:00-19:00</td>
<td>442</td>
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<tr>
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<td>9:00-10:00</td>
<td>807</td>
<td>5</td>
<td>2642</td>
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<td>99.1%</td>
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<td>100.0%</td>
<td>98.8%</td>
</tr>
<tr>
<td>Mon</td>
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<td>676</td>
<td>5</td>
<td>2854</td>
<td>0.5%</td>
<td>2.9%</td>
<td>100.0%</td>
<td>98.9%</td>
</tr>
<tr>
<td>Mon</td>
<td>15:00-16:00</td>
<td>440</td>
<td>5</td>
<td>1626</td>
<td>0.0%</td>
<td>2.4%</td>
<td>100.0%</td>
<td>98.2%</td>
</tr>
<tr>
<td>Mon</td>
<td>15:00-19:00</td>
<td>426</td>
<td>3</td>
<td>1416</td>
<td>0.7%</td>
<td>2.1%</td>
<td>100.0%</td>
<td>98.2%</td>
</tr>
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# Test case: Scenario #2

<table>
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<th>Scenario #2 - Central Segment</th>
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</thead>
<tbody>
<tr>
<td><strong>Contingency Plan</strong></td>
</tr>
<tr>
<td><strong>Description</strong></td>
</tr>
<tr>
<td><strong>Cancelled lines</strong></td>
</tr>
<tr>
<td><strong>Turned lines</strong></td>
</tr>
<tr>
<td><strong>Unchanged</strong></td>
</tr>
</tbody>
</table>
## Test case: Scenario #2

<table>
<thead>
<tr>
<th>Disruption</th>
<th>Time</th>
<th>Cols</th>
<th>Gap</th>
<th>Root</th>
<th>Cover</th>
<th>Seat</th>
<th>Mileage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fri</td>
<td>9:00-10:00</td>
<td>836</td>
<td>11</td>
<td>4 096</td>
<td>0.3%</td>
<td>15.1%</td>
<td>99.8%</td>
</tr>
<tr>
<td>Fri</td>
<td>9:00-13:00</td>
<td>782</td>
<td>18</td>
<td>6 068</td>
<td>0.5%</td>
<td>14.7%</td>
<td>99.8%</td>
</tr>
<tr>
<td>Fri</td>
<td>11:00-12:00</td>
<td>713</td>
<td>8</td>
<td>3 051</td>
<td>0.6%</td>
<td>16.7%</td>
<td>99.8%</td>
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<tr>
<td>Fri</td>
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<td>657</td>
<td>10</td>
<td>3 939</td>
<td>0.2%</td>
<td>14.8%</td>
<td>99.7%</td>
</tr>
<tr>
<td>Fri</td>
<td>15:00-16:00</td>
<td>468</td>
<td>6</td>
<td>2 379</td>
<td>0.3%</td>
<td>2.1%</td>
<td>99.6%</td>
</tr>
<tr>
<td>Fri</td>
<td>15:00-19:00</td>
<td>402</td>
<td>5</td>
<td>1 727</td>
<td>0.0%</td>
<td>1.9%</td>
<td>99.8%</td>
</tr>
<tr>
<td>Mon</td>
<td>9:00-10:00</td>
<td>820</td>
<td>13</td>
<td>4 129</td>
<td>0.4%</td>
<td>2.7%</td>
<td>99.8%</td>
</tr>
<tr>
<td>Mon</td>
<td>9:00-13:00</td>
<td>766</td>
<td>14</td>
<td>5 827</td>
<td>0.1%</td>
<td>2.5%</td>
<td>99.8%</td>
</tr>
<tr>
<td>Mon</td>
<td>11:00-12:00</td>
<td>697</td>
<td>10</td>
<td>3 665</td>
<td>0.5%</td>
<td>16.5%</td>
<td>99.8%</td>
</tr>
<tr>
<td>Mon</td>
<td>11:00-15:00</td>
<td>641</td>
<td>8</td>
<td>4 066</td>
<td>0.2%</td>
<td>14.3%</td>
<td>99.7%</td>
</tr>
<tr>
<td>Mon</td>
<td>15:00-16:00</td>
<td>451</td>
<td>6</td>
<td>2 239</td>
<td>0.0%</td>
<td>1.5%</td>
<td>99.6%</td>
</tr>
<tr>
<td>Mon</td>
<td>15:00-19:00</td>
<td>385</td>
<td>6</td>
<td>2 053</td>
<td>0.2%</td>
<td>1.9%</td>
<td>99.8%</td>
</tr>
</tbody>
</table>
Summing up

