

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

Andrea Bettinelli, Alberto Santini, Daniele Vigo



February 17, 2016

OR-Unibo

Operational Research
Group



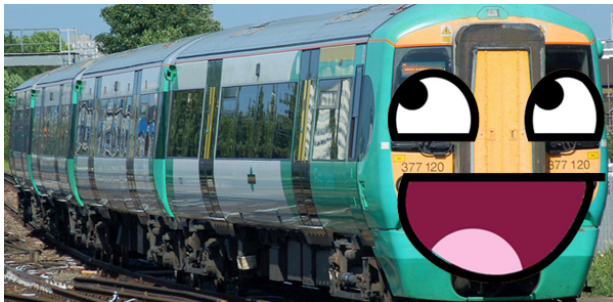
Thanks for the invitation to the Netherlands



- 1 Introduction
- 2 Modelling the problem
- 3 Real-time algorithm
- 4 Results
- 5 Conclusions

- 1 Introduction
- 2 Modelling the problem
- 3 Real-time algorithm
- 4 Results
- 5 Conclusions

Timetables



Timetables

NUOVO ORARIO
IN VIGORE DAL
25 AGOSTO 1896

ANDATA FIRENZE - S. ELLERO - SALTINO					RITORNO SALTINO - S. ELLERO - FIRENZE				
Stazioni		1	3	5	Stazioni		2	4	6
FIRENZE Centrale	part.	7.55	13.05	17.15	SALTINO	part.	6.10	11.15	17.20
FIRENZE (Campo Marzio)	"	8.05	13.21	17.23	FILIBERTI	"	6.35	11.28	17.17
S. ELLERO	arr.	8.54	14.18	18.04	DONNINI	"	6.40	11.56	18. —
					S. ELLERO	arr.	7. —	12.15	18.30
S. ELLERO	part.	9.20	14.30	18.10	S. ELLERO	part.	7.11	12.33	18.50
DONNINI	"	9.43	14.53	18.33	FIRENZE Campo Marzio	arr.	8.35	13.30	19.40
FILIBERTI	"	9.55	15.05	18.45	FIRENZE Centrale	"	8.45	13.40	19.50
SALTINO	arr.	10.20	15.30	19.10	ROMA	"	12.50	—	—

AVVERTENZA

E' 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 0.40x0.30x0.20.

Timetables

SOCIETÀ PER LE FERROVIE ADRIATICO-APPENNINO
ORARIO IN VIGORE DAL 25 Febbraio 1920
(SERVIZIO RIDOTTO)

