Automated, Passenger Time Optimal, Robust Timetabling, using Integer Programming

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Task

Belgian Infrastructure Management Company: Infrabel:

"Optimize Passenger Train Service, Minimizing Passenger Travel Time"

Goals:

Increased: Passenger Satisfaction, Robustness, Capacity Usage, Transfer Efficiency

Fixed:

Infrastructure, Train Lines, Halting Pattern, Delay Probabilities

Variable:

Timing: Supplement Times at every Ride, Dwell, Transfer Action

Specifics:

One Busy Day, Morning Peak Hour

Task Notes

- Demand by Infrastructure Company, not main operator: NMBS
- Robustness against Delays necessitates Stochastic Approach.
- Minimization Passenger Time implies
  - knowledge of local passenger flows
  - specific, automatic trade-off between robustness and speedy service.
- Single criterium where all terms have same units: time.

Goal Function:

Stochastic Total Expected Passenger Travel Time: $GF(E) = \sum_{e \in E} f_e d_e$

Constraints:

Periodicity, Symmetry, Regularity, Minimum Action (Ride, Dwell, Transfer) Times, Minimum Headway Times, Macro Approach.

Per OD-Pair Grouping

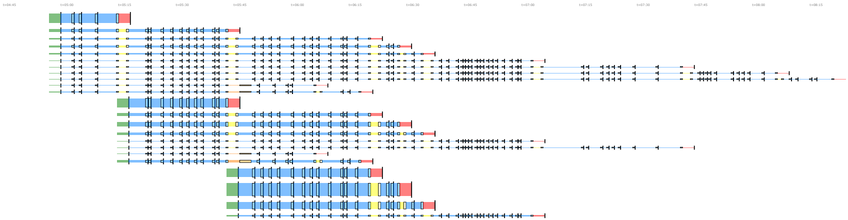
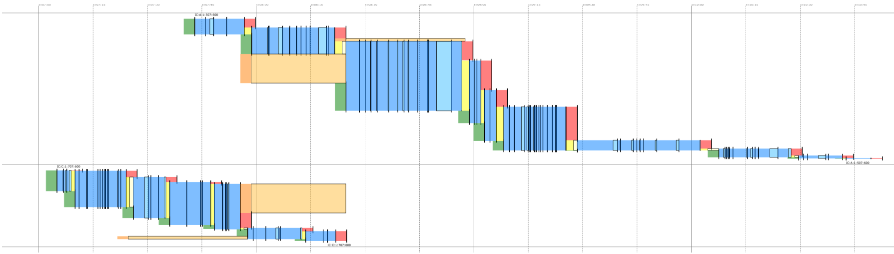
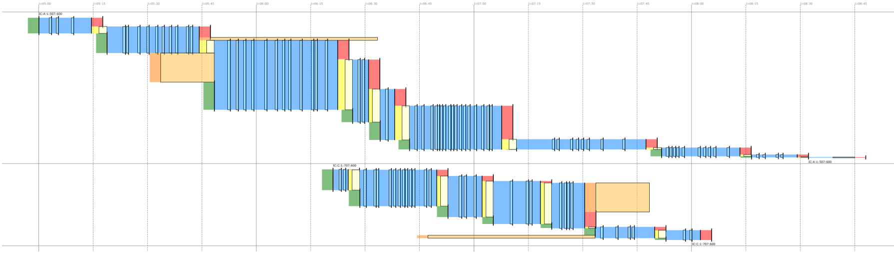


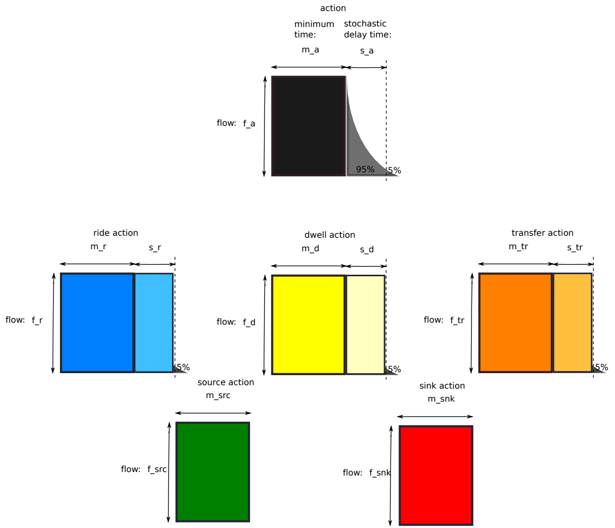
Figure: Follow all Passengers from Origin to Destination