• First work to integrate (timetabling), rolling stock, depot planning, maintenance, (crew)
• New “methodology” based on column generation
• Fast solution times
• Possible to weight criteria in objective

Big data problem

Disruption - lots of data
• Needs to be processed
• Filtered
• Reshaped
• Processed
• Communicated
Other projects in RobustRailS
Infrastructure robustness

• Verification of railway control systems
• Communication technologies support
Other Projects in RobustRailS
Robustness in rail operational process

- Independant subsystems
- Operations planning
Other Projects in RobustRails

Punctuality

On-Time Arrival at Final Destination

On-Time Arrival En-Route

Average Delay per Train

Passengers Affected

Passenger On-Time Performance

Passenger Hours Delay

(ISBeRB, Imperial College)
RobustRailS Prizes

- Linh Hong Vu, Jan Peleska, Anne Haxthausen “A Domain-specific Language for Railway Interlocking Systems” Best paper award FORMS/FORMAT 2014

- Jørgen Haahr, Richard Lusby, first prize, RAS Competition, Railway Application Section, INFORMS, 2014

From big-data to big-information

- David Hunt and Jason Kuehn (2013)

“Tomorrow, the quantity and the quality of railroad data will be even greater than today, and the demand for timely information from these data will also increase. Just like in “Moneyball,” the railroads that are best able to use analytics to improve decision making will be the ones that end up victorious. It is up to the OR community to deliver the right tool sets to make this possible.”
Railways leading role in big data revolution

• Lyndon (2013)
  “leading role that rail public transportation has been playing — actually for a number of decades — in the Analytics and Big Data revolution that has been sweeping through both the private and public sector of global economies.”

[Image of APTA and Rail Conference]

April 24-25, 2013
Philadelphia Marriott Downtown = Philadelphia, PA
Man on the moon project in this century
Thank you

www.robustrails.dtu.dk

Publications
www.robustrails.man.dtu.dk/Publications


- Future alternatives to GSM-R. Aleksander Sniady and José Soler. Poster presented at Danish Railway Conference 2013, Copenhagen.


Symposium on Formal Methods

- Linh Hong Vu, Jan Peleska, Anne Haxthausen
- A Domain-specific Language for Railway Interlocking Systems
- Best paper award
ROADEF/EURO Challenge 2014: Trains don't vanish

- Rolling stock unit management on railway sites
- Holistic approach to planning problems at stations
- Matching available trains, routing trains, maintenance, when and were to couple/decouple

- Many hard and soft constraints
- Extremely difficult
RAS competition

Plan Railroad Hump Yard Block-to-Track Assignment
Railway Application Section, INFORMS

- 42 days planning horizon
- 702 inbound trains
- 53,000 rail cars
- 52 tracks different length
- 20 outbound departures per day
- Certain number of engines

Best results, close to theoretical bound
Showed improvements possible by allowing delay on outbound train departures
Example

<table>
<thead>
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</tr>
<tr>
<td><strong>Unchanged</strong></td>
</tr>
</tbody>
</table>
Results: Minimize cancellation + small coupling costs

| Instance | $|T|$ | Tree | Columns | Runtime (s) |
|----------|-----|------|---------|-------------|
| Fri      | 1086 | 1    | 2747    | 94          |
| Sat      | 706  | 0    | 752     | 2           |
| Sun      | 690  | 0    | 669     | 2           |
| Mon      | 1074 | 4    | 3621    | 177         |
Minimize cancellations + seat shortage kilometers

