

# Automatically and Quickly Planning Platform and Route of Trains in Railway Stations

Peter Sels<sup>1,2,3</sup>, Thijs Dewilde<sup>1</sup>, Dirk Cattrysse<sup>1</sup>, Pieter  
Vansteenwegen<sup>1</sup>

<sup>1</sup>KU Leuven, Leuven Mobility Research Centre, CIB,  
Celestijnenlaan 300, 3001 Leuven, Belgium

<sup>2</sup>Logically Yours BVBA,  
Plankenbergstraat 112 bus L7, 2100 Antwerp, Belgium  
e-mail: sels.peter@gmail.com, corresponding author

<sup>3</sup>Infrabel, Traffic Management & Services,  
Fonsnylaan 13, 1060 Brussels, Belgium

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# Task

Belgian Infrastructure Management Company: Infrabel:

"Train Platforming Problem (TPP): platform and route as many trains as possible"

Objectives:

no conflicts in planning in stations, check robustness

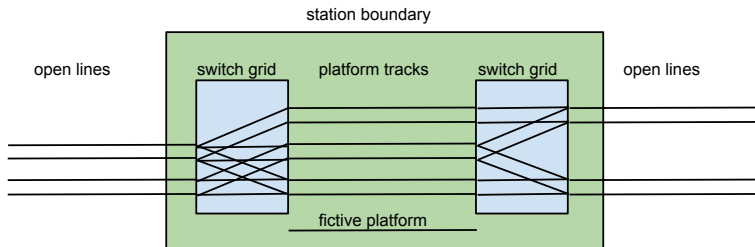
Fixed:

infrastructure, train lines, halting pattern, arrival & departure times

Specifics:

- one busy day, morning peak hours, periodic/non-periodic
- (check current platforming +) create new ('optimised') one

# Platforming = Mapping Trains on Infrastructure



# In objective function

## In objective function:

- Minimize penalties
  - of assigning to fictive a platform and
  - of moving assignment from preferred (real) to non-preferred (real) platforms,

for both initial  $O_{INI}$  and for supplementary  $O_{SUP}$  train sets

$$g(op_{o,p}) = \sum_{o \in O_{INI}} CF_{INI} \cdot f_o + CR_{INI} \cdot cr_o + \sum_{o \in O_{SUP}} CF_{SUP} \cdot f_o + CR_{SUP} \cdot cr_o. \quad (1)$$

where

$$\forall o \in O : f_o \equiv (o2p_{o,p} = pFICT)$$

$$\forall o \in O : cr_o \equiv (o2p_{o,p} \neq pORIG_o)$$

- uses fictive platform at a higher cost than real platform
- conservative optimisation  $(CF_{INI}, CF_{SUP}, CR_{INI}, CR_{SUP}) = (8, 4, 2, 1)$
- progressive optimisation  $(CF_{INI}, CF_{SUP}, CR_{INI}, CR_{SUP}) = (1, 1, 0, 0)$

# Not in objective function

## Not in objective function:

- weighting of trains by importance (e.g.:#passengers)
- important (e.g.:#passengers) transfer concerns, placing two trains close together
- robustness against delays

# Definitions: Movement & Occupation

## Movement Definition:

- Train 'IN/OUT movement' specifies:
  - IN/OUT line
  - platform arrival time
  - platform departure time
- IN route: connects IN line to platform,
- OUT route: connects platform to OUT line.