Per Train Grouping





Action: Negative Exponential Delay Distribution



Goal Function: Stochastic Expected Passenger Travel Time

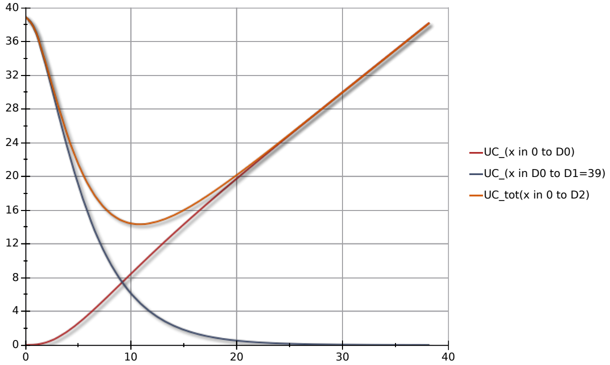


Figure: D_0 is introduced supplement, $D_1 > D_0$ is delta time of next chance action. Curve maps planned time to expected time.

Belgian Passenger Service Graph: Main Figures

Table: Many Transfers between Train Categories

Train Type	Lines	Service Edges		Potential Transfer Edges to					Total
		Ride	Dwell	**IC**	**IR**	**L**	**CR**	**P**	
IC	50	2294	2244	2897	2205	1338	989	38	7467
IR	41	1390	1349	2159	1431	1181	682	36	5489
L	92	1723	1631	1319	1184	1542	238	47	4330
CR	20	528	508	989	701	237	850	54	2831
P	2	53	51	35	34	45	50	0	164
Total	205	5988	5783	7399	5555	4343	2809	175	20281

FAPESP: Two Phased

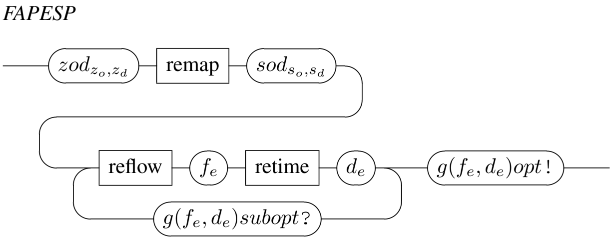


Figure: Two Phased implies Iterations

FAPESP: One Phased

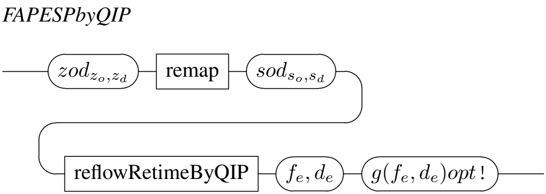


Figure: One Phased implies Optimal

CODFAPESP: Two Nested Loops

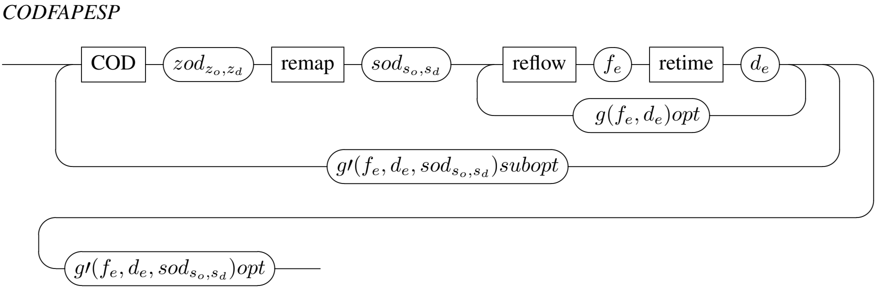


Figure: CODFAPESP: Dependent around Independent Iterations

Origin-Destination (OD) Matrix

- Ticket OD-Matrix Currently Symmetric
- Ticket OD-Matrix Currently Formulated in Zones i.o. Stations
- Currently no Passenger Countings for Destination Station

