A real-time conflict resolution algorithm for the train rescheduling problem

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ALSTOM

February 17, 2016

OR-Unibo

Operational Research Group

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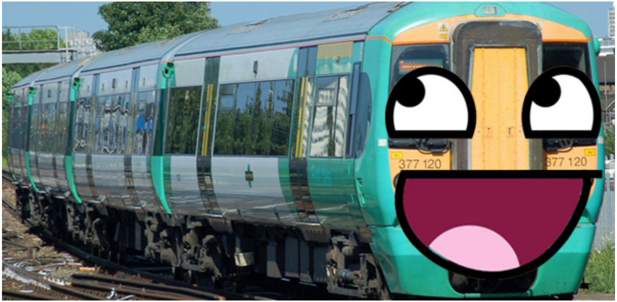
Thanks for the invitation to the Netherlands

Plan

Plan

Timetables



Timetables

NUOVO ORARIO

IN VIGORE DAL

25 AGOSTO 1896

ANDATA

FIRENZE - S. ELLERO - SALTINO

Stazioni		1	3	5
FIRENZE Centrale	part.	7.55	13.05	17.15
FIRENZE (Campo Marte)	»	8.05	13.21	17.23
S. ELLERO	arr.	8.54	14.18	18.06
S. ELLERO	part.	9.20	14.30	18.10
DONNINI	»	9.43	14.53	18.33
FILIBERTI	»	9.58	15.05	18.45
SALTINO	arr.	10.20	15.30	19.10

RITORNO

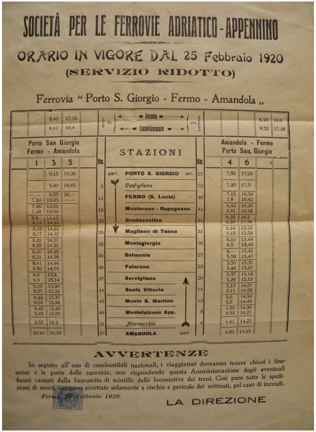
SALTINO - S. ELLERO - FIRENZE

Stazioni		2	4	6
SALTINO	part.	6.10	11.15	17.20
FILIBERTI	»	6.35	11.12	17.17
DONNINI	»	6.46	11.56	18.—
S. ELLERO	arr.	7.—	12.15	18.20
S. ELLERO	part.	7.11	12.33	18.50
FIRENZE Campo Marte	arr.	8.35	13.30	19.40
FIRENZE Centrale	»	8.45	13.40	19.50
ROMA	»	12.50	—	—

AVVERTENZA

È concesso sulla Ferrovia S. Ellero-Saltino, il trasporto gratuito di un piccolo bagaglio che non ecceda il peso di Kg. 10 ed il volume di 0.40×0.30×0.20.

Timetables



SOCIETÀ PER LE FERROVIE ADRIATICO-APPENNINO

ORARIO IN VIGORE DAL 25 Febbraio 1920

(SERVIZIO RIDOTTO)

Ferrovia "Porto S. Giorgio - Fermo - Amandola"

1	3	5			4	6
	8,49	17,36	arrivi da	← Ancona →	8,23	19,6
	8,17	19,4		← Castellammare → per partenze	8,52	17,38

