The Ideal Train Timetabling Problem

Tomáš Robenek Shadi Sharif Azadeh Yousef Maknoon
Jianghang Chen Michel Bierlaire

RailTokyo2015: March 23 – 26, 2015

March 25, 2015

Liberalisation – 01.01.2010

Purely commercial rail passenger services in Europe

(red)	Market closed for commercial national rail passenger services.
(yellow)	Open access, but no external RUs providing commercial national rail passenger services .
(green)	Open access with external RUs providing commercial national rail passenger services.
(hatched yellow/green)	AT and CZ: commencing end of 2011, external RUs providing purely commercial national rail passenger services.

Liberalisation – Overview

Liberalisation time line

1 January 1993
Access for international groupings providing international services and for international combined transport goods service providers

15 March 2003
Access to the Trans-European Rail Freight Network for international freight services

1 January 2006
Access to the entire EU rail network for international freight services

1 January 2007
Access to the entire EU rail network for all types of rail freight (including domestic)

1 January 2010
Access to the infrastructure in all EU Member States for the purpose of operating international passenger services (cabotage permitted)

? December 2019
Access to the infrastructure in all EU Member States for all rail services, including domestic passenger services

Public Sector – Accessibility/Mobility

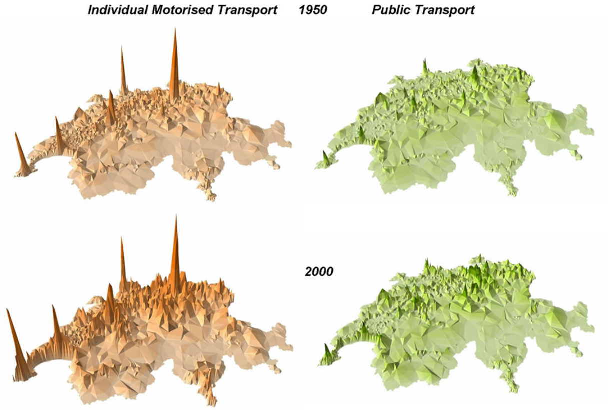


Figure : Mobility evolution in Switzerland[1]

[1] – source: Entwicklung der MIV und OV Erreichbarkeit in der Schweiz: 1950-2000; Ph. Frohlich, M. Tschopp and K.W. Axhausen

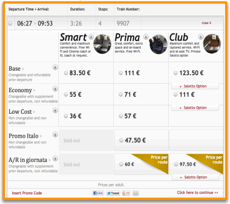
Private Sector

Market Settings

Travel Time is the same

Serve Different Destinations

Better Quality



Departure Time > Arrival:	Duration:	Stops:	Train Number:
06:27 > 09:53	3:26	4	9907

close X

	Smart – Comfort and maximum convenience. Free Wi-Fi and Cinema coach or XL coach at request.	Prima – Great comfort, extra space and on-board service. Free Wi-Fi.	Club – Maximum comfort and taylored service. Wi-Fi and at-seat TV. Private Salotto option
Base > Changeable and refundable prior departure	83.50 €	111 €	123.50 € (Salotto Option)
Economy > Changeable with supplement prior departure, non refundable	55 €	71 €	111 € (Salotto Option)
Low Cost > Non changeable and non refundable	36 €	57 €	
Promo Italo > Non changeable and non refundable	Sold out	47.50 €	
A/R in giornata > Changeable with supplement prior departure, non refundable	Sold out	60 € (Price per route)	97.50 € (Price per route) (Salotto Option)

Prices per adult.

Insert Promo Code — Like — Tweet — +1 — Click here to continue >>

Better Price

Better Departure Times

Origin of a Timetable?

Johnson City Enterprise.

Published Every Saturday,

$1. per year—Advance Payment.

SATURDAY, APRIL 7, 1883.

