Timetabling for Passengers

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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.

Four Major Railway Planning Problems

- Line Planning (operator)
- Timetabling & Platforming (infrastructure company)
  - **national timetable planning**
  - solving generated train platforming and routing problem (TPP) for each station
- Material Planning (operator)
- Personnel Planning (operator)

Cyclic Timetabling: Previous Research Milestones

- Periodic Event Scheduling Problem (PESP): Serafini & Ukovich: 1989
- Constraint Programming Model (CADANS): Schrijver & Steenbeek: 1993
  - PESP constraints $\rightarrow$ sometimes solves, sometimes doesn't
  - goal function: none
- Cyclic Periodicity Formulation (CPF): Nachtigall: 1994
  - Based on process times & (orthogonal) cycle basis
- Application of PESP & CPF on part of Dutch passenger train system: Peeters: 2003
  - CPF finds better solutions
  - CPF solves quicker since edge based
- First optimised timetable in practice: Liebchen: 2008
  - Berlin Underground: 37 trains
  - goal function: minimise for combo of operational cost, dwell-times & *some* transfer-times
  - saved one metro

Goal Function Pitfalls?

- too simple
  - none
    - e.g.: due to no clear/'conflicting' specification of stakeholder(s)
  - incomplete: covers only some aspects
    - e.g.: focus on minimizing dwell times only
    - e.g.: focus on only *some* transfers
- too complex: multi-stakeholder
  - e.g: heterogeneous units: somehow 'adding' operational cost and some robustness measure → unbalanced
  - e.g: pareto optimization → not a unique 'best' solution
- too artificial: indicated by magic constants
  - in goal function: e.g.: in adding apples and pears
  - in constraints: e.g.: add buffer time up to 5% of train duration (to compensate for incomplete goal function)

Goal Function = Expected Passenger Time. Why?

- as simple as possible
  - passengers are stakeholder nr 1
  - expected travel time is their concern nr 1
  - including expected delays automatically trades off between: efficient yet robust service
- complete enough: covers all:
  - train actions
  - passenger actions (e.g.: all *potential* transfers)
- no artificial constraints:
  - weighted with passenger flows, naturally
- evaluate secondary stakeholders
  - (expected) idle time of material → operational cost

FAPESP: Two Phased

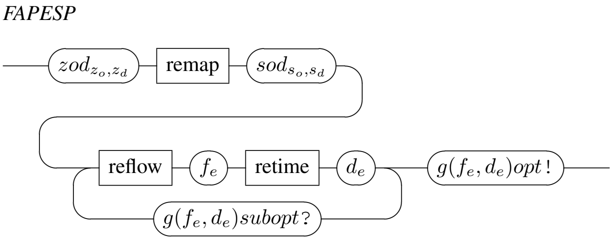
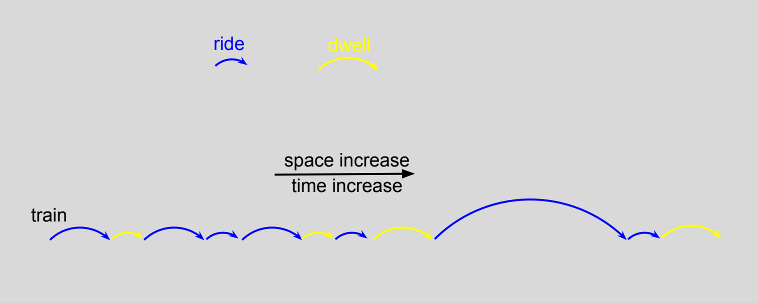