Porto San Giorgio Fermo - Amandola 1	3	5	Km.	STAZIONI	Km.	Amandola - Fermo Porto San Giorgio 4	6
	9,15	19,20		part. PORTO S. GIORGIO arr.	57	7,50	17,26
	9,40	19,45	5	*Castiglione*	52	7,30	17,5
—,— 7,30	9,55 13,35	20,— —,—	11	FERMO (S. Lucia)	46	7,15 7,8	16,50 16,42
7,46 7,48	13,51 13,53		16	Monturano - Rapagnano	41	6,43 6,41	16,20 16,18
8,8 8,11	14,13 14,16		25	Grottazzolina	33	6,25 6,20	16,2 15,59
8,16 8,17	14,21 14,22		26	Magliano di Tenna	31	6,16 6,15	15,55 15,54
8,22 8,25	14,27 14,30		28	Montegiorgio	30	6,10 6,5	15,49 15,46
8,30 8,31	14,35 14,36		30	Belmonte	27	6,— 5,59	15,41 15,40
8,41 8,50	14,46 14,55		34	Falerone	23	5,50 5,46	15,31 15,27
9,3 9,9	15,8 15,14		37	Servigliano	20	5,37 5,29	15,18 15,13
9,25 9,27	15,30 15,32		44	Santa Vittoria	14	5,13 5,11	14,57 14,55
9,32 9,33	15,37 15,38		45	Monte S. Martino	12	5,6 5,5	14,50 14,49
9,43 9,45	15,48 15,50		49	Montefalcone App.	8	4,55 4,53	14,39 14,37
9,57	16,2		53	*Marnacchia*	4	4,41	14,25
10,10	16,15		57	AMANDOLA part.		4,30	14,15

AVVERTENZE

In seguito all' uso di combustibili nazionali, i viaggiatori dovranno tenere chiusi i finestrini e le porte delle carrozze, non rispondendo questa Amministrazione degli eventuali danni causati dalla fuoruscita di scintille dalle locomotive dei treni. Così pure tutte le spedizioni di merci vengono accettate solamente a rischio e pericolo dei mittenti, pel caso di incendi.

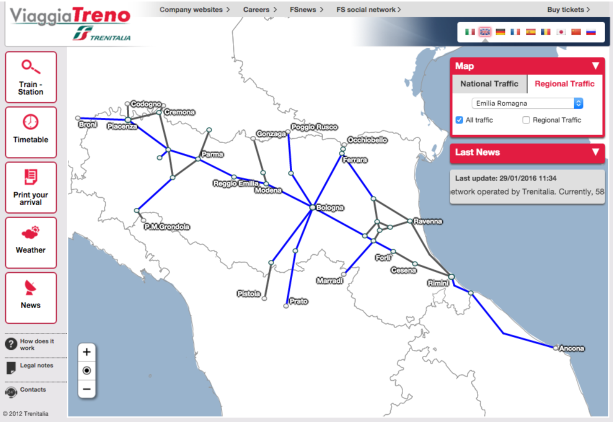
Fermo, 20 Febbraio 1920.

LA DIREZIONE

Timetables

Gioky3 www.delcampe.net

Timetables


ViaggiaTreno
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FSnews
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Train - Station
Timetable
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Weather
News
How does it work
Legal notes
Contacts
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Map
National Traffic
Regional Traffic
Emilia Romagna
All traffic
Regional Traffic
Last News
Last update: 29/01/2016 11:34
etwork operated by Trenitalia. Currently, 58
Codogno
Cremona
Broni
Piacenza
Parma
Gonzaga
Poggio Rusco
Occhiobello
Ferrara
Reggio Emilia
Modena
Bologna
Ravenna
P.M.Grondola
Forlì
Cesena
Rimini
Marradi
Pistoia
Prato
Ancona

Timetables


Arrivi Arrivals
Partenze Departures
27-01-2012
Treni Trains
Binari Platforms 14-22
Servizi Toilets