TIME TABLE

E. T., V. & G. R. R.

PASSENGER,	ARRIVES,
No. 1, West,	6:37, a. m.
No. 2, East,	9:45, p. m.
No. 3, West,	11:51, p.m.
No. 4, East,	3:56, a. m.
LOCAL FREIGHT,	ARRIVES,
No. 5,	7:20, a. m.
No. 8,	6:20, p. m.

JNO. W. EAKIN, Agent.

E. T. & W. N. C. R. R.

Passenger, leaves,	7, a. m.
" arrives,	6, p. m.

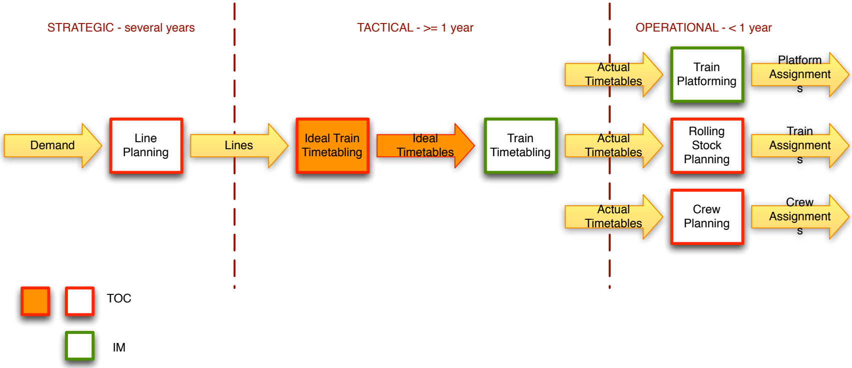
J. C. HARDIN, Agent.

- In the industry – historical
- Timetable design in the literature
  - non-cyclic: using so called "ideal timetables"
  - cyclic: does not take into account anything
- Need to account for passengers!

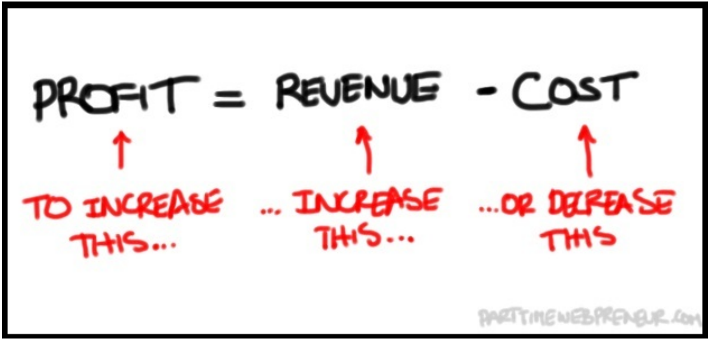
TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