Ferrovie "Porto S. Giorgio - Fermo - Amandola,,

Porto San Giorgio Fermo - Amandola		STAZIONI		Amandola - Fermo Porto San Giorgio	
1	3	5	6	4	6
5.15	11.20			5.15	11.20
5.17	10.4			5.17	10.4
5.18	10.45			5.18	10.45
5.20	10.50			5.20	10.50
5.22	10.55			5.22	10.55
5.24	11.00			5.24	11.00
5.26	11.05			5.26	11.05
5.28	11.10			5.28	11.10
5.30	11.15			5.30	11.15
5.32	11.20			5.32	11.20
5.34	11.25			5.34	11.25
5.36	11.30			5.36	11.30
5.38	11.35			5.38	11.35
5.40	11.40			5.40	11.40
5.42	11.45			5.42	11.45
5.44	11.50			5.44	11.50
5.46	11.55			5.46	11.55
5.48	12.00			5.48	12.00
5.50	12.05			5.50	12.05
5.52	12.10			5.52	12.10
5.54	12.15			5.54	12.15
5.56	12.20			5.56	12.20
5.58	12.25			5.58	12.25
6.00	12.30			6.00	12.30
6.02	12.35			6.02	12.35
6.04	12.40			6.04	12.40
6.06	12.45			6.06	12.45
6.08	12.50			6.08	12.50
6.10	12.55			6.10	12.55
6.12	13.00			6.12	13.00
6.14	13.05			6.14	13.05
6.16	13.10			6.16	13.10
6.18	13.15			6.18	13.15
6.20	13.20			6.20	13.20
6.22	13.25			6.22	13.25
6.24	13.30			6.24	13.30
6.26	13.35			6.26	13.35
6.28	13.40			6.28	13.40
6.30	13.45			6.30	13.45
6.32	13.50			6.32	13.50
6.34	13.55			6.34	13.55
6.36	14.00			6.36	14.00
6.38	14.05			6.38	14.05
6.40	14.10			6.40	14.10
6.42	14.15			6.42	14.15
6.44	14.20			6.44	14.20
6.46	14.25			6.46	14.25
6.48	14.30			6.48	14.30
6.50	14.35			6.50	14.35
6.52	14.40			6.52	14.40
6.54	14.45			6.54	14.45
6.56	14.50			6.56	14.50
6.58	14.55			6.58	14.55
7.00	15.00			7.00	15.00
7.02	15.05			7.02	15.05
7.04	15.10			7.04	15.10
7.06	15.15			7.06	15.15
7.08	15.20			7.08	15.20
7.10	15.25			7.10	15.25
7.12	15.30			7.12	15.30
7.14	15.35			7.14	15.35
7.16	15.40			7.16	15.40
7.18	15.45			7.18	15.45
7.20	15.50			7.20	15.50
7.22	15.55			7.22	15.55
7.24	16.00			7.24	16.00
7.26	16.05			7.26	16.05
7.28	16.10			7.28	16.10
7.30	16.15			7.30	16.15
7.32	16.20			7.32	16.20
7.34	16.25			7.34	16.25
7.36	16.30			7.36	16.30
7.38	16.35			7.38	16.35
7.40	16.40			7.40	16.40
7.42	16.45			7.42	16.45
7.44	16.50			7.44	16.50
7.46	16.55			7.46	16.55
7.48	17.00			7.48	17.00
7.50	17.05			7.50	17.05
7.52	17.10			7.52	17.10
7.54	17.15			7.54	17.15
7.56	17.20			7.56	17.20
7.58	17.25			7.58	17.25
8.00	17.30			8.00	17.30
8.02	17.35			8.02	17.35
8.04	17.40			8.04	17.40
8.06	17.45			8.06	17.45
8.08	17.50			8.08	17.50
8.10	17.55			8.10	17.55
8.12	18.00			8.12	18.00
8.14	18.05			8.14	18.05
8.16	18.10			8.16	18.10
8.18	18.15			8.18	18.15
8.20	18.20			8.20	18.20
8.22	18.25			8.22	18.25
8.24	18.30			8.24	18.30
8.26	18.35			8.26	18.35
8.28	18.40			8.28	18.40
8.30	18.45			8.30	18.45
8.32	18.50			8.32	18.50
8.34	18.55			8.34	18.55
