Towards a Better Train Timetable for Denmark, Reducing Total Expected Passenger Time

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Challenge / Puzzle

Danish Infrastructure Management Company: Banedanmark:

Improve timetable in terms of *expected passenger travel time*
(includes: ride, dwell, transfer time and primary and secondary delays)

Fixed:

Infrastructure, train lines, halting pattern, primary delay distributions

Variable:

Timing: supplements times at every ride, dwell, transfer action,
$\Rightarrow$ variable inter-train heading times $\Rightarrow$ variable train orders
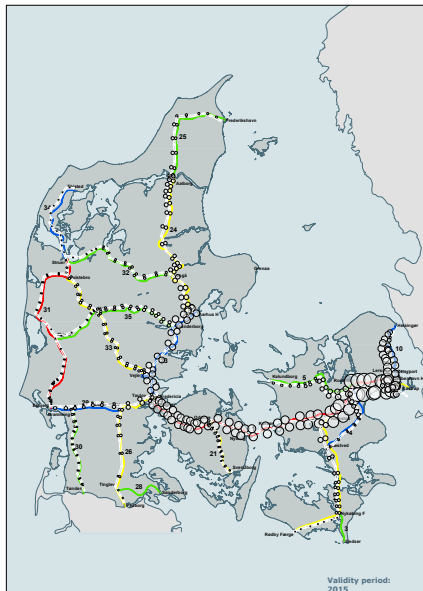
Note:

Includes primary and secondary delays $\Rightarrow$ opt. efficiency vs. robustness

Specifics:

One busy day, morning peak hour

Reflowing Results: via OD-Based Passenger Routing

Retiming Results for Hard Constraints: Minimum Run Time Violations?

Table 1: Realisability. Reduction of the number and size of minimum runtime violations from timetable Orig. $\rightarrow$ Opt.

time-table:	distribution: # actions with a violation per size of violation in seconds										
	6s	12s	18s	24s	30s	36s	42s	48s	56s	60s	66s
Orig.	107	88	44	22	6	6	5	0	3	1	0
	72s	78s	84s	90s	96s	102s	108s	114s	120s	126s	132s
Orig.	2	0	0	0	1	0	1	0	0	1	1

Table 2: Realisability. Reduction (elimination) of total and average violation from timetable Orig. $\rightarrow$ Opt.

timetable	weighted sum (s)	tot.#	avg. (s)
Orig.	4452	288	15.5
Opt.	0	0	0

Retiming Results for Hard Constraints: Realisability?

From headway histograms:

- Only Orig. has minimum run time violations.
- So Orig. is not realisable.
- Opt. is realisable.

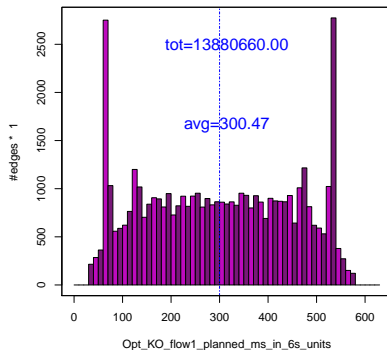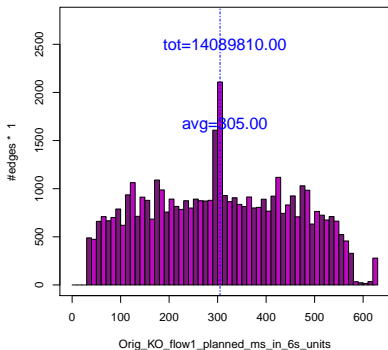# Retiming Results for Hard Constraints: Headway Conflicts?

Figure 2: #Edges per Planned headway. $m + s < 3'$ and $T - 3' < m + s$, are problematic. Orig: NOK, Opt OK.

