# Timetabling for Passengers

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# Task

**Belgian Infrastructure Management Company: Infrabel:**

Find Timetable that Minimises Expected Passenger Travel Time (includes: ride, dwell, transfer time and primary & secondary delays)

**Note:**

Reduce Expected Passenger Time $\Rightarrow$ Optimises Robustness

**Fixed:**

Infrastructure, Train Lines, Halting Pattern, Primary Delay Distributions

**Variable:**

Timing: Supplement Times at every Ride, Dwell, Transfer Action,
$\Rightarrow$ variable inter-Train Heading Times $\Rightarrow$ variable Train Orders

**Specifics:**

One Busy Day, Morning Peak Hour

# Context: FAPESP: Two Phased

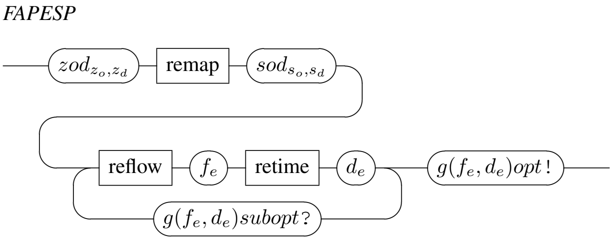
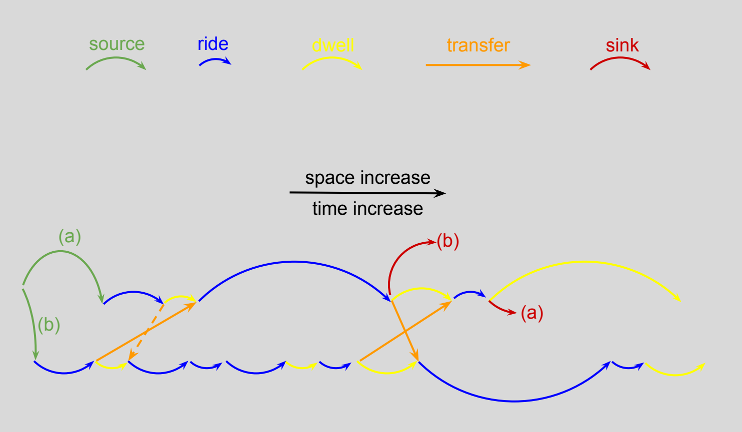
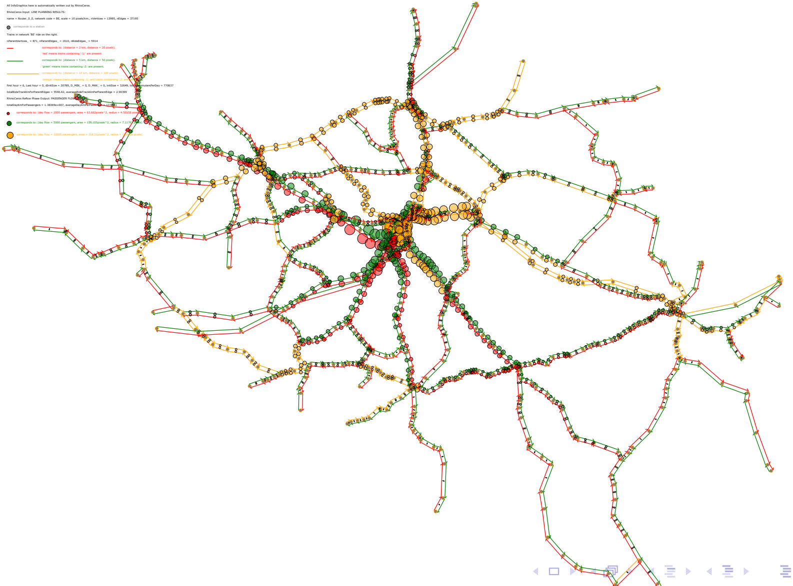



Figure: Two Phased implies Iterations

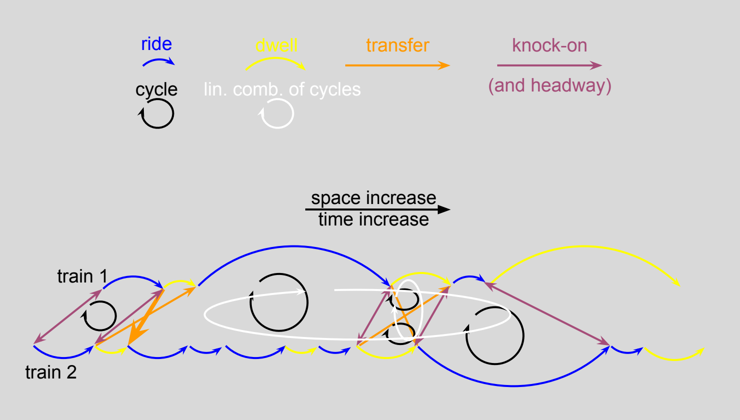
# Graph for Reflowing: add Source & Sink Edges