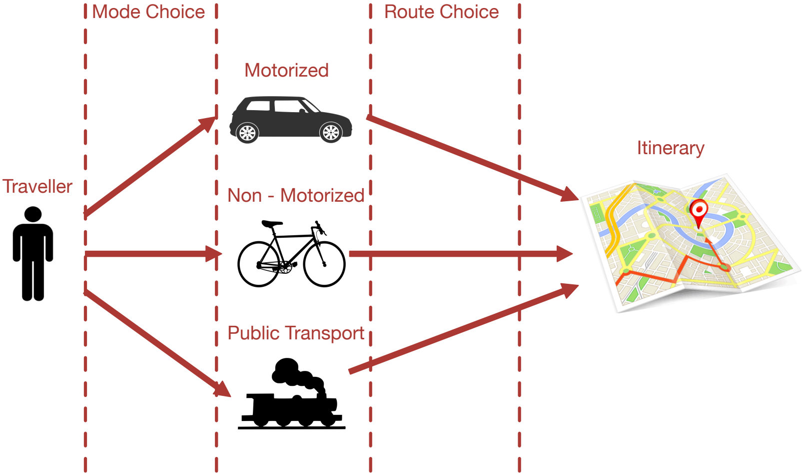
Update of Planning



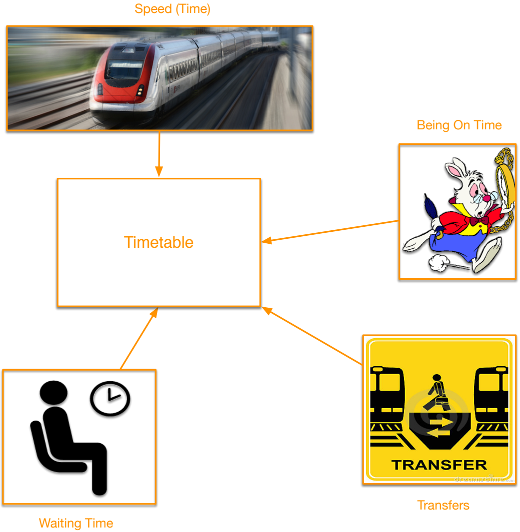
TOC Point of View



Transport Demand



Passenger Point of View



Passenger Cost

Perceived cost of a given path using a given timetable (a path is defined as a sequence of train lines, in order to get from an origin to a destination):

$$C = \text{argmin}\left(\alpha \cdot \sum_{i \in I} VT + \beta \cdot \sum_{j \in J^I} WT + \gamma \cdot NT + \min\left(\epsilon \cdot SD_e, \eta \cdot SD_l\right)\right)$$

for all possible sets I, where:

- I – set of possible trains in a given path
- J^I – set of transfers in a given path using given trains
- α – value of time (monetary units per minute)
- β – value of waiting time (monetary units per minute)
- γ – penalty for having a transfer (monetary units)
- ϵ – value of being early (monetary units per minute)
- η – value of being late (monetary units per minute)

TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

References (Passenger Behavior)

Moshe Ben-Akiva and Takayuki Morikawa
"Comparing ridership attraction of rail and bus."
Transport Policy, pp. 107 – 116, 2002.

Kay W. Axhausen and Stephane Hess and Arnd König and Georg Abay and John J. Bates and Michel Bierlaire
"Income and distance elasticities of values of travel time savings: New Swiss results."
Transport Policy, pp. 173 - 185, 2008.

B. de Keizer and K.T. Geurs and G.H. Haarsman
"Interchanges in timetable design of railways: A closer look at customer resistance to interchange between trains."
Proceedings of the European Transport Conference, Glasgow, 8-10 October 2012 (online).

T. Robenek, S. S. Azadeh, J. Chen, M. Bierlaire and Y. Maknoon
"The Ideal Train Timetabling Problem."
Proceedings of the 6th International Conference on Railway Operations Modelling and Analysis, 2015.

Small, Kenneth A.
"The Scheduling of Consumer Activities: Work Trips."
The American Economic Review, pp. 467-4797, 1982.

Mark Wardman
"Public transport values of time."
Transport Policy, pp. 363 - 377, 2004.

Decision Variables I

- $\mathcal{C}_i^t$ – the total cost of a passenger with ideal time t between OD pair i
- w_i^t – the total waiting time of a passenger with ideal time t between OD pair i
- x_i^{tp} – 1 – if passenger with ideal time t between OD pair i chooses path p; 0 – otherwise
- s_i^t – the value of the scheduled delay of a passenger with ideal time t between OD pair i
- d_v^l – the departure time of a train v on the line l (from its first station)

Decision Variables II

y_i^{tplv} – 1 – if a passenger with ideal time t between OD pair i on the path p takes the train v on the line l; 0 – otherwise

z_v^l – dummy variable to help modeling the cyclicity corresponding to a train v on the line l