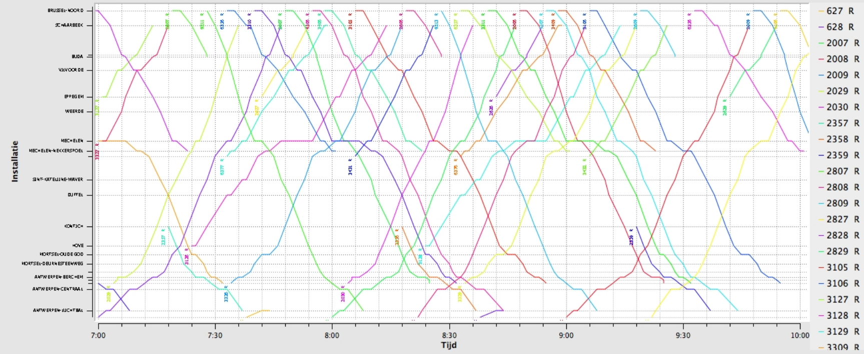
Routing Algorithms

- Dijkstra: hours
- Modified Dijkstra (includes Priority Queue): 67 min (1 core)
- Johnson: to do

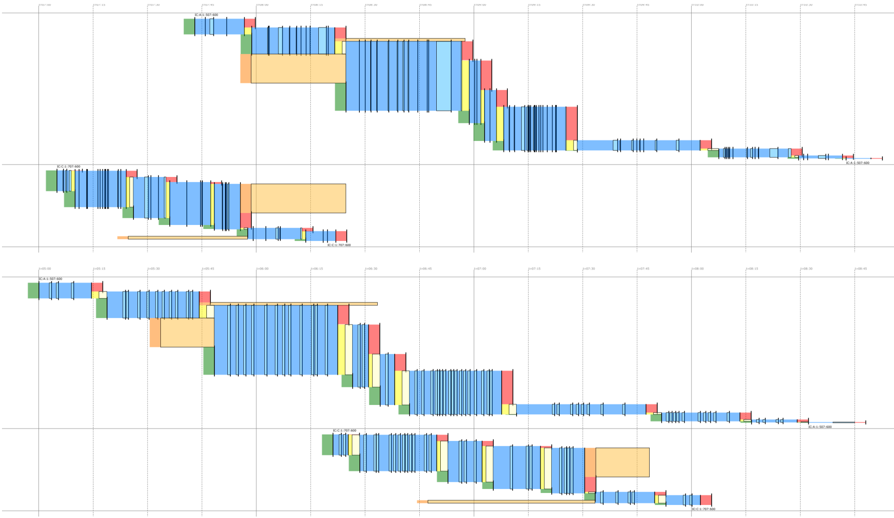
Mixed Integer Linear Programming

- cost
  - probability of train miss is used $\rightarrow$ stochastic
  - * missed train cost $=$ 1 hour
  - considers all time costs of all actions (ride, dwell, transfer, (enter, exit), knock-on delay)
  - weighted with passenger numbers f_e
  - modulated with typical (historical) delays
- constraints
  - $\leq$ 25% supplements allowed per train line
  - time continuity constraints
  - headway constraints (3 (e.g.) minutes separation between train pairs on same resource)
  - some cycle constraints

