Passenger-oriented railway disposition timetables in case of severe disruptions

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STRC 2015, April 17th

Outline

Outline

Motivation

Figure: Bray Head, Railway Accident, Ireland, 1867. The Liszt Collection.

Motivation

Figure: SBB Blackout, Luzern, June 22nd, 2005. AURA collection.

Brief literature review

	Disturbances	Disruptions
Microscopic	Albrecht et al. (2011), Boccia et al. (2013), Caimi et al. (2012), Corman et al. (2009, 2010a,b,c, 2011b, 2012), D'Ariano et al. (2007a,b, 2008,a,b,), Flamini and Pacciarelli (2008), Gély et al. (2006), Khosravi et al. (2012), Lamorgese and Mannino (2012), Lamorgese and Mannino (2013), Lusby et al. (2013), Lüthi et al. (2007), Mannino (2011), Mannino and Mascis (2009), Meng and Zhou (2011), Pellegrini et al. (2012), Rodriguez (2007), Schaafsma and Bartholomeus (2007)	Hirai et al. (2009), Corman et al. (2011a), Wiklund (2007)
Macroscopic	Acuna-Agost et al. (2011a), Acuna-Agost et al. (2011b), Chiu et al. (2002), Dollevoet et al. (2011, 2012, 2013). Dündar and Şahin (2013), Kanai et al. (2011), Kumazawa et al. (2010), Min et al. (2011), Schachtebeck and Schöbel (2010), Schöbel (2007), Schöbel (2009), Törnquist (2012), Törnquist and Persson (2007)	Albrecht et al. (2013), Louwerse and Huisman (2014), Nakamura et al. (2011), Narayanaswami and Rangaraj (2013), Shimizu (2008)

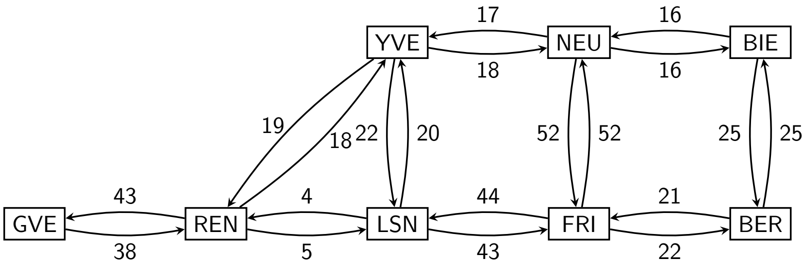
Figure: Classification of the recent literature on train rescheduling.
(Cacchiani, V., Huisman, D., Kidd, M., Kroon, L., Toth, P., Veelenturf, L., and Wagenaar, J. (2014). An overview of recovery models and algorithms for real-time railway rescheduling. Transportation Research Part B: Methodological, 63:15–37)

Outline

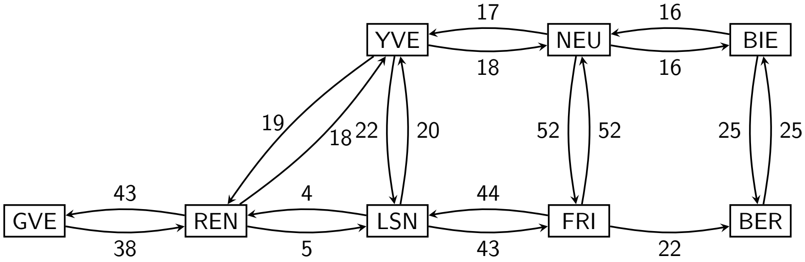
Research question

What are the impacts, in terms of passenger (dis-)satisfaction, of different recovery strategies in case of a severe disruption in a railway network?