<table>
<thead>
<tr>
<th>Instance</th>
<th>Runtime</th>
<th>Best</th>
<th>Tree</th>
<th>Columns</th>
<th>Seats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fri</td>
<td>261</td>
<td>21</td>
<td>308</td>
<td>2109</td>
<td>95.4%</td>
</tr>
<tr>
<td>Sat</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>395</td>
<td>99.8%</td>
</tr>
<tr>
<td>Sun</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>373</td>
<td>99.8%</td>
</tr>
<tr>
<td>Mon</td>
<td>1360</td>
<td>551</td>
<td>1375</td>
<td>7829</td>
<td>95.7%</td>
</tr>
</tbody>
</table>
Minimize cancellations + seat shortage kilometers + total mileage

<table>
<thead>
<tr>
<th>Param</th>
<th>Seats</th>
<th>Mileage</th>
<th>Gap</th>
<th>Root Gap</th>
<th>Runtime</th>
<th>Best</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>100.0%</td>
<td>$1.30 \cdot 10^6$</td>
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<td>0.0%</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>0.01</td>
<td>100.0%</td>
<td>$1.27 \cdot 10^6$</td>
<td>0.0%</td>
<td>0.0%</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>0.10</td>
<td>100.0%</td>
<td>$1.25 \cdot 10^6$</td>
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<td>0.0%</td>
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</tr>
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<td>1.00</td>
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<td>146</td>
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<tr>
<td>2.00</td>
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<td>0.1%</td>
<td>1 888</td>
<td>1 223</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<th>Seats</th>
<th>Mileage</th>
<th>Gap</th>
<th>Root Gap</th>
<th>Runtime</th>
<th>Best</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>99.9%</td>
<td>$1.90 \cdot 10^6$</td>
<td>0.0%</td>
<td>4.3%</td>
<td>822</td>
<td>33</td>
</tr>
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<td>0.01</td>
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<td>$1.85 \cdot 10^6$</td>
<td>red4.0%</td>
<td>4.0%</td>
<td>3 601</td>
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<td>0.10</td>
<td>99.6%</td>
<td>$1.69 \cdot 10^6$</td>
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<td>0.1%</td>
<td>1 248</td>
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</tr>
</tbody>
</table>
Integrated Disruption Management of Passenger Railway Transport

How does one optimally recover the timetable, rolling stock, depot schedules, and crew plans in a disrupted environment?

Results

- Prototype model for S-tog developed
- Tested on historic disruptions
- Fast solution time (30sec to 5 min)
- In most cases better recovery plan than manually found
New signalling system

- 2009 the Danish Parliament decided to fund a Euro 3.2 Billion complete replacement of Danish railway signalling before 2021.
- Intereuropean standard: main tracks (ERTMS-2), S-train (Light Rail System)
- Higher speed, more capacity, new possibilities for disruption handling
First large-scale project in Railways in DK

- From scattered projects to unified research
- Sparring and decision support to Danish railways
- International visibility
Holistic approach

- Tracks
- Robustness
- Signals
- Trains
- Crew
Partners
International collaborators

• Leo Kroon, professor at the Rotterdam School of Management of Erasmus University and logistic consultant at the Dutch railways.

• Jan Peleska, professor at Bremen University and founder of Verified Systems International. He has strong experience in industrial development and validation of safety-critical railway and avionics systems.

• Marion Berbineau. LEOST-IFSTTAR in France.
Robustness

• A robust system can
  - absorb small disruptions
  - quickly recover from larger disruptions

• Robust infrastructure
• Robust communication
• Robust timetables
• Robust recovery
Data from many sources
Robustness – Verbal definitions

• “A timetable is robust if we can cope with unexpected troubles without significant modifications”. (Norio in Tomii, 2005)

• “Robustness is here defined as the ability of a system to withstand model errors, parameters variations or changes in the operational conditions” (Giorgio Medeossi, 2009)

• “Robustness is the ability to avoid delay propagation as much as possible” (V. Cacchiani et al, 2009)

• “The ability of the railway system to operate normally despite disturbing influences” (Michiel Vromans, 2005)

• “A railway system is robust whenever the average travel time is as small as possible” (Dewilde et al, 2013)