Figure: Two Phased implies Iterations

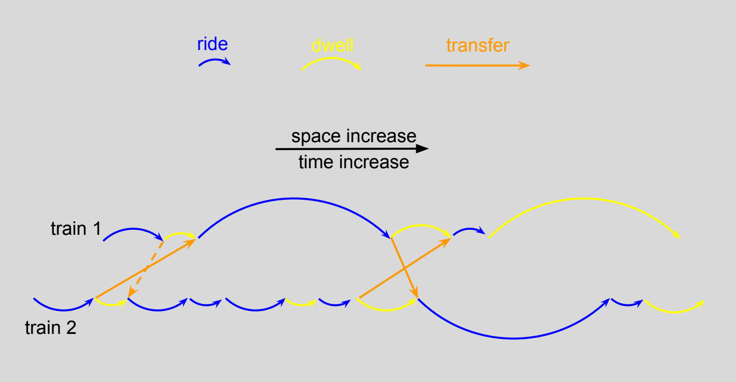
Origin-Destination (OD) Matrix

- Wanted
  - station to station OD-matrix
- Only Available
  - ticket OD-Matrix currently formulated in zones i.o. stations
  - currently only station/zone passenger ratios for departing passengers
  - currently no station/zone passenger ratios for arriving passengers
  - ticket OD-Matrix currently symmetric
    - full day periodicity → morning-evening symmetry
    - morning only: towards Brussels-inwards-outwards symmetry
- Use as follows
  - take ticket sales from zone to zone
  - diffuse over origin stations according to Entering Passengers
  - diffuse over destination stations according to *Entering* Passengers
  - cannot fix symmetry (asymmetric information lost)

Add to Graph: Ride, Dwell



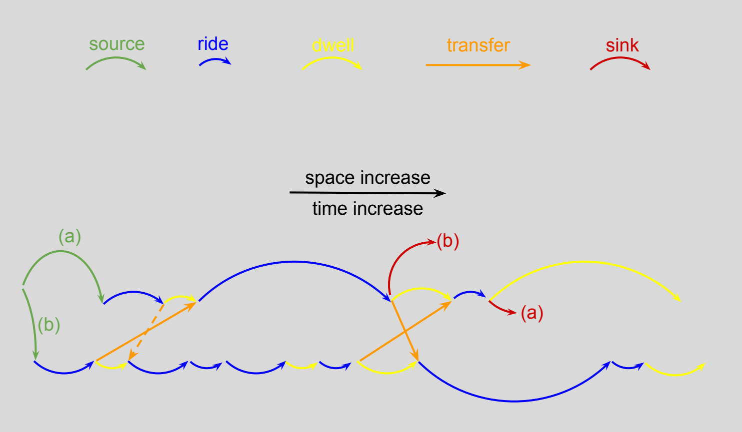
Add to Graph: Transfers



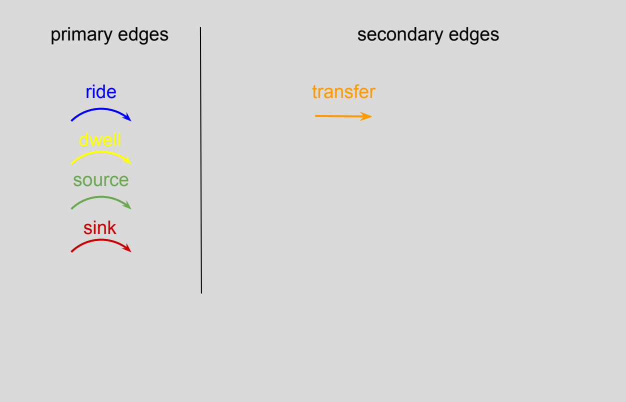
Potential Transfers

- 'Guaranteed Transfers'
  - listed by humans
  - criterium = human judgement of 'important'
  - about a hundred?
- Potential Transfers
  - automatically generated
  - criterium = whenever two trains stop in same station, irrespective of flow and timing (both are still unknown)
  - > 20000
  - all considered in reflowing & retiming, or in retiming: only the ones with e.g.: ≥ 50 people transferring

Graph for Reflowing: Add Source & Sink



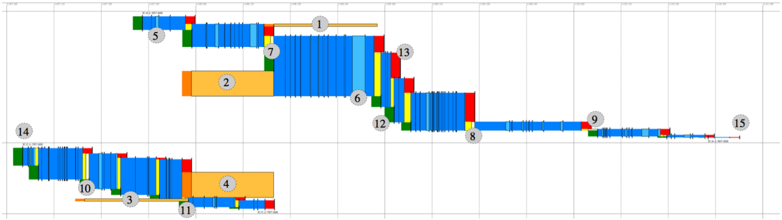
Graph for Reflowing: All Edge Types



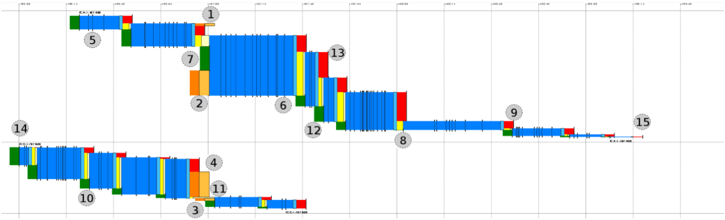
Routing Algorithms & Results

- Dijkstra: hours
- Modified Dijkstra (includes Priority Queue, single thread): 1 hour
- Modified Dijkstra (includes Priority Queue + OpenMP (8 cores) + OpenMPI (2 machines)): 4 min
- Johnson: to consider