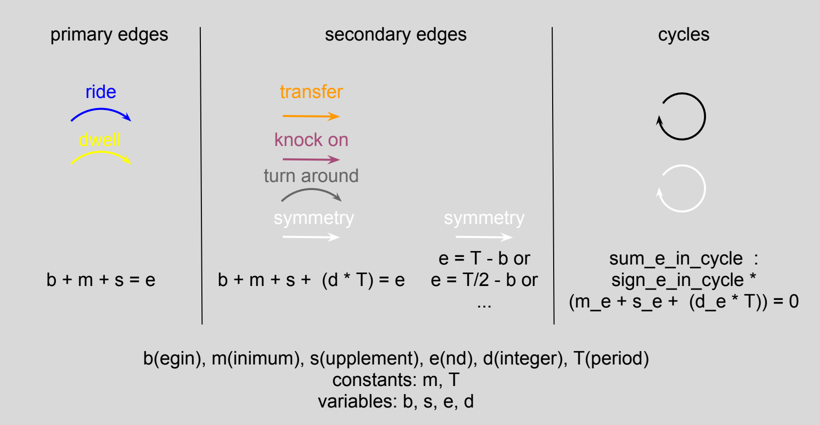
# Result of Reflowing: Disc Area = Daily Flow



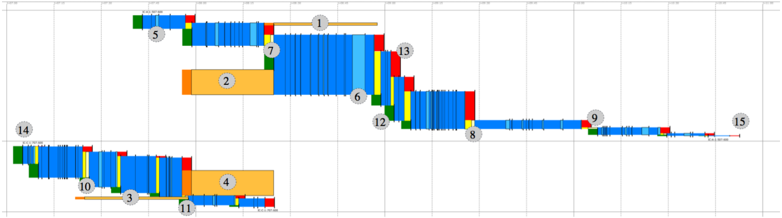
# Graph for Retiming: add Knock-On Edges & Cycles