8.36	19.00			8.36	19.00
8.38	19.05			8.38	19.05
8.40	19.10			8.40	19.10
8.42	19.15			8.42	19.15
8.44	19.20			8.44	19.20
8.46	19.25			8.46	19.25
8.48	19.30			8.48	19.30
8.50	19.35			8.50	19.35
8.52	19.40			8.52	19.40
8.54	19.45			8.54	19.45
8.56	19.50			8.56	19.50
8.58	19.55			8.58	19.55
9.00	20.00			9.00	20.00
9.02	20.05			9.02	20.05
9.04	20.10			9.04	20.10
9.06	20.15			9.06	20.15
9.08	20.20			9.08	20.20
9.10	20.25			9.10	20.25
9.12	20.30			9.12	20.30
9.14	20.35			9.14	20.35
9.16	20.40			9.16	20.40
9.18	20.45			9.18	20.45
9.20	20.50			9.20	20.50
9.22	20.55			9.22	20.55
9.24	21.00			9.24	21.00
9.26	21.05			9.26	21.05
9.28	21.10			9.28	21.10
9.30	21.15			9.30	21.15
9.32	21.20			9.32	21.20
9.34	21.25			9.34	21.25
9.36	21.30			9.36	21.30
9.38	21.35			9.38	21.35
9.40	21.40			9.40	21.40
9.42	21.45			9.42	21.45
9.44	21.50			9.44	21.50
9.46	21.55			9.46	21.55
9.48	22.00			9.48	22.00
9.50	22.05			9.50	22.05
9.52	22.10			9.52	22.10
9.54	22.15			9.54	22.15
9.56	22.20			9.56	22.20
9.58	22.25			9.58	22.25
10.00	22.30			10.00	22.30
10.02	22.35			10.02	22.35
10.04	22.40			10.04	22.40
10.06	22.45			10.06	22.45
10.08	22.50			10.08	22.50
10.10	22.55			10.10	22.55
10.12	23.00			10.12	23.00
10.14	23.05			10.14	23.05
10.16	23.10			10.16	23.10
10.18	23.15			10.18	23.15
10.20	23.20			10.20	23.20
10.22	23.25			10.22	23.25
10.24	23.30			10.24	23.30
10.26	23.35			10.26	23.35
10.28	23.40			10.28	23.40
10.30	23.45			10.30	23.45
10.32	23.50			10.32	23.50
10.34	23.55			10.34	23.55
10.36	24.00			10.36	24.00
10.38	24.05			10.38	24.05
10.40	24.10			10.40	24.10
10.42	24.15			10.42	24.15
10.44	24.20			10.44	24.20
10.46	24.25			10.46	24.25
10.48	24.30			10.48	24.30
10.50	24.35			10.50	24.35
10.52	24.40			10.52	24.40
10.54	24.45			10.54	24.45
10.56	24.50			10.56	24.50
10.58	24.55			10.58	24.55
11.00	25.00			11.00	25.00
11.02	25.05			11.02	25.05
11.04	25.10			11.04	25.10
11.06	25.15			11.06	25.15
11.08	25.20			11.08	25.20
11.10	25.25			11.10	25.25
11.12	25.30			11.12	25.30
11.14	25.35			11.14	25.35
11.16	25.40			11.16	25.40
11.18	25.45			11.18	25.45
11.20	25.50			11.20	25.50
11.22	25.55			11.22	25.55
11.24	26.00			11.24	26.00
11.26	26.05			11.26	26.05
11.28	26.10			11.28	26.10
11.30	26.15			11.30	26.15
11.32	26.20			11.32	26.20
11.34	26.25			11.34	26.25
11.36	26.30			11.36	26.30
11.38	26.35			11.38	26.35
11.40	26.40			11.40	26.40
11.42	26.45			11.42	26.45
11.44	26.50			11.44	26.50
11.46	26.55			11.46	26.55
11.48	27.00			11.48	27.00
11.50	27.05			11.50	27.05
11.52	27.10			11.52	27.10
11.54	27.15			11.54	27.15
11.56	27.20			11.56	27.20</