Reflowing = Deciding on Rectangle Heights

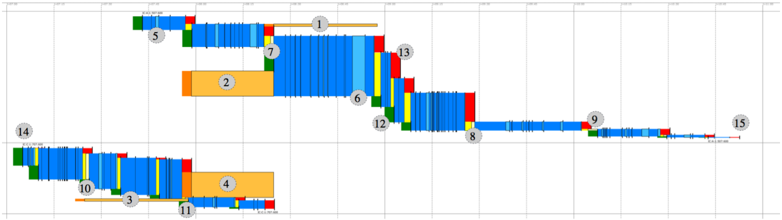


(a) Original Schedule

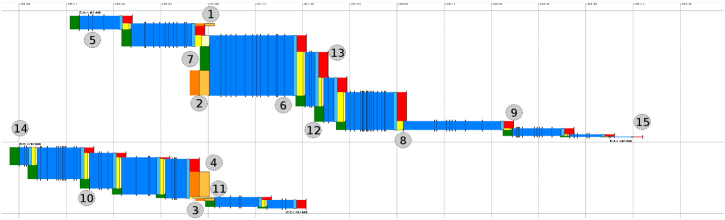


(b) Optimized Version

Retiming = Deciding on Rectangle Widths

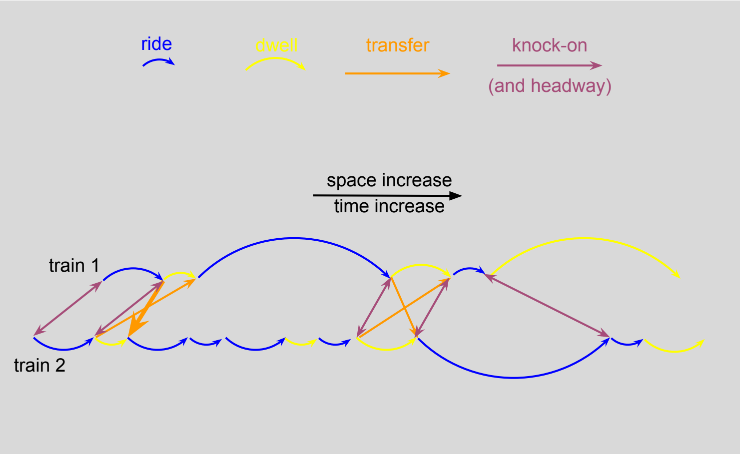


(c) Original Schedule