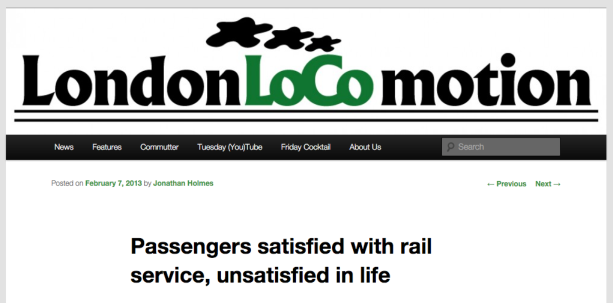
Timetables

Partenze Departures
R 10893 STRADELLA 18:19 60' 9.31) - STRADELLA (19.37) 1
R 2669 BRESCIA 18:22 100' FERMA A: TREV 5
R 10842 MILANO P.GAR 18:26 100' FERMA A: MIL 6
R 20366 MILANO G. P. 18:27 100' MILANO G. P. (18.33) 2
R 2629 PALAZZOLO 18:27 100' - PALAZZOLO (19.50) 7
R 2285 BOLOGNA C.LE 18:28 100' FERMA A: MI ROG 11
R 10489 CREMONA 18:30 100' - CAPRALBA (19.05) - CASA 5
R 33474 MILANO P.GAR 18:31 100' 44) - MILANO P.GAR (18.51) 3
R 2195 GENOVA BRIG. 18:33 50' IA (19.02) - VOGHERA (19. 11
R 10845 ROVATO 18:34 50' NANO (19.12) - CALCIO (19. 1
19:48
E' VIETATO ATTRAVERSARE I BINARI SERVIRSI DEL SOTTOPASSAGGIO
E' VIETATO OLTREPASSARE LA LINEA GIALLA

Timetables


Partenze Departures 18:36
treno train
Destinazione destination
orario time
ritardo delay
informazioni information
binario platform
S8 10875 MILANO P.GAR 18:37 20' 2
RE 2575 MILANO C.LE 19:01 10' 4
RE 2572 TIRANO 19:02 30' 3
S7 5160 MILANO P.GAR 19:07 1
S8 10877 MILANO P.GAR 19:07 CANC
5057 BERGAMO 19:12 3
5288 SONDRIO 19:15 5
S8 10879 MILANO P.GAR 19:37 4
RE 2579 MILANO C.LE 20:01 4
RE 2576 TIRANO 20:02 3
ATTENZIONE! AVVISIAMO CHE I TRENI

Timetables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Friday Cocktail
About Us
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Posted on February 7, 2013 by Jonathan Holmes
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Next →
Passengers satisfied with rail service, unsatisfied in life

Disturbances and Disruptions

- Disturbances: minor impact, solved by temporary timetable changes;
- Disruptions: major impact, solved by changing rolling stock, long reroutings, cancellations.

Disturbances and Disruptions
Outcome of a disruption

Forecast timetable

Nominal timetable $\Rightarrow$ Disturbance $\Rightarrow$ Forecast timetable.

The forecast timetable could now include conflicts!

Example: Train 1 delayed 10 minutes at platform 4, until 16:10; another train is due to platform 4 at 16:05!

Conflicts

- Capacity: two trains can't occupy the same track or platform at the same time;
- Illegal overtaking: overtaking can only take place on special segments of track;
- Headway: not enough time/space between two consecutive trains.

Conflicts
Quite illegal overtake!

Time dependencies

Time dependency: precedence relation between two events.

Example: train 1 has to wait for train 2 at station S $\Rightarrow$ the event "Train 1 departs from station S" can only occur 5 minutes after the event "Train 2 arrives at station S".

They can be mandatory or logical: in this latter case, the dependency is satisfied only if doing so introduces a limited amount of delay.

Split/merge

It occurs when trains entering a node $\neq$ trains exiting the same node.

Example: splitting (1 enters, >1 exit); merging (>1 enter, 1 exits); renaming (1 enters, 1 exits).

Plan

Objective function

Hierarchical objective function:

1. Unresolved conflicts get a big penalty;
2. Other terms get smaller penalties:
    - Delays
    - Braking logical time dependencies
    - Soft capacity violation
    - Taking detours
    - Not included: number of modified trains, increase in travel time, energy, etc.

Piecewise linear penalty profiles.

Graph

The network gets mapped on a digraph $G = (V, E)$.