ESTATE 1969 ORARI VALIDI DAL 1 GIUGNO AL 27 SETTEMBRE 1969 L. 200
(Dell'Orario Ufficiale delle Ferrovie dello Stato)

TUTTA ITALIA (A GRANDI LINEE CENTRO-SUD E ISOLE)

NUOVO GRIPPAUDO ORARIO ANNO 91°

Casa di Cura VILLA GEMMA
GARDONE RIVIERA
 TELEFONO 0365 / 20461-2-3
 CARDIOLOGIA - FORME NERVOSE
 FISIOTERAPIA - CURE DEPURATIVE




OTTICA INTERNAZIONALE
MILANO
 Galleria Vitt. Em. 80
 Via Montenapoleone, 26

ORARIO ESTIVO 1969 (ora legale)



OR-Unibo

Timetables

ViaggiaTreno  Company websites > Careers > FSnews > FS social network > Buy tickets >

Map

National Traffic Regional Traffic

Emilia Romagna

☒ All traffic ☐ Regional Traffic

Last News

Last update: 29/01/2016 11:34
network operated by Trenitalia. Currently, 58

Train - Station

Timetable

Print your arrival

Weather

News

How does it work

Legal notes

Contacts

© 2012 Trenitalia



Arrivi Arrivals

#	NAME	AGE	STATUS	REMARKS
# 02	ANDRA P.A.	1904	16	PRIMA CLASSE IN CC IS
# 03	VENEZIO S.A.	1905	17	PRIMA CLASSE IN
# 04	PESCARA C.	1905	17	CANCELATO
# 05	DRECCO	1905	17	CANCELATO
# 06	DEL	1905	17	CANCELATO
# 07	GENESE	1905	17	CANCELATO
# 08	TRINHO	1905	17	CANCELATO
# 09	SALERIO	1905	17	CANCELATO
# 10	BRASL SBB	1905	17	CANCELATO
# 11	DEGANO	1905	17	CANCELATO
# 12	ARPAOLI C.E.	1905	17	HE E BUSINESS IN T
# 13	ROGATO TEM	1905	17	
# 14	CLE	1905	17	
# 15	ROGATO TD	1905	17	
# 16	SALERIO	1905	17	E IN TESTA
# 17	NINOTTO	1905	17	
# 18	TRINHO P.A.	1905	17	ISE IN TESTA
# 19	BOLOGNA C.E.	1905	17	CANCELATO
# 20	TRINHO P.A.	1905	17	



27-01-2012



AL	PR	070	UNHEZIO S.A.	11030	ENRICH P.M. (12.57) - 9
AL	PR	080	E. LEE	11050	GG CHEN (11.20) - 10
AL	PR	0900	GE. I	11050	TERESINA (11.20)
AL	PR	1007	ROMA TERZANI	11060	U (14.59)
AL	PR	110	UNHEZIO S.A.	11060	PERATA (15.54) - PM
AL	PR	0900	ROMA TERZANI	11060	CHITTELLO
AL	PR	100	LA SPEZIA C.	11060	CHITTELLO
AL	PR	080	TORINO P.A.	11070	CHITTELLO
AL	PR	0900	TORINO	11070	CHITTELLO
AL	PR	0900	TORINO	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	1000	IMPIANTI C.A.E.	11070	CHITTELLO
AL	PR	110	UNHEZIO S.A.	11070	CHITTELLO
AL	PR	0900	IMPIANTI C.A.E.	11070	CHITTELLO

ATTENZIONE! RIVOLGENDO CHE DALLE ORE 21.00 DI GIOVEDÌ 26 ALLE ORE 21.00 DI VENERDÌ 27 GENNAIO 2012 I TRENI POTRANNO SUBIRE CANCELLAZIONI O RITARDI PER UNO SCOPPIO DEL PERSONALE DEL GRUPPO FERROVIE DELLO STATO ITALIANE E DI TRENORD.



Partenze Departures					
Linea Line	Destinazione Destination	Arrivo Time	Ritardo Delay	Informazioni Information	Binario Platform
10893	STRADELLA	18:19	60'	19.31) - STRADELLA (19.37)	1
2669	BRESCIA	18:22	100'	FERMA A: TREV.	5
10842	MILANO P.GAR	18:26	100'	FERMA A: MIL	6
20366	MILANO C. P.	18:27	100'	MILANO C. P. (18.33)	2
2629	PALAZZOLO	18:27	100'	- PALAZZOLO (19.50)	7
2285	BOLOGNA C.LE	18:28	100'	FERMA A: MI ROG	11
10489	CREMONA	18:30	100'	- CAPRALBA (19.05) - CASAI	5
33474	MILANO P.GAR	18:31	100'	44) - MILANO P.GAR (18.51)	3
2195	GENOVA BRIG.	18:33	50'	19.02) - VOGHERA (19.1	11
10845	ROVATO	18:34	50'	19.12) - CALCIO (19.1	1

16 SET 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
58 10875	MILANO P.GAR	18:37	20'		2
RE 2575	MILANO C.LE	19:01	10'		4
RE 2572	TIRANO	19:02	30'		3
57 5160	MILANO P.GAR	19:07			1
58 10877	MILANO P.GAR	19:07	CANC		
5057	BERGAMO	19:12			3
5288	SONDRIO	19:15			5
58 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



London LoCo motion

[News](#)[Features](#)[Commuter](#)[Tuesday \(YouTube\)](#)[Friday Cocktail](#)[About Us](#)

Posted on [February 7, 2013](#) by [Jonathan Holmes](#)

[← Previous](#) [Next →](#)

Passengers satisfied with rail service, unsatisfied in life

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



OR-Unibo

Disturbances and Disruptions

Outcome of a disruption



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!

- **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.



OR-Unibo

Conflicts Quite illegal overtake!



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.

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).

- 1 Introduction
- 2 Modelling the problem**
- 3 Real-time algorithm
- 4 Results
- 5 Conclusions

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.