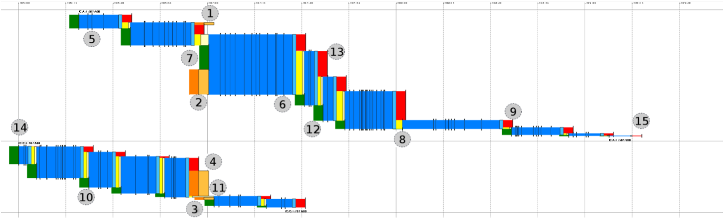
# Graph for Retiming: All Constraints



# Reflowing decides on Rectangle Heights
# Retiming (Timetabling) decides on Rectangle Widths

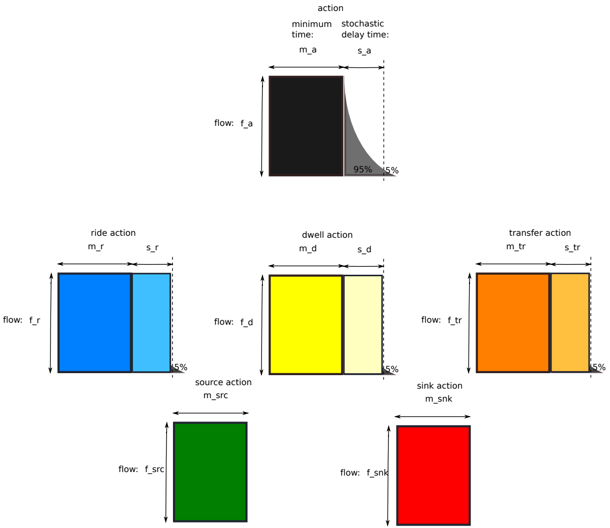



(a) Original Schedule




(b) Optimized Version

# Action: Negative Exponential Delay Distribution



# Stochastic Goal Function: Expected Passenger *Transfer* Time

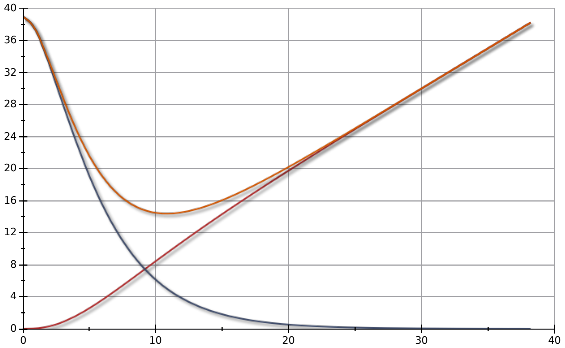
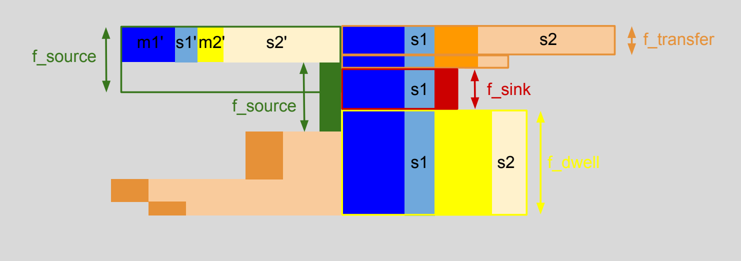


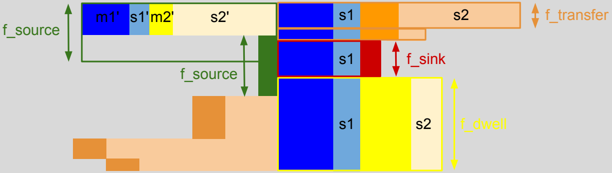

Figure: $D_0$ is introduced supplement, $D_1 > D_0$ is delta time of next chance action. Curve maps planned time to expected time.

# Grouping per Subsequent Action-Pair

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



# Grouping per Subsequent Action-Pair towards Cost



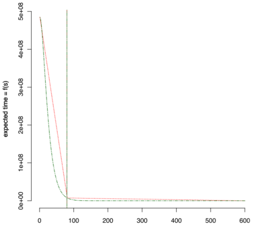

| flows | domain = planning: planned time | domain = execution: cost = expected time |
|---|---|---|
| f_departing = f_source | m1' + s1' + m2'+ s2' | m1' + m2'+ cost(s1'+ s2') |
| f_through = f_dwell | m1 + s1 + m2+ s2 | m1 + m2+ cost(s1+ s2) |
| f_changing = f_transfer | m1 + s1 + m2+ s2 | m1 + m2 + cost(s1+ s2) |
| f_arriving = f_sink | m1 + s1 | m1 + cost(s1) |

# In-Time and Over-Time

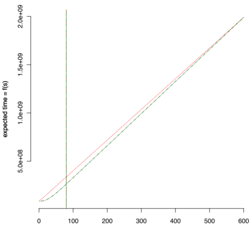
Table: In-Time and Over-Time Integrals when adding supplement $D_0$

| | 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 | ✓ | |

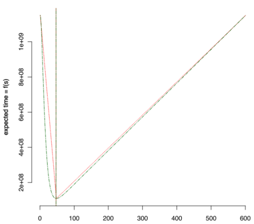
# Cost curves of 4 Passenger Categories



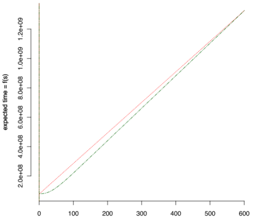

(a) departing=ride'+dwell' +source




(b) through=ride+dwell

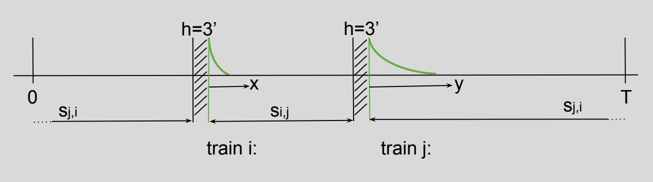



(c) changing=ride+transfer

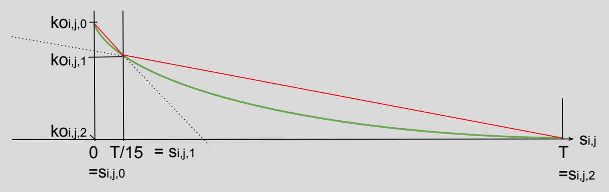



(d) arriving=ride+sink

# All Knock-On Costs for $N(N-1)$ Trains on Same Resource: Formula




$$\forall R : pKO_R = \sum_{\substack{i,j \in I_R \\ i \neq j}} f_j \cdot \frac{a_j e^{-a_i s_{i,j}}}{a_i(a_i + a_j)}. \quad (1)$$



# Knock-on Time Two Train Example: Supplement Calculation

Two trains with:

- train i: expected delay of $1/a_i = 3$ minutes and $f_i = 100$ passengers
- train j: expected delay of $1/a_j = 1$ minute and $f_j = 300$ passengers
- $T = 60$ minutes, period
- $h = 3$ minutes, headway time

are spread as

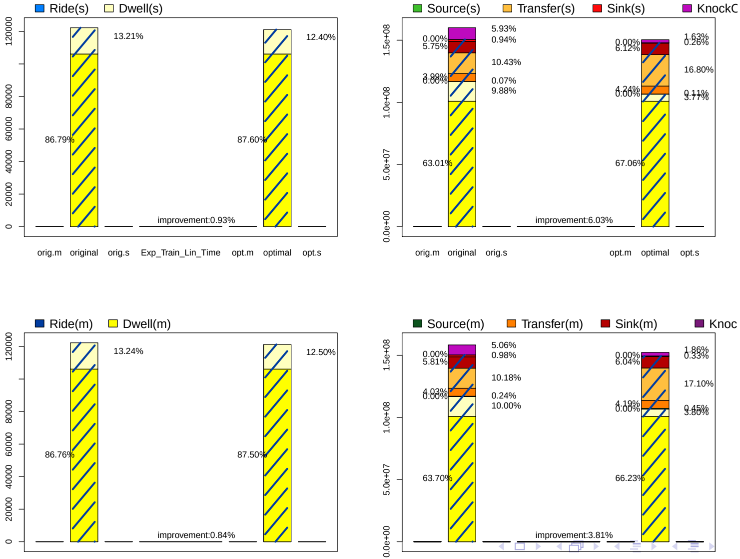
- $s_{i,j} = \frac{a_j(T-2h)+ln\left(\frac{f_j a_j}{f_i a_i}\right)}{a_i+a_j} = \frac{1(60-2\cdot3)+ln(300\cdot1/(100\cdot1/3))}{1/3+1} = 42.15$ min.
- $s_{j,i} = \frac{a_i(T-2h)+ln\left(\frac{f_i a_i}{f_j a_j}\right)}{a_i+a_j} = \frac{1/3(60-2\cdot3)+ln(100\cdot1/3/(300\cdot1))}{1/3+1} = 11.85$ min.

and indeed $42.15 + 3 + 11.85 + 3 = 60$ minutes.

# Graph and Problem Size

Graph size: 203 hourly trains, 5355 ride, 5152 dwell, 17553 major transfer, 31696 knock-on and 166 turn-around edges. Model size: 42609 supplement decision variables, 49415 integer decision variables, 41128 goal function terms for major flows and 58441 evaluation function terms for all flows.

# Expected (Non-)Linear Time, as used in Evaluation



# Conclusions

- defined and implemented remapping, reflowing, retiming & iterations
- reflowing: obtains local passenger numbers $\forall$ trains, $\forall$ locations
- retiming
  - defined all necessary constraints
    $\Rightarrow$ respects (ride, dwell, transfer, headway)-minimum times
  - added our particular cycle set
    $\Rightarrow$ solves model fast
  - defined stochastic passenger time goal function
    - derived Knock-On delay model for MILP timetable optmisation
      $\Rightarrow$ ideal order and headway of trains
      $\Rightarrow$ ideal passenger robustness
  - auto-generated first national timetable with full goal function = expected passenger time
  - reduction of passenger time with $\pm 3.81\%$, mind current assumptions:
    - primary delay = 2% 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?
- improve transfers by helping solver: cheat, ignore, exaggerate
- add temporal 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

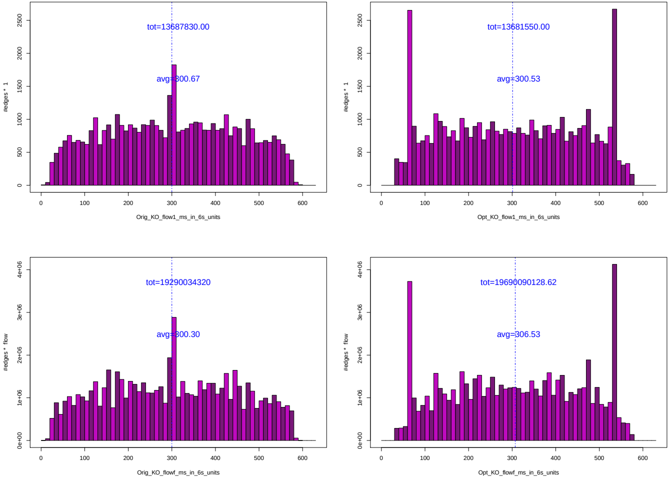



Figure: Headway times (minimum of 3 minutes + supplement) histograms, showing for each headway duration, how many edges occur and how many passengers experience the knock-on time associated to this headway duration.