Graph

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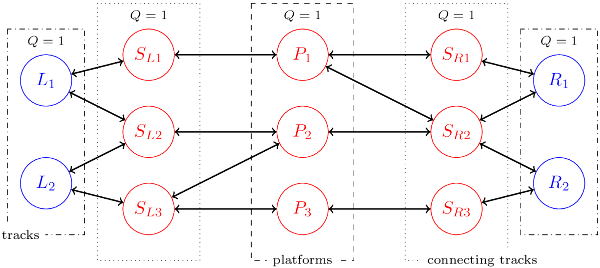
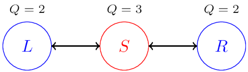
- Nodes represent resources.
    - What a resource is, depends on the level of detail we want to achieve.

Graph





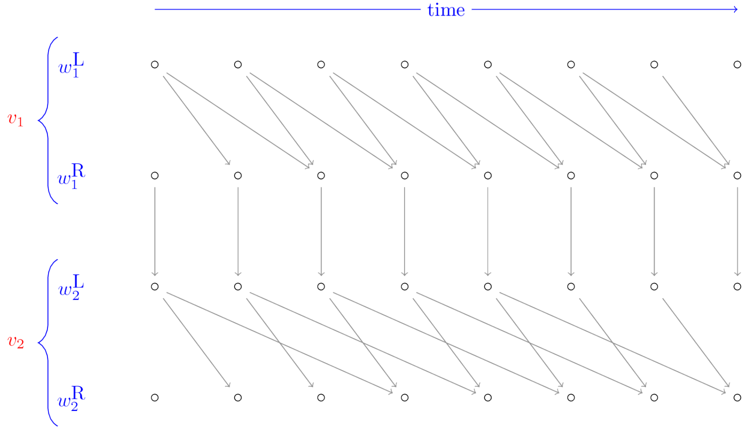
$P_1 \to R_2$ not compatible with $P_2 \to R_1$

Graph

The network gets mapped on a digraph $G = (V, E)$.

- Nodes represent resources.
  - What a resource is, depends on the level of detail we want to achieve.
- Arcs represent the possibility of moving from one resource to another.

Time-expanded graph



Time-expanded graph

Advantage: mixed micro- and macroscopic representations (time and space).

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Time-expanded graph

Advantage: many constraints can be modelled on the time-expanded graph.

- Capacity: count how many trains use each node;

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- Headway: check adjacent nodes in the same row;

Time-expanded graph

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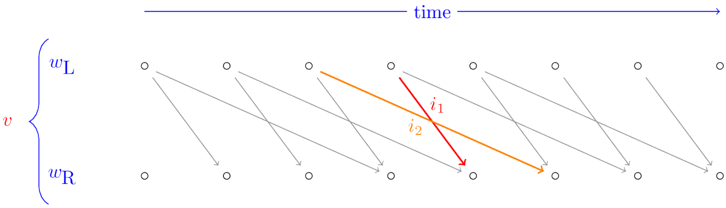
- Capacity: count how many trains use each node;
- Min/max entry/exit times: do not create nodes that violate them;
- Headway: check adjacent nodes in the same row;
- Crossing and overtake: check for crossing arcs;

Time-expanded graph



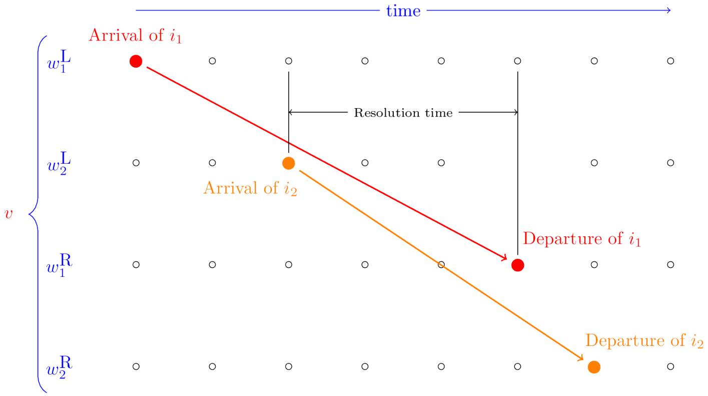
Overtaking

Time-expanded graph

Advantage: many constraints can be modelled on the time-expanded graph.