o_{vg}^l – train occupation of a train v of the line l on a segment g

u_v^l – number of train units of a train v on the line l

α_v^l – 1 – if a train v on the line l is being operated; 0 – otherwise

Model

$$\max\left(\textit{revenue} - \textit{cost}\right) \tag{1}$$

$$\textit{passenger cost} \leq \epsilon \tag{2}$$

$$\textit{cost function} \tag{3}$$

$$\textit{everyone gets served} \tag{4}$$

$$\textit{everyone gets one train of a line in the path} \tag{5}$$

$$\textit{cyclicity} \tag{6}$$

$$\textit{train scheduling} \tag{7}$$

$$\textit{train capacity} \tag{8}$$

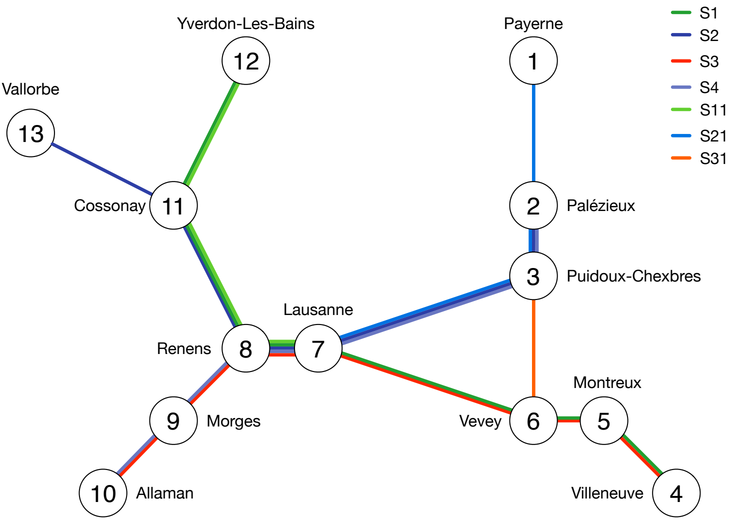
$$\textit{scheduled delay} \tag{9}$$

$$\textit{waiting time} \tag{10}$$

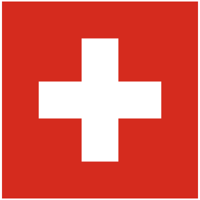
Case Study – Switzerland

[0]source: www.myswitzerland.com

S-Train Network Canton Vaud, Switzerland



SBB 2014 (5 a.m. to 9 a.m.)



- OD Matrix based on observation and SBB annual report
- 13 Stations
- 156 ODs
- 14 (unidirectional) lines
- 49 trains
- Min. transfer – 4 mins
- VOT – 27.81 CHF per hour

Current Timetable (Morning Peak)

Line	ID	From	To	Departures			
S1	1	Yverdon-les-Bains	Villeneuve	–	6:19	7:19	8:19
	2	Villeneuve	Yverdon-les-Bains	5:24	6:24	7:24	8:24
S2	3	Vallorbe	Palézieux	5:43	6:43	7:43	8:43
	4	Palézieux	Vallorbe	–	6:08	7:08	8:08
S3	5	Allaman	Villeneuve	–	6:08	7:08	8:08
	6	Villeneuve	Allaman	–	6:53	7:53	8:53
S4	7	Allaman	Palézieux	5:41	6:41	7:41	8:41
	8	Palézieux	Allaman	–	6:35	7:35	8:35
S11	9	Yverdon-les-Bains	Lausanne	5:26*	6:34	7:34	8:34
	10	Lausanne	Yverdon-les-Bains	5:55	6:55	7:55	8:55
S21	11	Payerne	Lausanne	5:39	6:39	7:38*	8:39
	12	Lausanne	Payerne	5:24	6:24	7:24	8:24
S31	13	Vevey	Puidoux-Chexbres	–	6:09	7:09	8:09
	14	Puidoux-Chexbres	Vevey	–	6:31*	7:36	8:36

Results I

ϵ [%]	0	20	40	60	80	100
profit [CHF]	175 185	175 180	175 108	172 630	155 554	146 099
cost [CHF]	290 094	261 713	233 334	204 955	176 576	148 197
lb [CHF]	175 711	175 711	175 711	175 711	175 711	132 489
gap [%]	0.30	0.30	0.34	1.78	12.96	10.60
gap [CHF]	526	531	603	3 081	20 157	15 708
time [s]	7 200	7 200	7 200	7 200	7 200	7 200
drivers [-]	36	36	36	39	47	48
rolling stock [-]	64	64	64	65	79	84