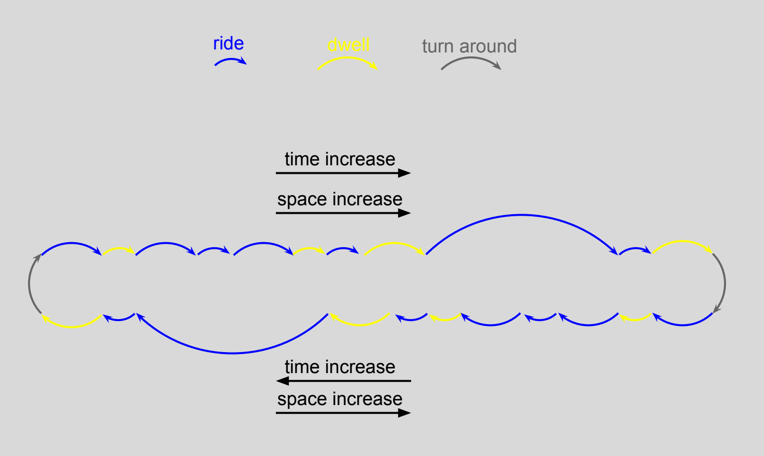


(d) Optimized Version

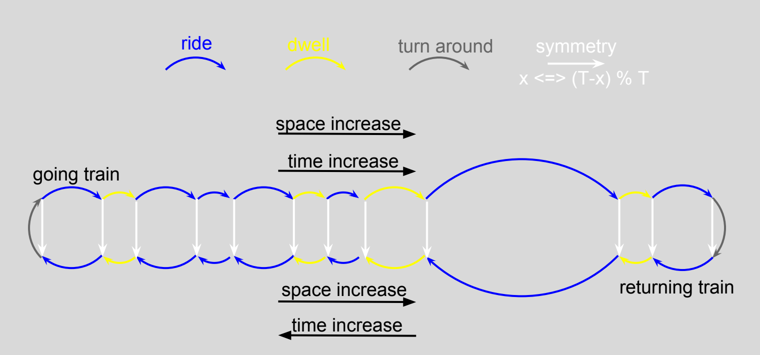
Add to Graph: Knock-Ons



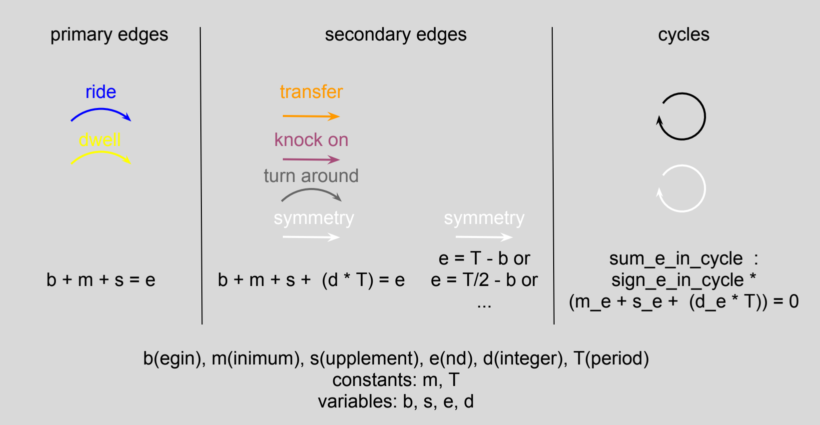
Add to Graph: Turn-Around



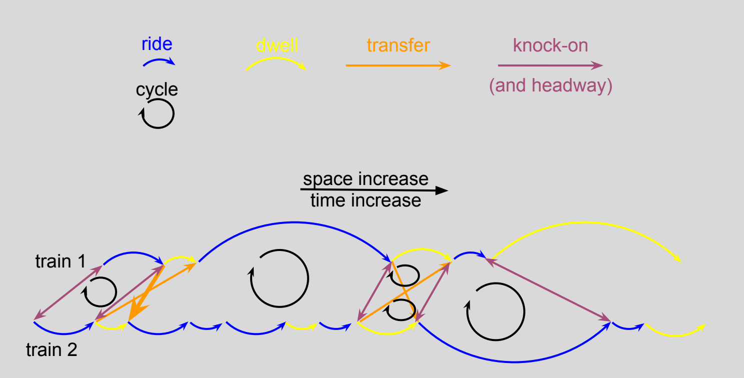
Add to Graph: Symmetry (Optional)