## Occupation Definition:

- platform 'occupation' specifies (bundles):
  - (list of) IN movement(s)
  - (list of) OUT movement(s)
  - e.g.: 1 IN movement, 2 OUT movements = train split
  - e.g.: 2 IN movements, 1 OUT movement = train merge

# In / Not In Variability

## In Variability:

- per occupation
  - one platform choice
- per movement
  - one route choice
  - (indirectly) one platform choice

## Not in Variability:

- per line-platform combination: only 1 *default* routing allowed for now
- only fixed platform arrival/departure times



# Constraints Requiring total Assignment

## Per-Movement, Per-Occupation and Compatibility Constraints:

- For each occupation, exactly one platform has to be chosen:

$$\forall o \in O : \sum_{p \in P} op_{o,p} = 1 \quad (2)$$

- For each movement, exactly one route has to be chosen:

$$\forall o \in O : \forall m \in M_o : \sum_{r \in R} mr_{o,m,r} = 1 \quad (3)$$

- all movements in 1 occupation need to come together on 1 platform track

$$\forall o \in O : \forall m \in M_o : mr_{o,m,r} \implies op_{m2o_m, r2p_r} \quad (4)$$

- via  $m2o_m$  function, movement-occupation *membership* is respected
- via  $r2p_r$  function, route-platform *connectivity* is respected

# Constraints Avoiding Conflicts

## Inter-Occupation Constraints:

- no 2 extended occupations use *equal* platform tracks at any time

$$\forall \begin{array}{l} o_0 \prec o_1 \\ [otLoLbC_{o_0}, otHiUbC_{o_0}] \cap \\ [otLoLbC_{o_1}, otHiUbC_{o_1}] \neq \phi: \end{array} \quad o_0, o_1 \in O : \forall_{p_0=p_1} (p_0, p_1) \in (P_{o_0}, P_{o_1}) : \\ op_{o_0, p_0} \wedge op_{o_1, p_1} \implies osep_{o_0, o_1} \quad (5)$$

## Inter-Movement Constraints:

- no 2 extended movements use *dependent* (equal or crossing) routings at any time

$$\forall \begin{array}{l} m_0 \prec m_1 \\ [mtLoLbC_{m_0}, mtHiUbC_{m_0}] \cap \\ [mtLoLbC_{m_1}, mtHiUbC_{m_1}] \neq \phi: \end{array} \quad m_0, m_1 \in M : \forall_{dep_{r_0, r_1}} (r_0, r_1) \in (R_{m_0}, R_{m_1}) : \\ mr_{o_0, m_0, r_0} \wedge mr_{o_1, m_1, r_1} \implies msep_{m_0, m_1} \quad (6)$$

# Separation boolean definitions

Occupation Separation boolean definition:

$$\forall \begin{array}{l} \sigma_0 \prec \sigma_1 \\ [otLoLbC_{\sigma_0}, otHiUbC_{\sigma_0}] \cap \\ [otLoLbC_{\sigma_1}, otHiUbC_{\sigma_1}] \neq \emptyset \end{array} \quad \sigma_0, \sigma_1 \in O : \quad \begin{array}{l} obef_{\sigma_0, \sigma_1} \equiv (otHiV_{\sigma_0} + dt_S \leq otLoV_{\sigma_1}) \\ obef_{\sigma_1, \sigma_0} \equiv (otHiV_{\sigma_1} + dt_S \leq otLoV_{\sigma_0}) \\ osep_{\sigma_0, \sigma_1} \equiv (obef_{\sigma_0, \sigma_1} \vee obef_{\sigma_1, \sigma_0}). \end{array} \quad (7)$$

Movement separation boolean definition:

$$\forall \begin{array}{l} m_0 \prec m_1 \\ [mtLoLbC_{m_0}, mtHiUbC_{m_0}] \cap \\ [mtLoLbC_{m_1}, mtHiUbC_{m_1}] \neq \emptyset \end{array} \quad m_0, m_1 \in M : \quad \begin{array}{l} mbef_{m_0, m_1} \equiv (mtHiV_{\sigma_0} + dt_S \leq mtLoV_{m_1}) \\ mbef_{m_1, m_0} \equiv (mtHiV_{\sigma_1} + dt_S \leq mtLoV_{m_0}) \\ msep_{m_0, m_1} \equiv (mbef_{m_0, m_1} \vee mbef_{m_1, m_0}), \end{array} \quad (8)$$

# User Interface Parameters

LeopardGUI: L'ean Optimiser of Platforms And Routings including routing Dependencies

Date: 16/04/2013

From Hour: 07:10

Up To Hour: 08:50 Select the start hour for which you want to run Leopard.