- Capacity: count how many trains use each node;
- Min/max entry/exit times: do not create nodes that violate them;
- Headway: check adjacent nodes in the same row;
- Crossing and overtake: check for crossing arcs;
- Time dependencies: check resolution time;

Time-expanded graph



Time dependency

Time-expanded graph

Advantage: many constraints can be modelled on the time-expanded graph.

- Capacity: count how many trains use each node;
- Min/max entry/exit times: do not create nodes that violate them;
- Headway: check adjacent nodes in the same row;
- Crossing and overtake: check for crossing arcs;
- Time dependencies: check resolution time;
- Split/merge: count arcs entering/exiting nodes and that there is enough time.

Plan

General outline

1. Initial sorting of trains;
2. Build the timetables one-by-one, in the chosen order;
3. “Shake” the train ordering;
4. Repeat 2 and 3 until the time limit hits.

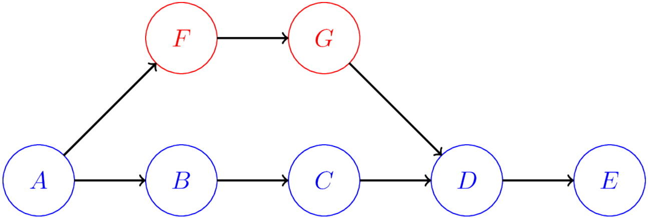
Initial sorting

Criteria used:

- Random;
- Congestion (# of conflicts caused if train delayed);
- Rev congestion;
- Path length;
- Time of earliest conflict;
- Speed;
- Rev speed.

Construction

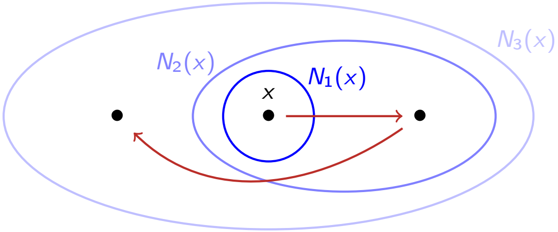
Label setting algorithm on the time-expanded graph.
Label extension respects topological order.



Only label component: cost.

Dispatching order: x
Nighbourhoods: $N_k(x)$ — perform at most k swaps

$$N_1(x) \subseteq N_2(x) \subseteq \ldots \subseteq N_k(x)$$



Shaking
Policy 2: Tabu search

Tabu move: precedence relations between trains.

$$\text{A} - \text{B} - \text{C} - \textcolor{blue}{\text{D}} \quad \Rightarrow \quad \text{A} - \textcolor{blue}{\text{D}} - \text{B} - \text{C}$$
$$T = \{(B, D), (C, D)\}$$

Swap (A,B):

- A – D – B – C $\Rightarrow$ B – D – A – C ✗
- A – D – B – C $\Rightarrow$ D – B – A – C ✓

Sparsification

Acceleration technique: time-expanded graph's travel arcs removal.

- Disabled
- Fixed-step
- Fixed-step with threshold
- Fixed-step linearly proportional to travel time
- Progressive

Plan

Instances

- 13 instances: small, dense, network with single tracks used in both directions.
  - 15-33 trains
  - 1-37 conflicts
  - 1-4 hrs time horizon
- 6 instances: busy regional network, with few big stations and several small ones.
  - 103-151 trains
  - 20-97 conflicts
  - 45-75 min time horizon
- 4 instances: high-speed network, with frequent long-distance trains.
  - 55-71 trains
  - 22-72 conflicts
  - 1 hr time horizon

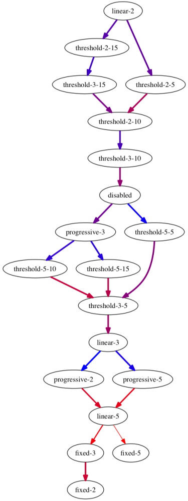
Parameter tuning
Algorithm ingredients

- Policy
  - RVNS or Tabu
- Sparsification method
  - 19 combinations of methods and respective parameters
- Initial sorting
  - 7 sortings
- Time limit
  - 2, 10, (60) secs

Parameter tuning
First step

For each policy and time limit, find the best sparsification method.