• ……
Robustness – Analytical definitions

- A few attempts to create an analytical measure e.g. The Robustness Index (Salido et al, 2008)

\[ R(x) = \sum_{T=1}^{NT} \sum_{S=1}^{NS} Buf_fT_S \times \%Flow_{ST} \times TT_S \times NSF_{CT} \times (NS - S)/NS \]

- Weighted Average Distance of the allocated buffer from the starting point (Fischetti, 2009)

\[ WAD_h = \frac{1}{\sum_{i=1}^{len(h)-1} s_{i,i+1}} \sum_{i=1}^{len(h)-1} \frac{s_{i,i+1} (t_{i+1}^h + t_i^h)/2}{t_{i+1}^h - t_i^h} \]

- Trying to allocated the same amount of time supplement between services \( i \) and \( j \) (Dewilde et al, 2013)

\[ \text{Min.} \sum_{ij} \text{buffertime}_{ij}^{-1} \]

- Simulation studies aiming at reducing delay propagation e.g. (Fischetti et al, 2009).
Robustness – the trade-off

- Recovery time
- Capacity utilisation
- Heterogeneity
- Average speed

(Salido et al, 2012)
Robustness

Cost (mio. dollar) vs. Robustness Penalty

Technical University of Denmark
Robustness

2%

cost (mio. dollar)

robustness penalty
How to increase robustness

- Infrastructure robustness
- Robust operational process
- Perceived robustness
Infrastructure robustness

- Verification of railway control systems
- Communication technologies support
Verification of Railway Control Systems

New signaling system

Provide methods and tools for **efficient** (cheap and fast) development and verification

- Use *automated, formal methods* as these are efficient for detecting errors
- Tried with success the idea for existing systems. Now look at new systems.
- Working on a model of the new interlocking systems.
- Formal model for time tabling.
- Developed and verified a model of a ceiling speed monitor module for ETCS.
Robust Communication Technologies

• ERTMS is already outdated
• Capacity problems (e.g. Copenhagen Central Station)
• Investigate alternatives

• Mainly based on simulation of infrastructure and different scenarios with OPNET network simulation tool

LTE is a viable alternative

• Capacity performance of LTE for ERTMS, in Copenhagen Central.
• Novel Quality of Service mechanisms in LTE for ERTMS.
• Resilience performance of LTE for ERTMS.
Robustness in rail operational process

- Independant subsystems
- Operations planning
- Disruptions management
Independant subsystems

- Working with DSB to investigate independent train subsystems in Danish train networks.

- Disruptions from one subsystem does not propagate to other subsystem

- 18 unit types
- 17 trip types
- Benefits/costs of partitioning lines and units into independent pools
Integrated Disruption Management of Passenger Railway Transport

How does one optimally recover the timetable, rolling stock, depot schedules, and crew plans in a disrupted environment?

Results
• Prototype model for S-tog developed
• Tested on historic disruptions
• Fast solution time (30sec to 5 min)
• In most cases better recovery plan than manually found
# Punctuality

<table>
<thead>
<tr>
<th>Category</th>
<th>Diagram</th>
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<tbody>
<tr>
<td>On-Time Arrival at Final Destination</td>
<td><img src="image1" alt="Diagram" /></td>
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<td>Passengers Affected</td>
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<td><img src="image5" alt="Diagram" /></td>
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<tr>
<td>Passenger Hours Delay</td>
<td><img src="image6" alt="Diagram" /></td>
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</table>

(ISBeRB, Imperial College)

Technical University of Denmark
Passenger delays equal train delays?

Are passengers delayed if this train is being delayed?
Difference between passenger and train delays

Number of passenger per train varies

- More “stressed” timetable in the rush hours
- Higher frequency, more passenger interactions
- Often more passengers per train

Passenger transfers between lines

- They may reach the same second line (no delay at destination)
- They may miss a transfer (much more transferring time)
- They may even catch an earlier (but delayed) departure of the second line

If several lines run parallel along a rail-track, passengers may have alternative options
Generations of passenger delay definitions

0-generation models
  Counting delayed trains
  Changes in passengers route choices are not considered

1. generation models
  Optimal route choice

1½ generation models
  Considering the delay distribution a priori, but follow the route afterwards

2. generation
  simulate the schedule, but follow the planned route

3. generation model
  Adaptive route choice
Publications

www.robustrails.man.dtu.dk/Publications


- **Can LTE become an alternative to GSM-R?** Aleksander Sniady and José Soler. Abstract presented at "Strategisk forskning i transport og infrastruktur" Conference ("Strategic Research in Transportation and Infrastructure" Conference), Technical University of Denmark, 2013.