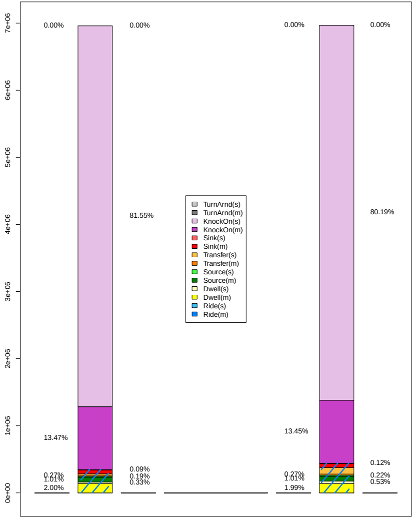
Traditional Space Time Graph

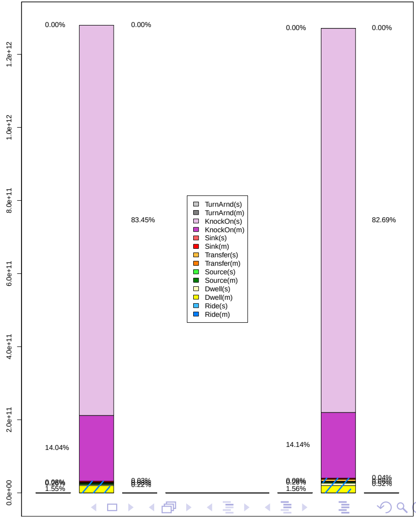


Per Train Grouping Graph

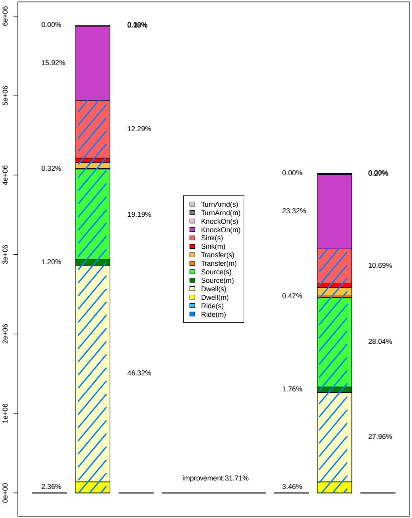


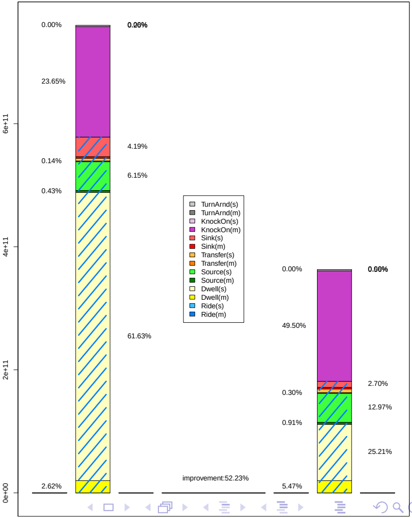
Planned Time Graph



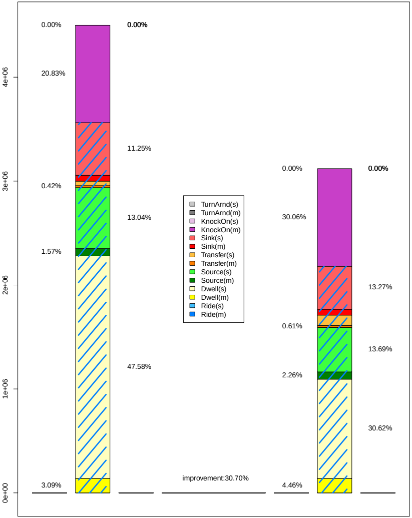


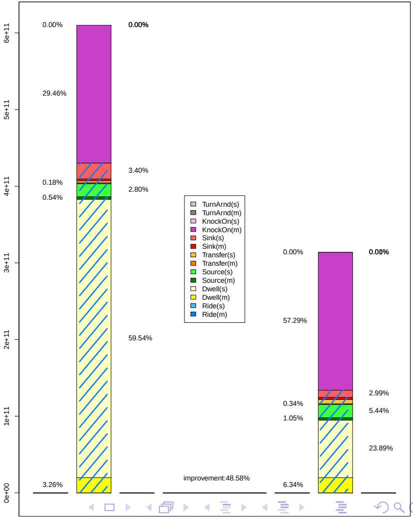
Executed Optimized Time Graph





Executed Simulated Time Graph





Conclusions & Future Work

- Conclusions
  - extended PESP (retime) to FAPESP (reflow + retime)
  - implemented remapping
  - implemented reflowing:
    - generated all current local passenger flows
    - recommended data collection procedures
  - implemented retiming: optimal schedule is very robust
- Further Work
  - reflow:
    - further verification with new data
    - faster routing algorithms (Johnson)
    - more refined routing algorithms, balancing multiple path choices
  - retime: fine tune expected passenger time in retime phase
  - iterate
  - possibly combine reflow and retime in one phase

Questions

Questions?
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