Extract Macro Infrastructure From: a371

Select Station: BRUGGE[210]

Fix Station Movements: fix

if in original plan: same relation, same platform track then enforce in optimised plan: same platform track too

if = real orig. platform tracks  if = fictive orig. platform tracks

Mirror unmatched movements by turn-around time: 5,0

Avoid routing conflicts also for Mirrored movements:

Fixed train length in meter (-1 for actual length): 400

Draw Long Text for Movements:

Mark and name times in occupations:

Warn for (Real, Real)-dependent Route low reuse times

**Overlap**  **Too close**  **Quite close**  **Robust**

Define warning level Upper Times (min)

0,0 1,0 2,0 5,0

Warn for (Real,Fictive)-Route time overlaps

**Potential conflict**


Popup Platforming Plan for

Original  Optimised  Both

About

FINAL Station Connectivity that Luks Routes will be checked against and rejected against in case of no match.

```
incOrDeckm,io,L_id,L_nm,LST_jdc,LST_track_dir,LST_nm,LST_vMax,LS_jdc,LS_side,PIP2_orient,P1_id,P1_nm,P1_sym_nm,P2_id,P2_nm,P2_sym_nm,LS_SiSi
de
[inc],[out],503,[50A],1,[1],A,140,1022,1,1,210,BRUGGE,FR,609,JABBEKE,[FGB],2
[inc],[in],503,[50A],1,[1],A,140,598,2,1,1596,Y.OOSTKAMP,[YFPO],210,BRUGGE,FR,1
[inc],[out],503,[50A],2,[2],B,140,1022,1,1,210,BRUGGE,FR,609,JABBEKE,[FGB],2
[inc],[in],503,[50A],2,[2],B,140,598,2,1,1596,Y.OOSTKAMP,[YFPO],210,BRUGGE,FR,1
[inc],[in],508,[50A/51.1],[1],A,40,81,2,1,1510,BRUGGE-F,[RERF],210,BRUGGE,FR,1
```



# Solver running times

**Table:** Solver running times on a Xeon CPU E31240 Quad Core 3.3 GHz, comparing CPLEX v12.5.0.0 32 bit, XPRESS BCL v4.6.1 64 bit and Gurobi v5.6.3 64 bit

Solver	# Stations Optimally Solved in						# Stations Suboptimally Solved in
	< 1s	< 10s	< 20s	< 30s	< 50s	< 130s	$\geq 7200s$
CPLEX	526	8	0	0	1	1	0
XPRESS	528	5	1	1	0	0	1
Gurobi	533	3	0	0	0	0	0