- **Future alternatives to GSM-R.** Aleksander Sniady and José Soler. Poster presented at Danish Railway Conference 2013, Copenhagen.


# Ongoing PhD Projects, and affiliated projects

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<td>Scheduling of maintenance work on tracks</td>
<td>(Shahrzad Pour) Banedanmark</td>
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Symposium on Formal Methods

- Linh Hong Vu, Jan Peleska, Anne Haxthausen
- *A Domain-specific Language for Railway Interlocking Systems*
- Best paper award
ROADEF/EURO Challenge 2014: Trains don't vanish

- Rolling stock unit management on railway sites
- Holistic approach to planning problems at stations
- Matching available trains, routing trains, maintenance, when and were to couple/decouple

- Many hard and soft constraints
- Extremely difficult
ROADEF/EURO Challenge 2014: Trains don't vanish
RAS competition

Plan Railroad Hump Yard Block-to-Track Assignment
Railway Application Section, INFORMS
- 42 days planning horizon
- 702 inbound trains
- 53,000 rail cars
- 52 tracks different length
- 20 outbound departures pr day
- Certain number of engines

Best results, close to theoretical bound
Showed improvements possible by allowing delay on outbound train departures
RobustRailS

WAS THAT THE EXPRESS?

NO, THAT WAS BRAKE FAILURE
Barriers

From prototype to real implementations
- People largest barrier (goal, conservative, background)
- Necessary to build system confidence (visualization, difference between old and new solution,
- jobs are not threatened, professionalism is not threatened
- will have time for other (fun) stuff
- Customers are concerned with data
- Interact with existing software to be successful
Barriers

Passenger satisfaction
- Historic reasons not focusing on passengers
- Difficult to split responsibility among operators (bus delay, train delay)
- Distinguish between passenger groups (commuters, occasional users)
- Operators should focus on the service in a journey that is hardest to replace
- Passengers remember the (very) bad experiences for a long time
International projects on robust railways
Thank you

"I know it's yesterday's ticket! That's when I got on this bloody train!"
Thank you
WP5: Optimization of Railway Operations with regard to Passenger Benefits

(Otto Anker Nielsen, DTU Transport)

• Jens Parbo PhD december 2012
• Conducted a literature review of methods to impose robustness in railway operations.

• Two projects in the pipeline:
  1. Analyzing data from the passenger delay model. The idea is to get enhanced knowledge on the differences between train delays and passenger delays.
  2. SP-questionnaire (Stated Preference) to assess one of the hidden disbenefits of a non-robust railway system, namely the correlation between robustness and passengers’ departure time.
WP3.1: Operations Planning

- (Alex Landex, DTU Transport)
- Lars Wittrup Jensen PhD-student October 2012
- PhD project: Network effects within railways.
- Goal: To identify factors that affect robustness of train operations and develop methods that can evaluate robustness.

Work done

- Capacity consumption, capacity utilization and scheduled waiting time have been identified as key indicators to describe robustness.
- A running time calculator for single train operation and development of a prototype of a line capacity analyzer has been developed
WP2: Robustness in Rail Operations

(Jesper Larsen, DTU Management)

• Delayed due to problems recruiting
• Simon Bull finally employed.
• Two meetings/seminars have been held with focus on defining robustness
• Meeting with stakeholders in April 2013 on robustness

Currently two projects initiated
• Robustness in crew plans (DSB S-tog)
• Independant trains system (DSB)

• Strong focus on how OR and optimization can contribute to produce better and more robust plans – this could be the time schedule, the plans for rolling stock or crew or other planning problems.
WP6: Dissemination of results

March 2014:
- 5 journal papers with peer review.
- 10 conference papers with peer review.
- 5 conference papers without peer review.
- 3 scientific reports.
- 6 working papers.
- 3 book chapters.