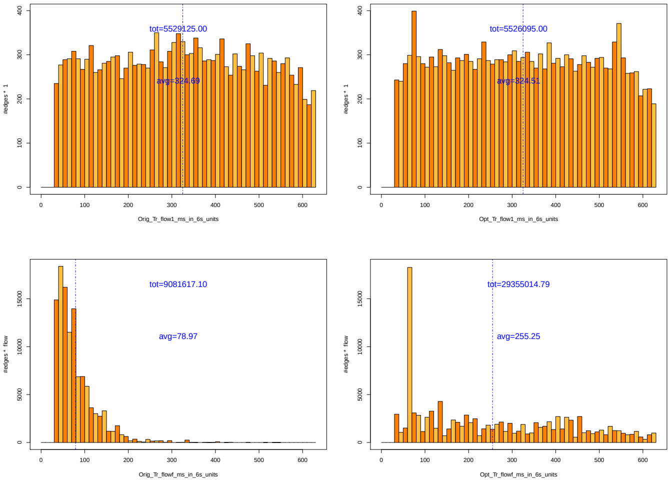



Figure: Transfer times (minimum of 3 minutes + supplement) histograms, showing for each transfer duration, how many edges occur and how many passengers experience the transfer time associated to this transfer duration.

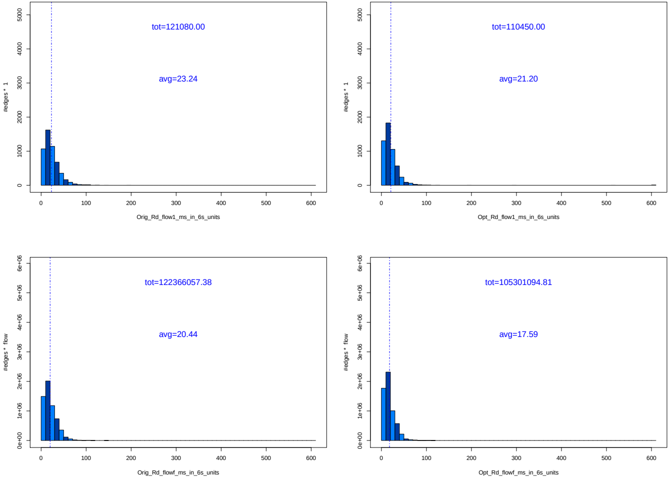



Figure: Ride times (minimum ride time + supplement) histograms, showing for each ride duration, how many edges occur and how many passengers experience the ride time associated to this ride duration.

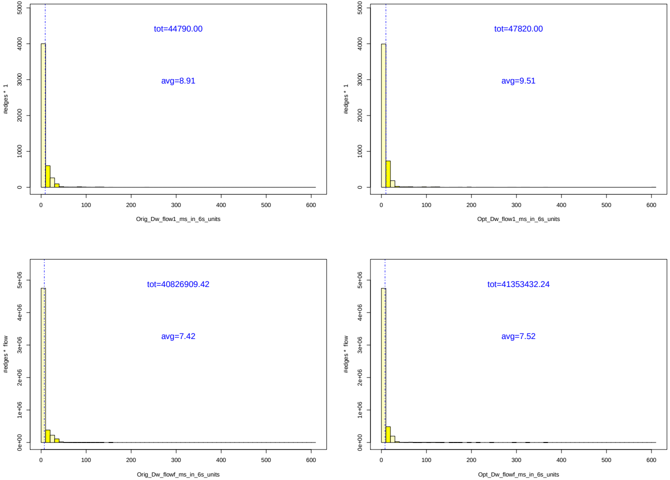



Figure: Dwell times (minimum dwell time + supplement) histograms, showing for each dwell duration, how many edges occur and how many passengers experience the dwell time associated to this dwell duration.

# Questions / Next Steps

- Your questions?
  - www.LogicallyYours.com/research/
  - sels.peter@gmail.com
- My questions:
  - things missing for us in input:
    - recent OD-matrix,
    - list of important transfers,
    - list of trains to spread (eg: IC-A, E F, ...)
    - other hard/soft constraints?, ...
  - How to solve transfer-component-time-still-increasing problem?
  - (Why do I get knock-on reduction and transfer increase?)
  - Can column/row generation help speed up things?
  - Other modelling suggestions?
  - Other suggestions?
- Other stuff?...