# Original Assignment

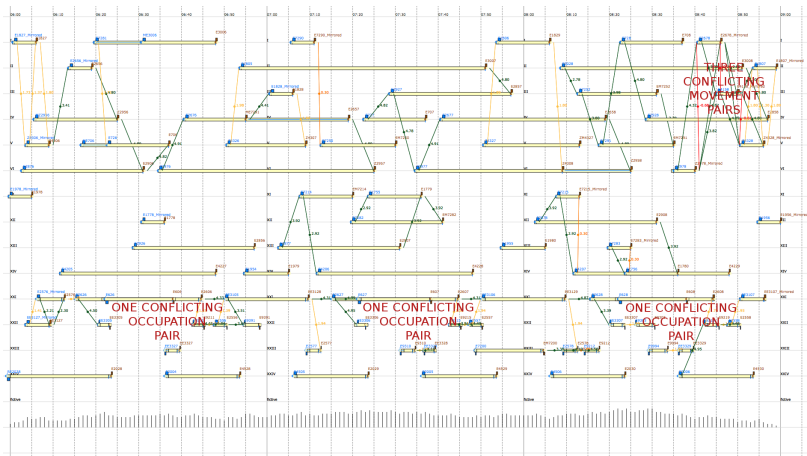
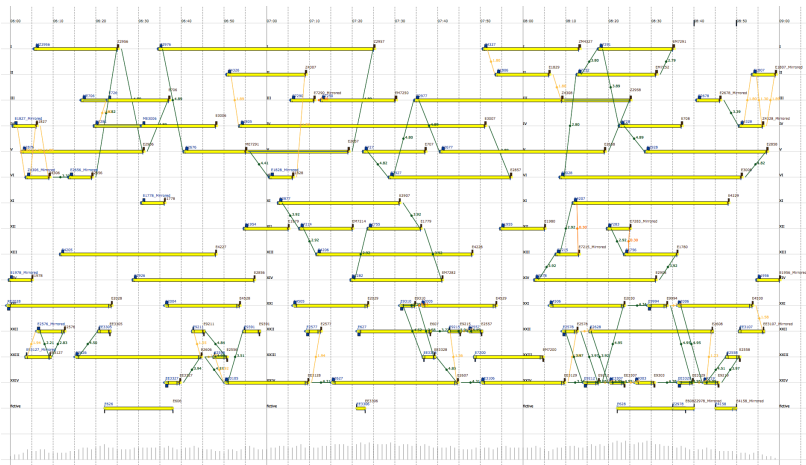


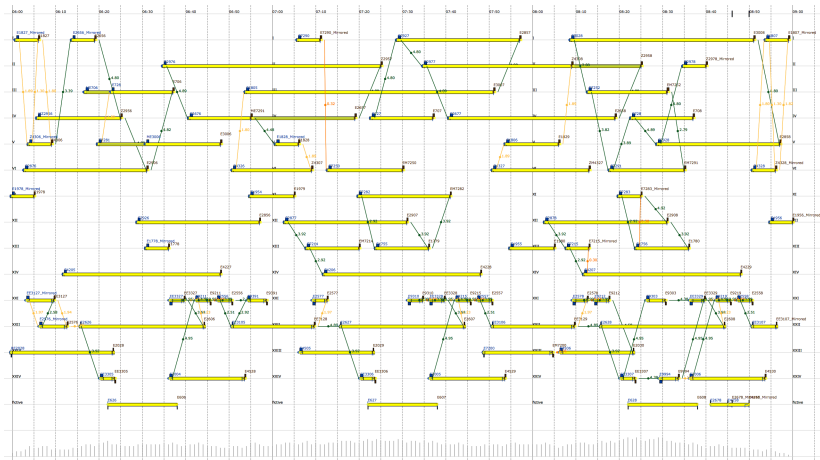
Figure: Antwerp-Central original Assignment: 3 levels, some conflicts