- Meetings with stake holders, several times a year
- Mini-conferences

- www.robustrails.man.dtu.dk
# Ongoing PhD Projects, and affiliated projects

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Vurdering af færdiggørelsesgrad

- Alle work-packages kører fint
- Simon Bull (WP2 - robustness) forsinket
## Gantt diagram

Nedenstående Gantt diagram illustrerer projektstyring af junior medarbejderne

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<td>Ind.PhD Per Thorlacius (*)</td>
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* PhD Per Thorlacius is industrial PhD funded by DSB S-tog, but his work is somehow related to WP 3.2, and he will work closely with the RobustRailS researchers. ** Shahrzad Pour is PhD funded by Banedanmark, working on robust maintena
Den organisatoriske dimension

- Intern organisering som planlagt
- CITEF (Spain) erstattet af IFSTTAR (France)
- Kontaktperson for WP 4.1 (Banedanmark) forladt
- Ressourcer på plads, Kun Simon Bull forsinket
Økonomisk dimension

- Ca et halvt år bagude.
- Grundet sen start af Simon Bull bliver vi nødt til at bede om forlængelse

- Øvrige udgifter, konferencer, gæster, m.m. som planlagt
Styregruppe møder

Månedlige møder, alternerende mellem
• Styregruppe møde hvor WP ledere deltagere
• Videnskabelige møder, hvor alle VIP deltager

Styregruppe møder
• Diskuterer organisation, ansættelser, økonomi

Videnskabelige møder
• Alle VIP fremlægger status på projekter
• Videnskabelig præsentation på 45 minutter
Styregruppe møder

Korte, velorganiserede
• Nogle gange svært at planlægge møder

Eksempler på beslutninger
• Bedre integrering mellem projekter (seminar, med-vejledning phd projekter, phd-studerende prøver flere miljøer)
• Diskussion af robusthed (alle fremlagde deres definition, robusthed skal ses i kontekst)
Samarbejde

Kun én værtsinstitution, gør tingene nemmere

Samarbejde med virksomheder / offentlige partnere
- Partner møder (2-3 møder årligt)
- Stort engagement
- Blevet bedre og bedre
- Udvidet netværk (lokalbanen, metro, præcisionsprogrammet)
- Flere deltagere på partner-møder
- Partnere holder oplæg om robusthed, best practice

Men,
- På projekt-niveau er partnere lidt træge
- Svært at forandre
Væsentligste videnskabelige resultater

- Forstår robusthed bedre
- GSM-R (outdated) kan erstattes af LTE
- Focus på passager-punktlighed frem for tog-punktlighed
- Prototype for genopretning af S-togs net som tager hensyn til rullende materiale, depoter, og mandskab
- Prototype for formel verifikation af signalsystemer

Mange publikationer

Mini-konference om robust jernbanedrift 3. oktober

Samlende platform for forskning i jernbaner
Hovedudfordringer

- Rekruttering af medarbejdere
- Definere robusthed
- Involvere samarbejdsfirksomheder og udenlandske partnere
Lessons learned

Organisering

• Ikke undervurdere opgaven med at rekruttere gode folk
• Involvere udenlandske partnere mere (udveksle phd studerende, invitere konferencer)
• Involvere udenlandske partnere tidligere
• Kigge ud i verden på relaterede projekter

Forskning

• Robusthed defineret ved tommelfingerregler. Havde håbet på simulering, stokastisk programmering)
• Bruge hinandens netværk lidt bedre
• Projektet meget bredt
Publications

Publications 2012:


A Variety of Performance Indicators Can Be Used

- On-Time Arrival at Final Destination
- On-Time Arrival En-Route
- Average Delay per Train
- Passengers Affected
- Passenger On-Time Performance
- Passenger Hours Delay

Increasing Customer Focus
Approaches to reduce passenger delays and improve travel time – Challenges of the Railway

Jens Parbo Jensen
PhD-Student
jepar@transport.dtu.dk
Outline

• RobustRailS

• Purpose of today's presentation

• Presentation and assessment of Service Characteristics

• Conclusions & Future perspectives
Project Description

• Robustness in Railway OperationS – RobustRailS

• Large interdisciplinary project (2012-2015) financed by the Danish Council for Strategic Research.