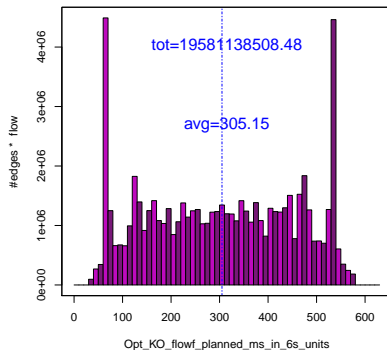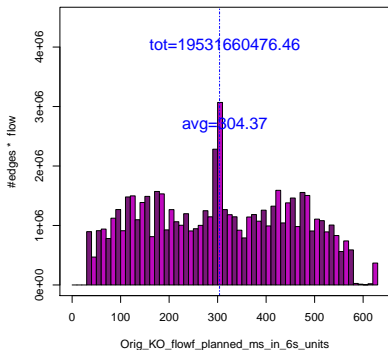# Retiming Results for Hard Constraints: Headway Conflicts?

Figure 3: #Passengers per Planned headway. $m + s < 3'$ and $T - 3' < m + s$, are problematic. Orig: NOK, Opt OK.

Retiming Results for Hard Constraints: *Macroscopically* Feasible?

From headway histograms:

- Only Orig. has minimum headway time violations.
- So Orig. is not *macroscopically* feasible = not conflict-less.
- Opt. is *macroscopically* feasible = conflict-less.

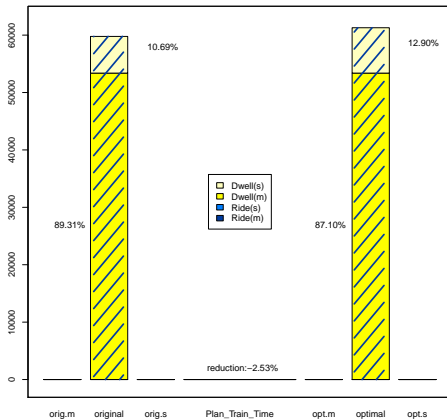# Retiming Results in the Planned Train Time Domain

Figure 4: Increase of 2.53% of total planned train time from Orig. to Opt.

Retiming Results in the Planned Train Time Domain

Bargraphs show: Orig. $\rightarrow$ Opt.

- Same planned train minimum ride + dwell time:
  - due to same number of trains and same minima in Orig. and Opt. timetables,
- (relatively) more planned train ride + dwell supplement time:
  - steered by objective function trading off efficiency with robustness,
  - effectiveness for passenger service of this is to be judged in expected passenger time domain.

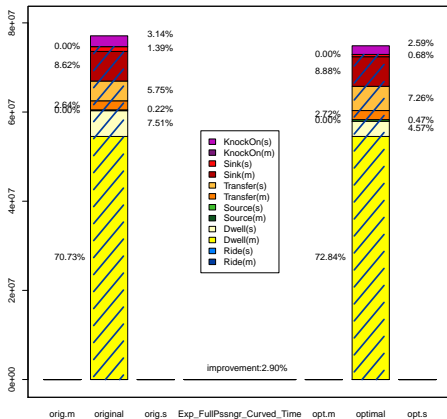# Results in the Expected Passenger Time Domain

Figure 5: Reduction by 2.90% of total exp. passenger time from Orig. to Opt.

Results in the Expected Passenger Time Domain

Bargraphs show: Orig. $\rightarrow$ Opt.

- = same (expected) minimum ride + dwell time due to:
  - same train line plan
  - passengers (still) taking same routes
- + less expected ride + dwell supplement time $\rightarrow$ more efficient
- + lowered expected knock-on delay $\rightarrow$ better robustness
- - increased expected transfer time due to:
  - difficulty for solver to plan many transfers with few passengers
- + overall reduction of 2.90% in expected passenger time

Reduction of missed transfer probability from 11.34% to 2.45%

Conclusions

- practical method to optimise timetables (in 65 minutes)
- objective $=$ minimal expected passenger time
- showed Orig. $\rightarrow$ Opt. reduction of 2.90% in exp. passenger. time
- evaluation reports on hard constraints, deterministic
  - stability (ride & dwell & transfers)
  - feasibility $=$ conflict freeness (headways)
- evaluation reports on soft constraints, stochastic
  - efficiency versus robustness
  - does not consider resilience