Parameter tuning
First step: example RVNS 2s



Parameter tuning

Second step

For each policy, time limit and corresponding sparsification, chose four initial sortings so to maximise the number of instances for which at least one of the chosen sortings provides the best result.

Parameter tuning
Second step

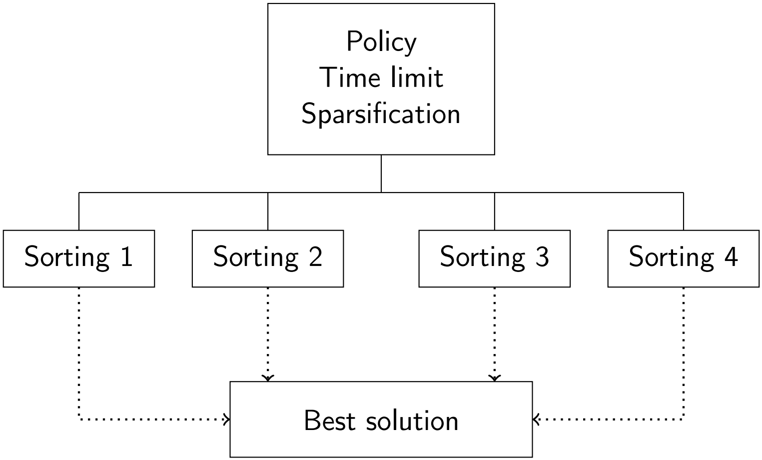
- Instances I, sortings S.
- $\delta_{is} = 1$ iff sorting s provided the best result on instance i.
- Variable $x_s = 1$ iff sorting s should be selected.
- Variable $y_i = 1$ iff there is at least one slected sorting that produces the best result for instance i.

$$\min \quad \sum_{i \in I} y_i \tag{1}$$

$$\text{s.t.} \quad \sum_{s \in S} x_s = 4 \tag{2}$$

$$y_i \le \sum_{s \in S} x_s \delta_{is} \qquad \forall i \in I \tag{3}$$

Parallel algorithm



Parallel algorithm

Tabu 2s progressive-2	**Tabu 10s progressive-2**	**RVNS 2s linear-2**	**RVNS 10s progressive-3**
Congestion	Congestion	Congestion	Congestion
Length	Conflict Time	Conflict Time	Conflict Time
Rev Congestion	Rev Congestion	Rev Congestion	Speed
Random	Rev Speed	Rev Speed	Random

Parallel algorithm
2s results

	Tabu				RVNS			
Instance	Sorting	Dev	Conf	Inf	Sorting	Dev	Conf	Inf
L1	Random	†1.00	1	0	Conflict time	†1.00	1	0
L2	Rev congestion	†1.10	0	0	Conflict time	1.30	0	0
L3	Random	†1.00	2	0	Rev speed	†1.00	2	0
L4	Rev congestion	1.29	0	0	Rev congestion	†1.23	0	0
L5	Length	1.38	0	0	Rev speed	†1.26	0	0
L6	Length	1.27	0	0	Rev speed	†1.23	0	0
P1	Rev congestion	1.47	0	0	Congestion	†1.00	0	0
P2	Rev congestion	†1.31	0	0	Conflict time	1.32	0	0
P3	Congestion	1.16	0	0	Conflict time	†1.08	0	0
P4	Random	2.04	0	0	Congestion	†1.81	0	0
N1	Length	1.20	0	0	Rev congestion	†1.19	0	0
N2	Length	†1.13	0	0	Rev congestion	1.26	0	0
N3	Rev congestion	†1.00	3	1	Rev congestion	†1.00	3	1
N4	Congestion	†1.00	0	0	Rev congestion	1.07	0	0
N5	Random	†1.00	0	0	Congestion	1.41	0	0
N6	Congestion	†1.00	0	0	Congestion	†1.00	0	0
N7	Length	†1.05	0	0	Rev speed	1.10	0	0
N8	Congestion	†1.24	0	0	Conflict time	3.52	0	0
N9	Congestion	†2.25	0	0	Conflict time	3.25	0	0
N10	Congestion	1.22	0	0	Conflict time	†1.11	0	0
N11	Congestion	†1.00	0	0	Congestion	†1.00	0	0
N12	Congestion	†1.00	0	0	Congestion	†1.00	0	0
N13	Congestion	†1.00	2	0	Congestion	†1.00	2	0
Overall		1.22	0.35	5.13		1.35	0.35	0.04