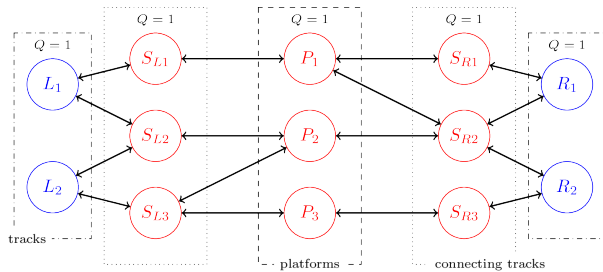
Piecewise linear penalty profiles.

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

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.

Graph

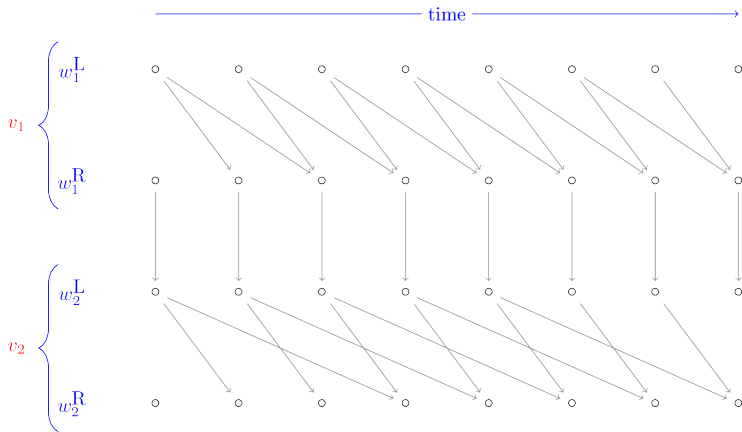


$P_1 \rightarrow R_2$ not compatible with $P_2 \rightarrow R_1$

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).

Time-expanded graph

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

- **Capacity:** count how many trains use each node;

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;

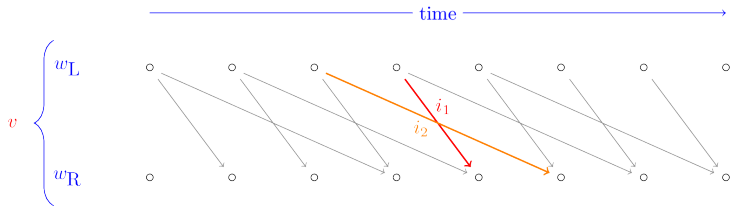
Advantage: many constraints can be modelled on the time-expanded graph.

- **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;

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-expanded graph

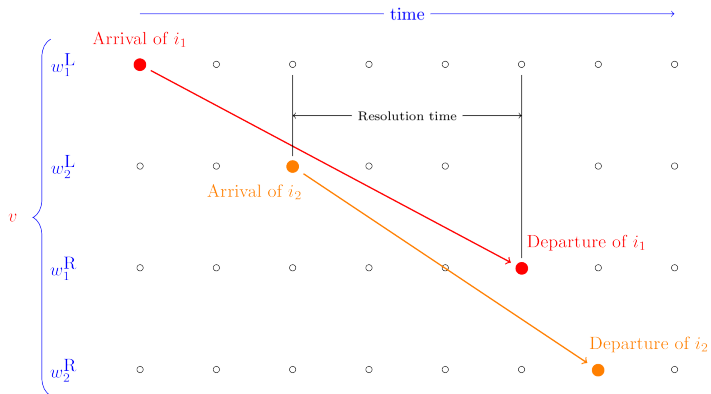


Overtaking

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

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

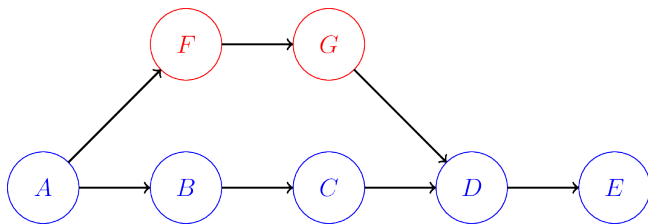
- 1 Introduction
- 2 Modelling the problem
- 3 Real-time algorithm**
- 4 Results
- 5 Conclusions

- 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.