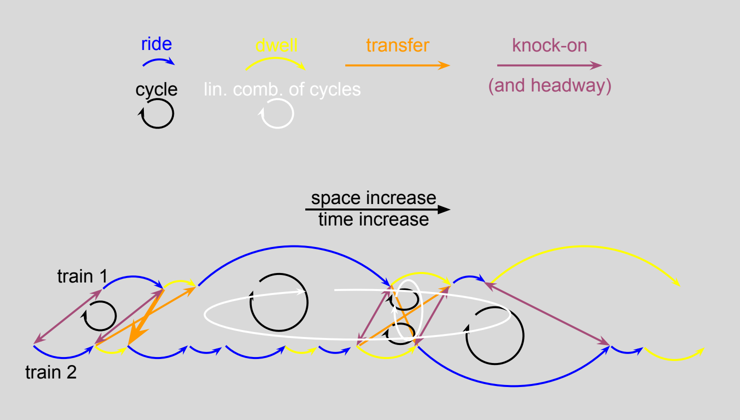
Graph for Retiming: All Edge Types



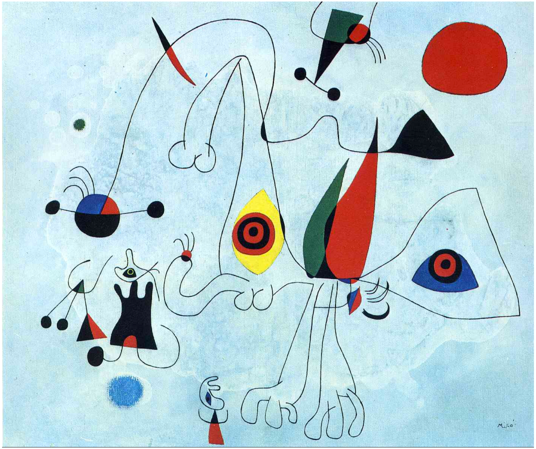
Graph for Retiming: Basic Cycles



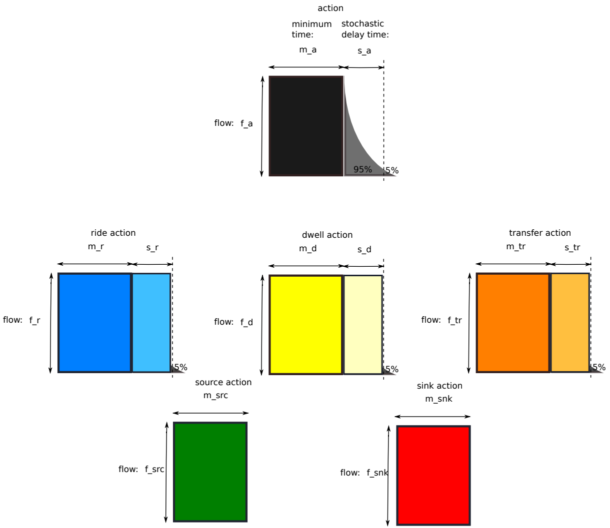
Graph for Retiming: Linear Combination of Cycles



Looks a lot like Miro, right?



Action: Negative Exponential Delay Distribution



In-Time and Over-Time

	In-Time	Over-Time
probability	$\int_0^{D_0} p_a(x)dx$	$\int_{D_0}^{D_1} p_a(x)dx$
inc./dec. in D_0	inc.	dec.
expected time	$\int_0^{D_0} p_a(x)D_0dx$	$\int_{D_0}^{D_1} p_a(x)D_1dx$
inc./dec. in D_0	inc.	dec.
departing = ride' + dwell' + source		✓
through = ride + dwell	✓	
changing = ride + transfer	✓	✓
arriving = ride + sink	✓	

Stochastic Goal Function: Expected Passenger *Transfer* Time

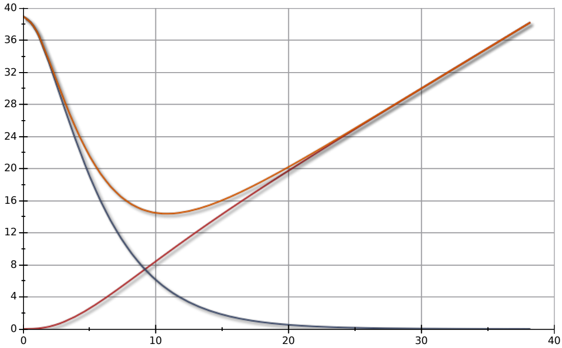
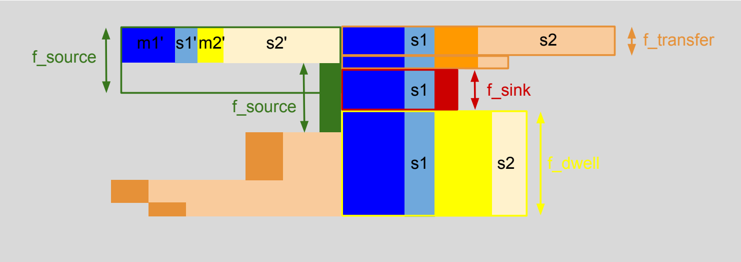


Figure: D_0 is introduced supplement, $D_1 > D_0$ is delta time of next chance action. Curve maps planned time to expected time.