• Main question: Can we get trains to run on time?

• Title “Optimization of rail operations with regard to passenger benefits”.

• Focusing on improving tactical parts of railway operations.

• Main question for my work: Can we provide approaches for a more coherent and reliable service to the passengers?
Purpose

• Getting familiar with the Service Characteristics used within Railways.

• Examine how Service Characteristics are measured.

• Are there shortcomings or bias in today’s Service Characteristics?

• A process of finding the right objective for a future optimization
Presentation of Service Characteristics

- Punctuality
- Robustness
- Capacity
- Frequency
- Etc.
Punctuality

• From the Freedictionary.com: “Precise”

• Measuring punctuality (DSB, 2012):

\[
\left(\frac{\text{#ScheduledArrivals}-\text{#DelayedArrivals}}{\text{#ScheduledArrivals}}\right)\times 100\%
\]

• Most common definition: “The amount of trains arriving at/departing from the final station (or several large stations) within a given threshold from the scheduled time”

• Thresholds for considering trains as being delayed:
  – Most European countries: 5 minutes
  – Switzerland: 3 minutes (89.8 % punctual in 2012)
  – The Netherlands 3 minutes
  – DSB S-train 2 minutes
  – DSB IC/Reg. 5 minutes and 59 seconds
Punctuality

On-Time Arrival at Final Destination

On-Time Arrival En-Route

Average Delay per Train

Passengers Affected

Passenger On-Time Performance

Passenger Hours Delay

(Steen Larsen, 2013)
Robustness

• From the Freedictionary.com: “Powerfully built”

• No common definition!

• Majority of Robustness definitions are verbal

• Some (non-generic) analytical measures have been proposed
Robustness – Verbal definitions

• “A timetable is robust if we can cope with unexpected troubles without significant modifications”. (Norio in Tomii, 2005)

• “Robustness is here defined as the ability of a system to withstand model errors, parameters variations or changes in the operational conditions” (Giorgio Medeossi, 2009)

• “Robustness is the ability to avoid delay propagation as much as possible” (V. Cacchiani et al, 2009)

• “The ability of the railway system to operate normally despite disturbing influences” (Michiel Vromans, 2005)

• “A railway system is robust whenever the average travel time is as small as possible” (Dewilde et al, 2013)

• ......
Robustness – Analytical definitions

- A few attempts to create an analytical measure e.g. The Robustness Index (Salido et al, 2008)

\[ R(x) = \sum_{T=1}^{NT} \sum_{S=1}^{NS} B_{TS} \times P_{T} \times T_{TS} \times N_S \times T_{TS} \times (N_S - S)/N_S \]

- Weighted Average Distance of the allocated buffer from the starting point (Fischetti, 2009)

\[ WAD_h = \frac{1}{\sum_{i=1}^{\text{len}(h)-1} s_{i,i+1}} \sum_{i=1}^{\text{len}(h)-1} \frac{\sum_{i=1}^{\text{len}(h)-1} s_{i,i+1} (t_{i+1}^h + t_i^h)/2}{t_{i+1}^h - t_i^h} \]

- Trying to allocate the same amount of time supplement between services \(i\) and \(j\) (Dewilde et al, 2013)

\[ \text{Min.} \sum_{ij} \text{buffer time}^{ij}_{ij} \]

- Simulation studies aiming at reducing delay propagation e.g. (Fischetti et al, 2009).
Robustness – the trade-off

- A balance between the following (figure)
  - Adding recovery time
  - Decreasing capacity utilisation
  - Decreasing heterogeneity
  - Optimizing average speed

- Definition should capture these parameters (both verbal & analytical)

(Salido et al, 2012)
Shortcomings & bias

- No proper measure or definition of Robustness does yet exist.

- The well established Service Characteristics only consider trains – to whom are the train service in reality provided?