A sample network



A disrupted sample network



Recovery strategies

- Train cancellation
- Partial train cancellation
- Global re-routing of trains
- Additional service (buses/trains)
- "Direct train"
- Increase train capacity

The two sides of the problem

Supply (Operator)

- Network
- Trains
- (Rolling stock / Crew)

Demand (Passengers)

- Origins / Destinations
- Preferences / Choices

Assumptions on the supply side

- Homogeneity of trains
- Passenger capacity of trains / buses
- Depots at stations where trains can depart

Assumptions on the demand side

- Disaggregate passengers : origin, destination and desired departure time
- Path chosen according to generalized travel time (made of travel time, waiting time and penalties for transfers and early/late departure)
- Perfect knowledge of the system
- No en-route re-rerouting

Sets

Stations	$s \in S$
Time steps	$t \in T$
Depots	$r \in R$
Passengers	$p \in P$
Nodes (representing station s at time t)	$n_s^t \in N$
Train nodes	$i \in V = N \cup R$
Train arcs	$(i,j) \in A \subseteq V \times V$
Passenger p's nodes	$i \in V_p = N \cup O \cup D$
Passenger p's arcs	$(i,j) \in A_p \subseteq V_p \times V_p$
Disrupted train arcs	$(i,j) \in A_D \subseteq A$

Parameters

Number of trains available in depot r	$n_r \in \mathbb{N}$
Origin of passenger p	$o_p \in O$
Destination of passenger p	$d_p \in D$
Capacity of arc $(i, j) \in A$	$cap_{(i,j)} \in \mathbb{N}$
Passenger p's cost on arc $(i, j) \in A_p$	$c^p_{(i,j)} \in \mathbb{R}^+$
Cost of starting a train	$c_t \in \mathbb{R}^+$

Decision variables

- $x_{(i,j)} = \begin{cases} 1 & \text{if a train runs on arc } (i,j) \in A \\ 0 & \text{otherwise} \end{cases}$
- $w^p_{(i,j)} = \begin{cases} 1 & \text{if passenger } p \text{ uses arc } (i,j) \in A_p \\ 0 & \text{otherwise} \end{cases}$

Objective function

$$\min \sum_{p \in P} \sum_{(i,j) \in A_p} c^p_{(i,j)} \cdot w^p_{(i,j)} + \sum_{(i,j) \in A | i \in R} c_t \cdot x_{(i,j)}$$

Constraints

$$\sum_{j\in N} x_{(r,j)} \leq n_r \qquad \forall r \in R \qquad (1)$$

$$\sum_{i\in V} x_{(i,k)} = \sum_{j\in V} x_{(k,j)} \qquad \forall k \in V \qquad (2)$$

$$x_{(i,j)} = 0 \qquad \forall (i,j) \in A_D \qquad (3)$$

$$\sum_{(i,j)\in A_p | i=o_p} w^p_{(i,j)} = 1 \qquad \forall p \in P \qquad (4)$$

$$\sum_{(i,j)\in A_p | j=d_p} w^p_{(i,j)} = 1 \qquad \forall p \in P \qquad (5)$$

$$\sum_{i\in V_p} w^p_{(i,k)} = \sum_{j\in V_p} w^p_{(k,j)} \qquad \forall k \in V_p, \forall p \in P \qquad (6)$$

$$w^p_{(i,j)} \leq x_{(i,j)} \qquad \forall p \in P, \forall (i,j) \in A \cap A_p \qquad (7)$$

$$\sum_{p\in P} w^p_{(i,j)} \leq cap_{(i,j)} \cdot x_{(i,j)} \qquad \forall (i,j) \in A \cap A_p \qquad (8)$$

$$x_{(i,j)} \in \{0,1\} \qquad \forall (i,j) \in A \qquad (9)$$

$$w^p_{(i,j)} \in \{0,1\} \qquad \forall (i,j) \in A_p, \forall p \in P \qquad (10)$$

Outline

Macroscopic timetable re-scheduling framework

Adaptive large neighbourhood search (ALNS) is a common meta-heuristic used for train scheduling. It combines:

- Simulated annealing
- Destroy and Repair operators

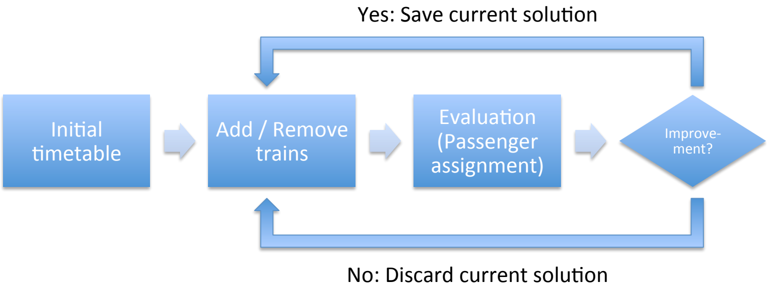
$\Rightarrow$ Inclusion of recovery strategies

