Train Timetabling – New Approach

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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)	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

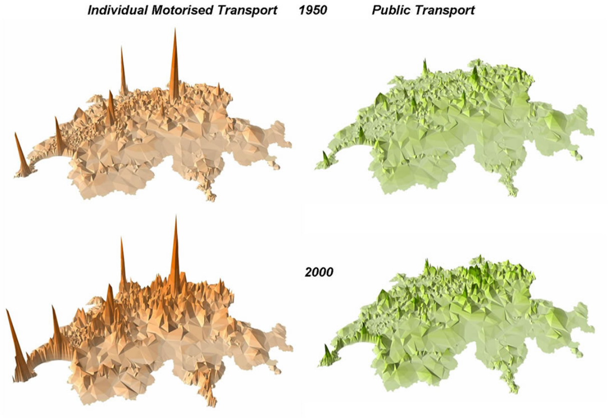


Figure : Mobility evolution in Switzerland[1]

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

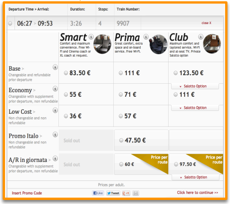
Private Sector

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 measure quality of a timetable!

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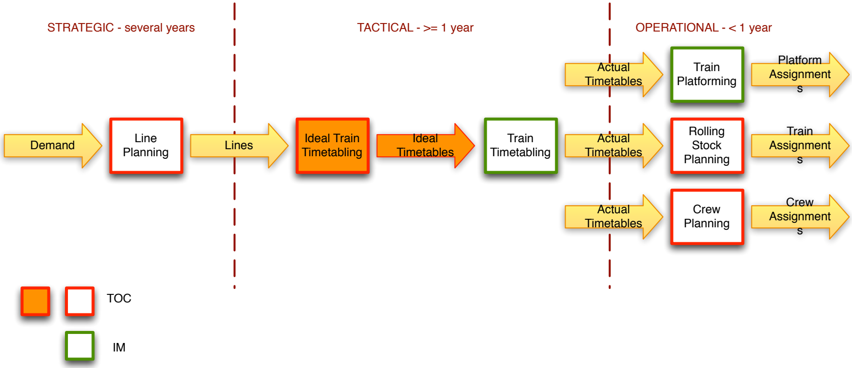
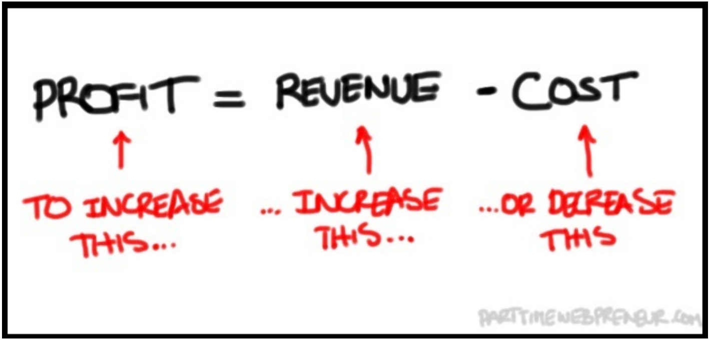
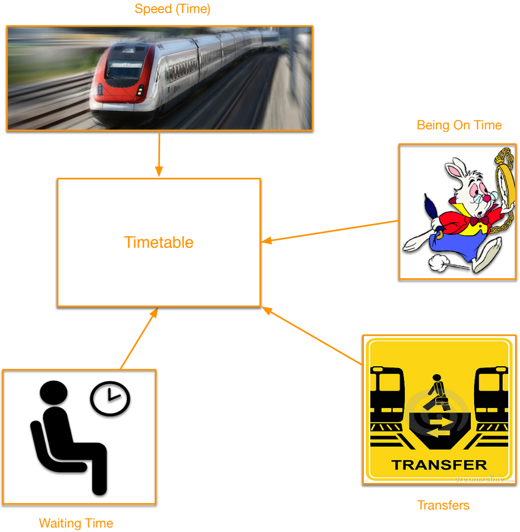
Update of Planning