Criteria used:

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

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

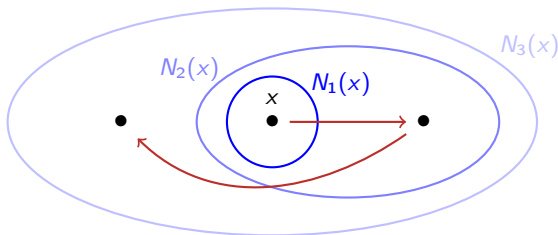


Only label component: cost.

Dispatching order: x

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

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



Tabu move: precedence relations between trains.

$$A - B - C - D \Rightarrow A - D - B - C$$

$$T = \{(B, D), (C, D)\}$$

Swap (A,B):

$$\blacksquare A - D - B - C \Rightarrow B - D - A - C \quad \text{red X}$$

$$\blacksquare A - D - B - C \Rightarrow D - B - A - C \quad \text{green checkmark}$$

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

- 1 Introduction
- 2 Modelling the problem
- 3 Real-time algorithm
- 4 Results**
- 5 Conclusions

- 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

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

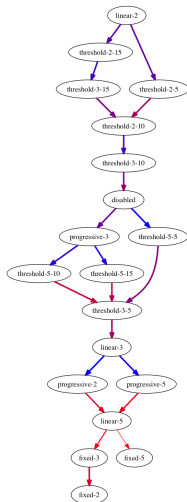
Parameter tuning

First step

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

Parameter tuning

First step: example RVNS 2s



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.

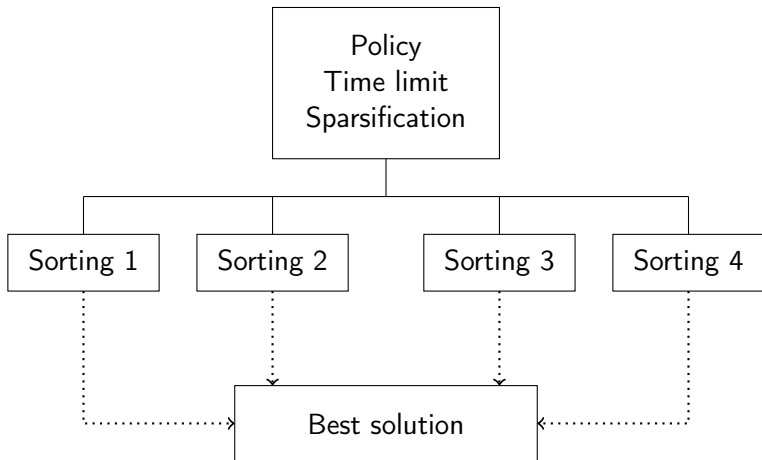
- Instances I , sortings S .
- $\delta_{is} = 1$ iff sorting s provided the best result on instance i .
- **Variable** $x_s = 1$ iff sorting s should be selected.
- **Variable** $y_i = 1$ iff there is at least one selected sorting that produces the best result for instance i .

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

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

$$y_i \leq \sum_{s \in S} x_s \delta_{is} \quad \forall i \in I \quad (3)$$

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

Instance	Tabu				RVNS			
	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

Parallel algorithm

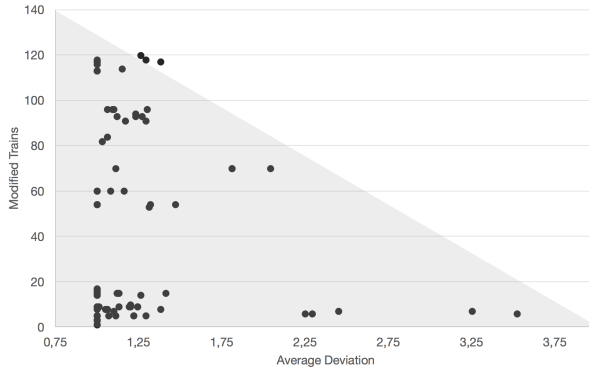
10s results

Instance	Tabu				RVNS			
	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?



- 1 Introduction
- 2 Modelling the problem
- 3 Real-time algorithm
- 4 Results
- 5 Conclusions**

Conclusions

- Versatile model (micro/macro);
- Rich model;
- Fast algorithm (one iteration ~ 0.1 sec);
- Solves real problems “out there”;
- Validation?