- Though, passengers are not totally forgotten. A few studies considered passenger delays (Zhi-bin et al, 2012; Nielsen et al, 2005)

- Both these studies suggest the use of passenger punctuality rather than train punctuality.
Example - Difference between train and passenger delays

- Green train (headway: 20 minutes) is on time

- Blue train (headway: 10 minutes) is 4 minutes late when it reaches its final destination

- 50 % of the alighting passengers from the blue train transfers to the green train in order to reach their destination.

- These passengers miss their connection, even though the blue train technically is punctual (Danish standard).

- Transferring Passengers will be 20 minutes late – Trains will be on time.
Conclusions & Future perspectives

• Train delays are not equal to passenger delays.

• Tracking passenger delays is not easy.

• The way Service Characteristics are measured may bias the optimization.

• Improving Robustness is a trade-off.

• Robust Timetables should attract more passengers.

• Intelligent allocation of time supplements with a special passenger focus e.g. emphasizing dwell time supplements at transfer heavy stations.

• Defining Robustness as an objective to maximize.
Questions
The passenger perspective in robust railway operations

Jens Parbo Jensen

Otto Anker Nielsen & Carlo Prato
jepar@transport.dtu.dk
Comprehensive knowledge of trains – what about the passengers?

• Vast amount of train data - a priori, real time and measured.

• Passenger behavior is difficult to track.

• Why is this important?
Are passenger delays equal to train delays?

- We know when trains are delayed.

- Passengers may carry a delay - transfers.

- Trains tend to be more delayed during peak hour (larger capacity utilization).

- Peak hour delays normally affects more passengers.

- Several lines serving the same O-D pair reduces the effect on passengers of a delayed/cancelled train.
Project outline (WP5).

- Literature review on how robustness is measured and improved within railways.

- Stated Preference - analysis (quantify the “hidden” effects of a non-robust railway system e.g. early departure).

- Combining knowledge of passengers’ travel behavior and mathematical optimization of the robustness of the railway system.

- The outcome: generic methods to improve the robustness of the system with regard to the passengers.
Discussion.

- Emphasizing passengers in the planning phase.

- Train delays and passenger delays differ significantly.

- Often operators only measure train punctuality, not passenger punctuality.

- Discuss:
  - The pros and cons of focusing on the passengers when designing the timetable.
  - Discuss the challenges and which steps should be taken to enforce such a paradigm shift (if, at all?).
• Problemer
  • vis vits + kø banegård + avisartikel
• Robustrails Vision
• Robustness slide
• Robustrails Vision
• Robustness slide
• Præsentere robustrails
• Integrated disruption management
• Pointe om big-data optimization
• hvis vi vil gøre noget seriøst ved robusthed, så big-data
  • - mange data fra mange kilder
  • - filtre for hvornår data frigives
  • - integrere mange IT-systemer
• Going from "big data" to "big information"
Lige nu måles rettidighed ved at måle hvor mange tog kom til tide.
I stedet burde vi måle på hvor mange folk der når frem på arbejde til tide.
• Go from "punctuality" to "just in time"
• Lean: from push-based systems to pull-based systems

• Big Data and Railroad Analytics
• David Hunt and Jason Kuehn, Oliver Wyman;
  David.Hunt@oliverwyman.com and Jason.Kuehn@oliverwyman.com

Tomorrow, the quantity and the quality of railroad data will be even greater than today, and the demand for timely information from these data will also increase. Just like in “Moneyball,” the railroads that are best able to use analytics to improve decision making will be the ones that end up victorious. It is up to the OR community to deliver the right tool sets to make this possible.
In a paper presented this past June (2013) to the annual Rail Conference of the American Public Transportation Association (APTA) in Philadelphia, Light Rail Now Project technical consultant Lyndon Henry (also an independent transportation planning consultant with Urban Rail Today and a blog columnist for Railway Age magazine) emphasized the leading role that rail public transportation has been playing — actually for a number of decades — in the Analytics and Big Data revolution that has been sweeping through both the private and public sector of global economies. (Lyndon is also a blog writer for the All Analytics online forum, sponsored by business analytics provider SAS.)

- Fortsætte integrering, for bedre transport, men også som innovations driver for samfundet.
- Man on the moon
- Man on the train
- Jernbane har i mange været udskældt
- Vi skal vende det til et man-on-the-train projekt