# Optimised Assignment, Non-Periodic



**Figure:** Antwerp-Central Opt. assignment, non-periodic: no conflicts, some unplaced trains

# Optimised Assignment, Periodic



**Figure:** Antwerp-Central Opt. assignment, periodic: no conflicts, some  
unplaced trains



# Both Assignments, Non-Periodic

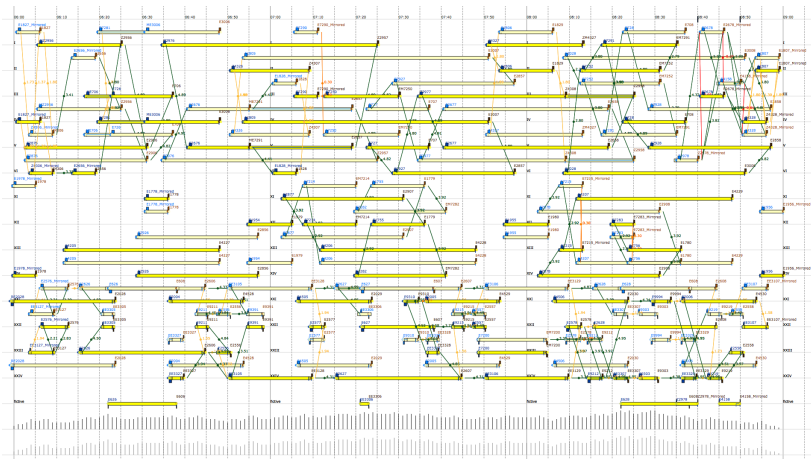


Figure: Antwerp-Central: comparing original and optimised assignments

# Antwerp Station



© Catamount Imaging

Figure: Antwerp Station

# Original Assignment

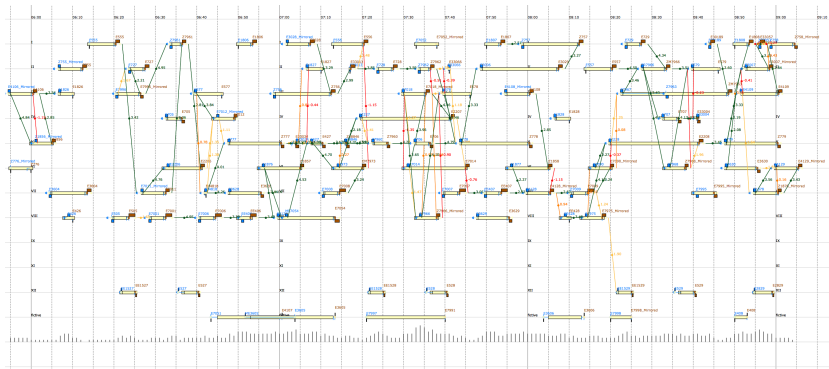
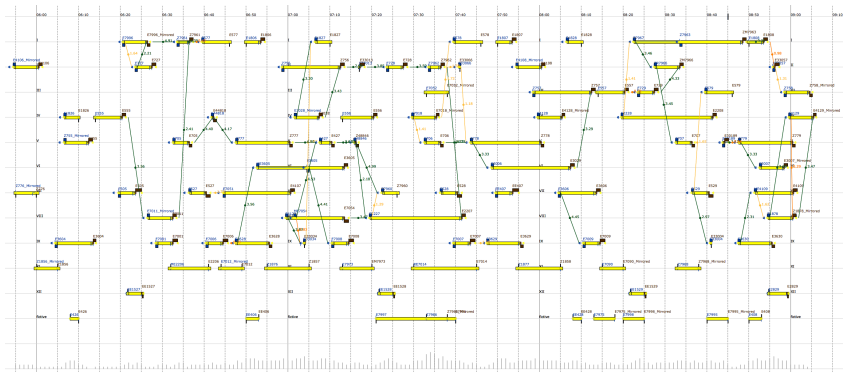