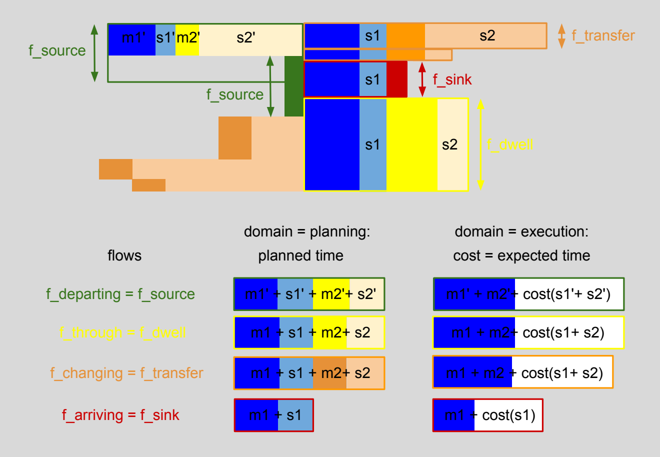
Grouping per Subsequent Action-Pair

- departing = ride' + dwell' + source
- through = ride + dwell
- changing = ride + transfer
- arriving = ride + sink

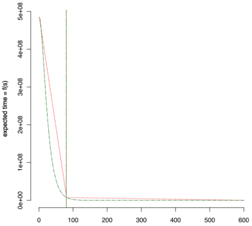


Looks a lot like Mondriaan, right?

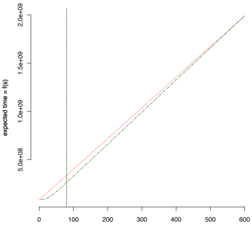
Grouping per Subsequent Action-Pair towards Cost



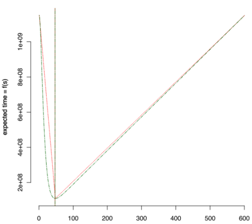
Cost curves of 4 Passenger Categories



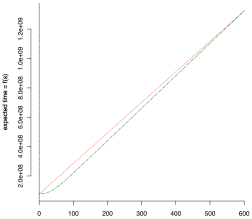
(a) departing=ride'+dwell' +source



(b) through=ride+dwell

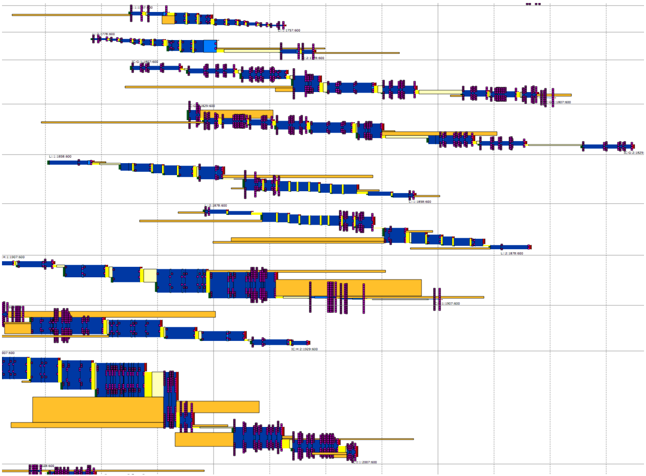


(c) changing=ride+transfer



(d) arriving=ride+sink

Results: Flow * Duration Rectangle Representation

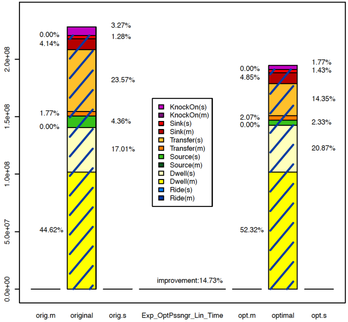


Results: 7 to 8am: 5% Proportional Delay: Numbers

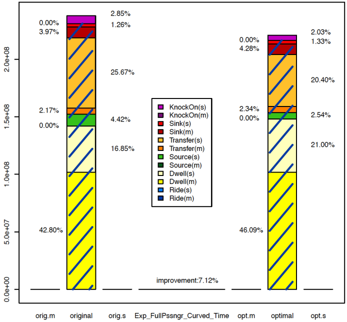
Table: Scalability of our Integer Linear Programming Model with necessary Constraints and the Derived Objective Function

train types	trains (#)	model rows (#)	model columns (#)	solver time (s)	passenger time reduction (%)	missed transfer probability (%)
IC	43	18747	13361	50	10.73	2.95
IC IR	82	48267	33035	449	12.38	3.11
IC IR L	186	102652	68504	2426	10.03	2.31
IC IR L P	203	225132	158860	3706	7.12	2.43