Table : *Computational results of the current model*

ϵ [%]	0	20	40	60	80	100
profit [CHF]	175 185	175 180	175 108	172 630	155 554	144 492
cost [CHF]	290 094	261 713	233 334	204 955	176 576	138 140
lb [CHF]	176 543	176 543	176 543	176 543	176 543	99 153
gap [%]	0.78	0.78	0.82	2.27	13.49	28.22
gap [CHF]	1 358	1 363	1 435	3 913	20 989	38 987
time [s]	7 200	7 200	7 200	7 200	7 200	7 200
drivers [-]	36	36	36	39	47	48
rolling stock [-]	64	64	64	65	79	87

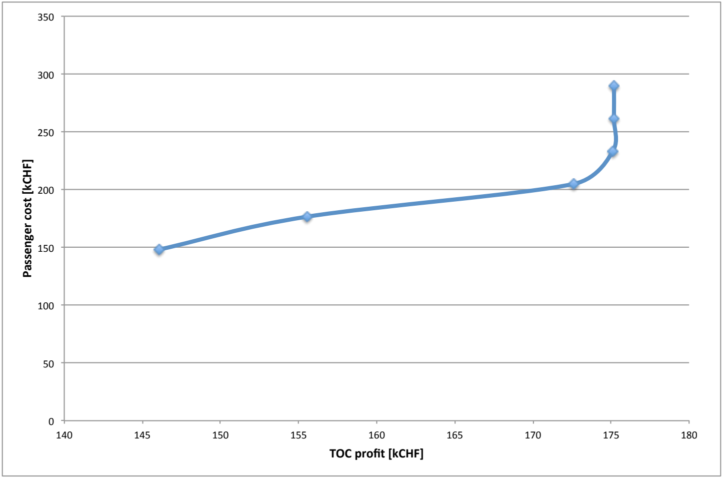
Table : *Computational results of the cylic model*

Results II

ϵ [%]	0	20	40	60	80	100
profit [CHF]	175 185	175 180	175 108	172 630	155 590	144 971
cost [CHF]	290 094	261 713	233 334	204 955	176 576	135 455
lb [CHF]	176 543	176 543	176 543	176 543	176 543	97 706
gap [%]	0.78	0.78	0.82	2.27	13.47	27.87
gap [CHF]	1 358	1 363	1 435	3 913	20 953	37 749
time [s]	7 200	7 200	7 200	7 200	7 200	7 200
drivers [-]	36	36	36	39	47	47
rolling stock [-]	64	64	64	65	79	85

Table : *Computational results of the non-cylic model*

Pareto Frontier



Scheduled Delay

	Current			Cyclic			Non-Cyclic		
SD	half	original	double	half	original	double	half	original	double
profit [CHF]	140 358	146 099	149 155	140 176	144 492	145 335	139 848	144 971	146 013
cost [CHF]	135 596	148 197	169 893	124 431	138 140	163 557	122 132	135 455	158 772
lb [CHF]	119 997	132 489	155 604	98 396	99 153	100 395	97 504	97 706	98 009
gap [%]	11.50	10.60	8.41	20.93	28.22	38. 62	20.17	27.87	38.27
gap [CHF]	15 599	15 708	14 289	26 045	38 987	63 162	24 628	37 749	60 763
time [s]	7 200	7 200	7 200	7 200	7 200	7 200	7 200	7 200	7 200
drivers [-]	48	48	47	48	48	48	48	47	47
rolling stock [-]	96	84	81	96	87	84	96	85	82

Issues

- Uniform OD flows
- Uncongested scenario

Conclusions and Future Work

Conclusions

- We formulate the ITTP problem
  - max profit or min pax cost
  - cyclic or non-cyclic timetables
  - pax flows (connections)
- For a non-congested network with uniform flows – cyclic timetable is better

Future Work

- Heuristics
- Full day
- Full comparison of cyclic vs. non-cyclic timetable

Thank you for your attention.

[0]source: www.laiaprats.com