Figure: Ghent Sint-Pieters original Assignment: some conflicts

# Optimised Assignment, Non-Periodic



**Figure:** Ghent Sint-Pieters Opt. assignment, non-periodic: no conflicts, some unplaced trains

# Both Assignments, Non-Periodic

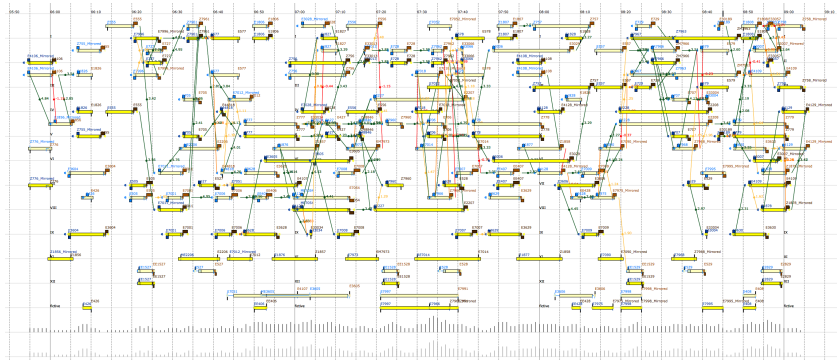


Figure: Ghent Sint-Pieters: comparing original and optimised assignments

# Ghent Station



Figure: Ghent Station

# Comparing Original and Optimised Assignment KPIs

#platform	#UnplatformedOrig	Orig	#redLin	#darkOra	#lightOra	#greenLin	RobustnessSc	#platform	#UnplatformedOpt	Opt	#redLin	#darkOra	#lightOra	#greenLin	RobustnessSc	Both
20	0	Orig Plan 401	0	0	0	0	0	20	0	Opt Plan 401	0	0	0	0	0	Both Plan 401
23	0	Orig Plan 402	35	8	8	13	-337	17	6	Opt Plan 402	0	7	3	9	-31	Both Plan 402
9	0	Orig Plan 404	0	0	0	0	0	9	0	Opt Plan 404	0	0	0	0	0	Both Plan 404
10	0	Orig Plan 405	0	0	0	0	0	10	0	Opt Plan 405	0	0	0	0	0	Both Plan 405
23	0	Orig Plan 406	0	0	0	5	0	23	0	Opt Plan 406	0	2	1	9	-9	Both Plan 406
9	0	Orig Plan 409	0	0	0	0	0	9	0	Opt Plan 409	0	0	0	0	0	Both Plan 409
13	0	Orig Plan 412	0	0	0	0	0	13	0	Opt Plan 412	0	0	0	0	0	Both Plan 412
21	0	Orig Plan 413	0	0	1	4	-1	21	0	Opt Plan 413	0	0	1	4	-1	Both Plan 413
28	0	Orig Plan 414	0	0	2	5	-2	28	0	Opt Plan 414	0	0	2	5	-2	Both Plan 414
46	0	Orig Plan 415	0	8	20	18	-52	46	0	Opt Plan 415	0	8	20	18	-52	Both Plan 415
14	0	Orig Plan 418	0	0	0	0	0	14	0	Opt Plan 418	0	0	0	0	0	Both Plan 418
17	0	Orig Plan 421	0	0	0	0	0	17	0	Opt Plan 421	0	0	0	0	0	Both Plan 421
15	0	Orig Plan 422	0	0	0	1	0	15	0	Opt Plan 422	0	0	0	1	0	Both Plan 422
7	0	Orig Plan 423	0	0	0	0	0	7	0	Opt Plan 423	0	0	0	0	0	Both Plan 423
24	0	Orig Plan 424	0	1	2	1	-4	24	0	Opt Plan 424	0	1	2	1	-4	Both Plan 424
23	1	Orig Plan 427	0	0	0	4	0	24	0	Opt Plan 427	0	0	0	4	0	Both Plan 427
0	12	Orig Plan 432	0	0	0	0	0	12	0	Opt Plan 432	0	0	0	0	0	Both Plan 432
14	0	Orig Plan 433	0	0	0	0	0	14	0	Opt Plan 433	0	0	0	0	0	Both Plan 433
11	0	Orig Plan 434	0	0	0	0	0	11	0	Opt Plan 434	0	0	0	0	0	Both Plan 434
10	0	Orig Plan 435	0	0	0	0	0	10	0	Opt Plan 435	0	0	0	0	0	Both Plan 435
12	0	Orig Plan 436	0	0	0	0	0	12	0	Opt Plan 436	0	0	0	0	0	Both Plan 436
34	0	Orig Plan 438	0	4	10	8	-35	33	0	Opt Plan 438	0	5	9	11	-25	Both Plan 438
9	0	Orig Plan 442	0	0	0	0	0	9	0	Opt Plan 442	0	0	0	0	0	Both Plan 442
15	0	Orig Plan 446	0	1	2	1	-6	15	0	Opt Plan 446	0	1	2	1	-6	Both Plan 446
33	0	Orig Plan 447	0	0	0	9	0	33	0	Opt Plan 447	0	0	0	9	0	Both Plan 447
33	1	Orig Plan 449	0	0	0	1	0	34	0	Opt Plan 449	0	0	0	2	0	Both Plan 449
87	7	Orig Plan 455	16	13	20	17	-216	92	2	Opt Plan 455	0	14	17	16	-73	Both Plan 455
36	0	Orig Plan 457	0	2	5	9	-13	36	0	Opt Plan 457	0	2	5	9	-13	Both Plan 457
34	1	Orig Plan 458	0	1	7	6	-38	34	1	Opt Plan 458	0	4	7	6	-23	Both Plan 458