Railway Timetable Performance Indicators

Table 3: Railway Timetable Performance Indicators

deterministic		stochastic	
stable	feasible	robust	resilient
property in realised domain			
timetable-internal delays settle	no timetable-internal delays	timetable absorbs common prim. & sec. delays	timetable allows dispatching to absorb more rare delays
cause or measure taken in planned domain			
some supplements can be negative but some are *compensatingly* positive	no supplements are negative	supplements are *sufficiently* large	timetable-tuned dispatching measures

International Comparison

Table 4: Current Quality Levels of some European Railway Timetables

| Level | stable | ....feasible............... | | robust | resilient | Country |
		realiasable	no μ-HW-conflicts			
0						FR,IT,BE,DK
1	v					NL,UK
2	v	v	v			DE
3	v	v	v	v		CH,SE
4	v	v	v	v	v	
stable	**realiasable**	**no 3-HW-conflicts**	**robust**	**resilient**	**Country**	
?,?	v,v	v,v	v,v	v,v	resilient	BE'*, DK'*

- Black text above [Goverde and Hansen(2013)], based on inquiries and timetable process descriptions of 2013, may be incorrect.
- [Sels et al.(2015a)Sels, Cattrysse, and Vansteenwegen]
- [Sels et al.(2015b)Sels, Dewilde, Cattrysse, and Vansteenwegen]
- [Sels et al.(2015c)Sels, Dewilde, Cattrysse, and Vansteenwegen]
- μ-HW = microscopically calculated min. headway times.
- 3-HW = 3 minute macroscopically assumed min. headway times.

Future Work

- evaluate over only real transfers ← data?
- vary parameter 'a' value: 1% .. 5%
- add parameter 'r'
  - r% of passengers benefit from temporal spreading of trains
- parameter 'r' value: 0% .. 100%

Questions / Next Steps

- Your questions?
  - here and now, or ...
  - sels.peter@gmail.com
  - www.LogicallyYours.com/research/
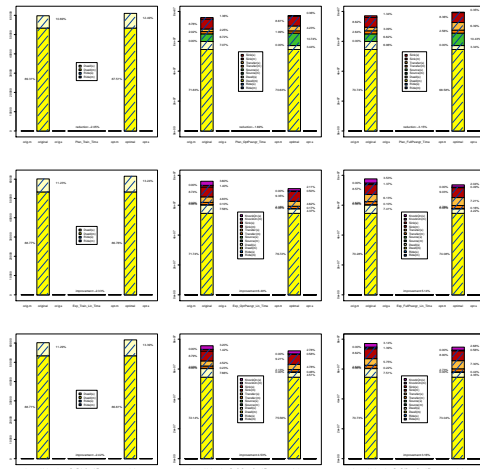
Results in all Time Domains

Figure 6: Reduction by 3.16% of total exp. passenger time from Orig. to Opt.

Goverde, R., Hansen, I., 2013. Performance indicators for railway timetables. Proceedings of IEEE International Conference on Intelligent Rail Transportation: ICIRT2013, August 30-September 1, 2013, Beijing, China., 301–306.

Sels, P., Cattrysse, D., Vansteenwegen, P., Jul. 2015a. Practical Macroscopic Evaluation and Comparison of Railway Timetables. Proceedings of the 18th Euro Working Group on transportation (EWGT2015), 14-16 July 2015, Delft, The Netherlands. URL http://4c4u.com/ED2015.pdf.

Sels, P., Dewilde, T., Cattrysse, D., Vansteenwegen, P., 2015b. Reducing the Passenger Travel Time in Practice by the Automated Construction of a Robust Railway Timetable. submitted to Transportation Research Part B URL http://4c4u.com/TRB2015.pdf.

Sels, P., Dewilde, T., Cattrysse, D., Vansteenwegen, P., Jul. 2015c. Towards a Better Train Timetable for Denmark, Reducing Total Expected Passenger Time. Proceedings of the 13th Conference on Advanced Systems in Public Transport (CASPT2015), 19-23 July 2015, Rotterdam, The Netherlands. URL http://4c4u.com/CR2015.pdf.