Results: 7 to 8am: 5% Proportional Delay: Bar Graphs

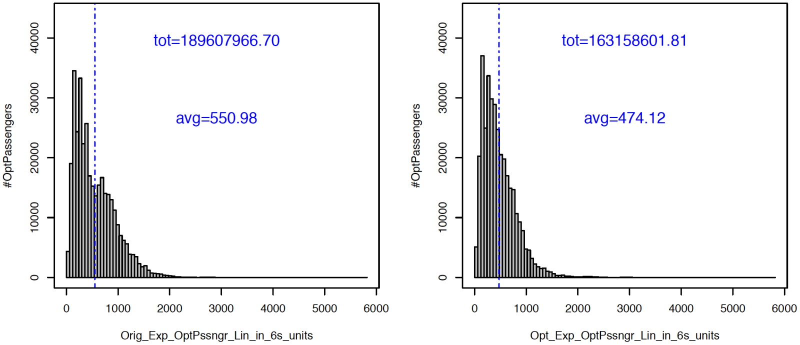


(e) Linear, Passenger Flows ≥ 50

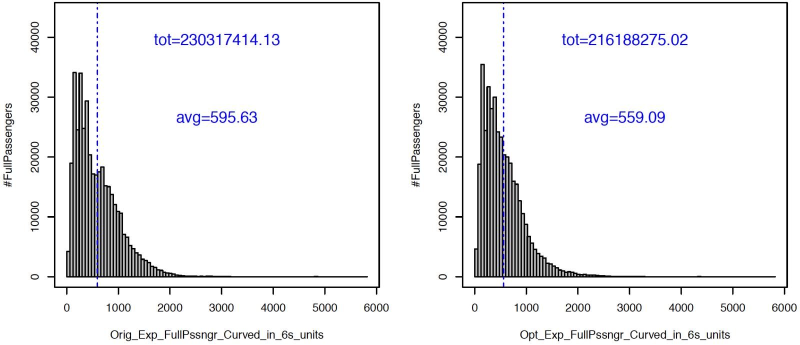


(f) Non-Linear, Passenger Flows ≥ 0

Results: 7 to 8am: 5% Proportional Delay: Linear, Passenger Flows $\geq$ 50: Histograms



Results: 7 to 8am: 5% Proportional Delay: Non-Linear, Passenger Flows ≥ 0: Histograms



Conclusions

- defined and implemented remapping, reflowing, retiming & iterations
- reflowing
  - extended PESP (retime) to FAPESP (reflow + retime)
  - auto-generated all current local passenger flows
  - recommended some better data collection procedures
- retiming
  - defined all necessary constraints & found & added some more (cycles) to solve model fast
  - defined stochastic passenger time goal function
  - auto-generated first national timetable with full goal function = expected passenger time
    - respects (ride, dwell, transfer, headway)-minimum times
    - is robust (optimally for passengers)
  - reduction of passenger time with ±7%, mind current assumptions:
    - primary delay = 5% of minimum-time, everywhere
    - zone-to-station-(overly?)-diffused passenger streams

Future Work

- further verification with new data
  - measured (place, train)-dependent delays i.o. averaged one
  - asymmetric station-OD?
- add spreading measure for alternative OD-routes and evaluate effect
- allow boundary timing conditions at frontiers/sub-zones
- output TPP problems to platformer
  - guarantee/increase chance on feasibility
    - add station capacity constraints to retiming
    - add constraints avoiding simultaneous arrival/departure of train pair that has to cross in station
  - adapt platformer so that it optimises for passengers i.o. maximising # trains platformed

Questions

- Your Questions?
  - www.LogicallyYours.com/Research/
  - sels.peter@gmail.com
- My Questions:
  - Is it best to use primary delays from the old timetable or to just assume them to be relative to minimum times?
  - If relative, what is the best (average(?)) percentage to assume for primary delays w.r.t minimum times?