List of operators

The following operators were implemented:

- R1 — Remove trains randomly
- R2 — Remove trains with lowest demand
- I1 — Insert trains randomly
- I2 — Insert trains after highest demand train

Macroscopic timetable re-scheduling framework



Adaptive large neighbourhood search

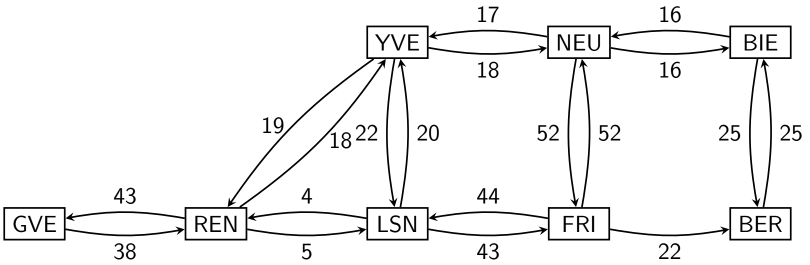
```
input  : Initial solution s, Initial (final) temperature T_0 (T_f)
T ← T_0, s* ← s
while T > T_f do
    s' ← s
    Choose Removal and Insertion operator
    Apply the operators to s'
    Assign passengers on s'
    if z(s') < z(s) then
        s ← s'
        if z(s) < z(s*) then
            s* ← s
            Update score of chosen operators with σ_1
        else
            Update score of chosen operators with σ_2
    else
        if s' is accepted by simulated annealing criterion then
            s ← s'
            Update score of chosen operators with σ_3
    if Iteration count is multiple of L_s then
        Update weights of all operators and reset scores
    Update T
return s*
```

Outline

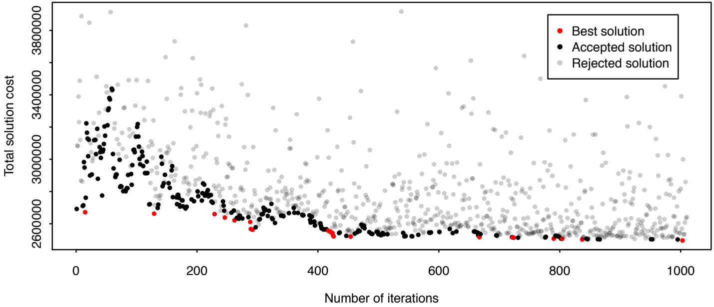
Case study characterstics

- **8 stations** : GVE, REN, LSN, FRI, BER, YVE, NEU, BIE
- **207 trains** : All trains departing from any of the stations between 5am and 9am
- **40'446 passengers** : Synthetic O-D matrices, generated with Poisson process
- **Disruption** : Track unavailable between BER and FRI between 7am and 9am

Case study network



Results — Simulated annealing



Results (2) — Comparison of algorithms

Operators	z [min] (Improv.)	z_p [min]	z_o [min]	# DP	# T	Time [s]
Disrupted	2,674,223.5	2,666,630.5	7,593.0	2,847	197	< 1
R1-I1	2,674,223.5 (0%)	2,666,630.5	7,593.0	2,847	197	663
R1-R2-I1	2,536,551.1 (-5.1%)	2,525,843.1	10,708.0	2,152	186	1,024
R1-R2-I1-I2	2,496,095.8 (-6.7%)	2,483,594.8	12,501.0	1,645	194	1,140

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Conclusion

Contributions of the present work:

- **Novel perspective**
  Demand-driven framework to generate disposition timetables
- **Passenger routing flexibility**
  Linear disutility function
- **Practice-inspired framework**
  Inclusion of operational recovery strategies as operators
- **Network considerations**
  Possibility of re-routing due to consideration of whole network (instead of a single line)

Further research

- Comparison between exact and heuristic approach
- More realistic operators for ALNS, based on operational recovery strategies
- Real data (up to now: proof-of-concept)

Thank you for your attention!

Questions?