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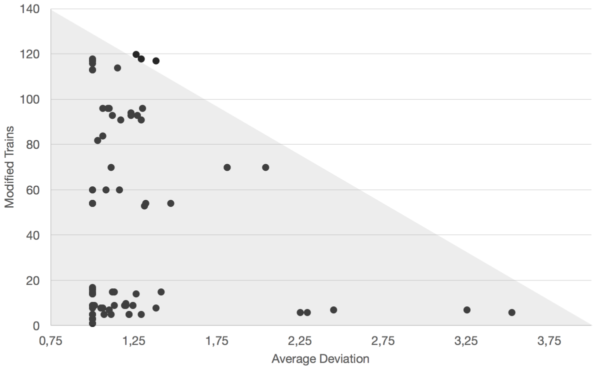
Parallel algorithm
10s results

	Tabu				RVNS			
Instance	**Sorting**	**Dev**	**Conf**	**Inf**	**Sorting**	**Dev**	**Conf**	**Inf**
L1	Rev congestion	†1.00	1	0	Conflict time	†1.00	1	0
L2	Rev congestion	1.09	0	0	Conflict time	1.30	0	0
L3	Conflict time	†1.00	2	0	Rev speed	†1.00	2	0
L4	Rev congestion	1.17	0	0	Rev congestion	†1.23	0	0
L5	Rev speed	1.29	0	0	Rev speed	†1.26	0	0
L6	Congestion	1.12	0	0	Rev speed	†1.23	0	0
P1	Rev speed	†1.00	0	0	Congestion	†1.00	0	0
P2	Conflict time	†1.00	0	0	Conflict time	1.32	0	0
P3	Congestion	†1.00	0	0	Conflict time	†1.08	0	0
P4	Rev speed	†1.11	0	0	Congestion	†1.81	0	0
N1	Rev speed	1.20	0	0	Rev congestion	†1.19	0	0
N2	Conflict time	†1.00	0	0	Rev congestion	1.26	0	0
N3	Congestion	†1.00	3	1	Rev congestion	†1.00	3	1
N4	Congestion	†1.00	0	0	Rev congestion	1.07	0	0
N5	Congestion	†1.00	0	0	Congestion	1.41	0	0
N6	Congestion	†1.00	0	0	Congestion	†1.00	0	0
N7	Congestion	†1.01	0	0	Rev speed	1.10	0	0
N8	Congestion	†1.24	0	0	Conflict time	3.52	0	0
N9	Congestion	†1.38	0	0	Conflict time	3.25	0	0
N10	Congestion	†1.22	0	0	Conflict time	†1.11	0	0
N11	Congestion	†1.00	0	0	Congestion	†1.00	0	0
N12	Congestion	†1.00	0	0	Congestion	†1.00	0	0
N13	Congestion	†1.00	2	0	Congestion	†1.00	2	0
Overall		1.08	0.35	0.04		1.19	0.35	0.04

Parallel algorithm
Does modifying more trains help?



Plan

Conclusions

- Versatile model (micro/macro);
- Rich model;
- Fast algorithm (one iteration $\sim$0.1 sec);
- Solves real problems "out there";
- Validation?