12281	813	398	752	1524	2245	-8123	12641	253	0	707	1578	2409	-4406
hi=red=work to do		hi=bad lo=good	hi=bad lo=good	hi=bad lo=good	hi=bad lo=good	low=bad hi=good	hi=red=work to do		hi=bad lo=good	hi=bad lo=good	hi=bad lo=good	low=bad hi=good	
Sum	12894						Sum	12894					
% Unplatformed	4,75%						% Unplatformed	1,96%					
% Platformed	95,25%						% Platformed	98,04%					

# TPP Research and Integration

publication	integrated:	
	company	in tool(s)
[Zwaneveld et al.(1996)Zwaneveld, Kroon, Romeijn, Salomon, Dauzère-Perès, Van Hoesel, and Ambergen] [Zwaneveld(1997)]	ProRail NL	STATIONS
[De Luca Cardillo(1998)]		
[Delorme and Rodriguez(2001)]	SNCF	RECIFE FR
[Billionnet(2003)]		
[Carey and Carville(2003)]	British Rail, UK	
[Caprara et al.(2011)Caprara, Galli, and Toth]	RFI, IT	
[Lusby et al.(2011)Lusby, Larsen, Ryan, and Ehrgott]		
[Sels et al.(2014)Sels, Dewilde, Catrysse, and Vansteenwegen]	Infrabel BE	Ocapi Leopard

Table: Comparing TPP Research & Integration









# Conclusions & Future Work

- Conclusions
  - Leopard usable as check of current platform assignment
    - indicates all conflicts
    - indicates all robustness issues
  - Leopard usable as generator of correct platform assignment
    - guarantees no conflicts
    - can have robustness issues, indicates them
  - fast as a Leopard
- Further Work
  - roll-out with Infrabel planners
  - avoid robustness issues
  - weight trains per # passengers
  - allow some variability of platform times
  - allow multiple routes per line-platform combination

# Questions

- Questions?
- [sels.peter@gmail.com](mailto:sels.peter@gmail.com)
- [www.LogicallyYours.com/Research/](http://www.LogicallyYours.com/Research/)
- [www.LogicallyYours.com/Company/](http://www.LogicallyYours.com/Company/)

-  Billionnet, A., 2003. Using Integer Programming to Solve the Train Platforming Problem. *Transportation Science* 37 (1), 213–222.
-  Caprara, A., Galli, L., Toth, P., 2011. Solution of the train platforming problem. *Transportation Science* 45 (2), 246–257.
-  Carey, M., Carville, S., 2003. Scheduling and platforming trains at busy complex stations. *Transportation Research, Part A* 37 (1), 195–224.
-  De Luca Cardillo, D., 1998.  $k$  L-List  $\tau$  Colouring of Graphs. *European Journal of Operational Research* 106 (1), 160–164.
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-  Lusby, R. M., Larsen, J., Ryan, D., Ehrgott, M., 2011. Routing Trains Through Railway Junctions: A New Set-packing Approach. *Transportation Science* 45 (1), 228–245.

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-  Zwaneveld, P. J., 1997. Railway Planning and Allocation of Passenger Lines. Ph.D. thesis, Rotterdam School of Management.
-  Zwaneveld, P. J., Kroon, L., Romeijn, H., Salomon, M., Dautère-Perès, S., Van Hoesel, S. P. M., Ambergen, H. W., 1996. Routing Trains Through Railway Stations: Model Formulation and Algorithms. *Transportation Science* 30 (1), 181–194.