TOC Point of View



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)

Routing Model

$$\max\left(revenue - cost\right) - \sum_{i \in I}\sum_{t \in T_i} D_i^t \cdot \mathcal{C}_i^t \tag{1}$$

$$\sum_{p \in P_i} x_i^{tp} = 1, \qquad \forall i \in I, \forall t \in T_i, \tag{2}$$

$$\sum_{v \in V^l} y_i^{tplv} = 1, \qquad \forall i \in I, \forall t \in T_i, \forall p \in P_i, \forall l \in L^p, \tag{3}$$

$$\left(d_v^l - d_{v-1}^l\right) = c \cdot z_v^l, \qquad \forall l \in L, \forall v \in V^l : v > 1, \tag{4}$$

$$\mathcal{C}_i^t \geq 0, \qquad \forall i \in I, \forall t \in T_i, \tag{5}$$

$$d_v^l \geq 0, \qquad \forall l \in L, \forall v \in V^l, \tag{6}$$

$$x_i^{tp} \in (0,1), \qquad \forall i \in I, \forall t \in T_i, \forall p \in P_i, \tag{7}$$

$$y_i^{tplv} \in (0,1), \qquad \forall i \in I, \forall t \in T_i, \forall p \in P_i, \forall l \in L^p, \forall v \in V^l, \tag{8}$$

$$z_v^l \in \mathbb{N}, \qquad \forall l \in L, \forall v \in V^l. \tag{9}$$

Train Capacity

$$u_{v_1}^{l_1} = \sum_{i \in I} \sum_{t \in T_i} \left(\sum_{p \in P_i} \sum_{l_2 \in L^p : l_2 = l_1} \sum_{v_2 \in V^{l_2} : v_2 = v_1} y_i^{tpl_2 v_2} \right) \cdot D_i^t, \qquad \forall l_1 \in L, \forall v_1 \in V^{l_1}, \tag{10}$$

$$cap \cdot b_v^l \geq u_v^l, \qquad \forall l \in L, \forall v \in V^l, \tag{11}$$

$$u_v^l \geq 0, \qquad \forall l \in L, \forall v \in V^l, \tag{12}$$

$$b_v^l \in \mathbb{N}, \qquad \forall l \in L, \forall v \in V^l, \tag{13}$$

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Defining Passenger Cost

$$\mathcal{C}_i^t = \beta \cdot w_i^t + \gamma \cdot \sum_{p \in P} x_i^{tp} \cdot (|L^p| - 1) + \alpha \cdot \sum_{p \in P} \sum_{l \in L^p} r_i^{pl} \cdot x_i^{tp} + s_i^t, \qquad \forall i \in I, \forall t \in T_i. \tag{14}$$

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Scheduled Delay

$$s_i^t \geq s_i^{tp} - M \cdot \left(1 - x_i^{tp}\right), \qquad \forall i \in I, \forall t \in T_i, \forall p \in P_i, \tag{15}$$

$$\begin{aligned} s_i^{tp} \geq \eta \cdot \left(\left(d_v^{|L^p|} + h_i^{|L^p|} + r_i^{p|L^p|}\right) - t\right) & \\ -M \cdot \left(1 - y_i^{tp|L^p|v}\right), & \qquad \forall i \in I, \forall t \in T_i, \forall p \in P_i, \forall v \in V^{|L^p|}, \end{aligned} \tag{16}$$

$$\begin{aligned} s_i^{tp} \geq \epsilon \cdot \left(t - \left(d_v^{|L^p|} + h_i^{|L^p|} + r_i^{p|L^p|}\right)\right) & \\ -M \cdot \left(1 - y_i^{tp|L^p|v}\right), & \qquad \forall i \in I, \forall t \in T_i, \forall p \in P_i, \forall v \in V^{|L^p|}, \end{aligned} \tag{17}$$

$$s_i^t \geq 0, \qquad \forall i \in I, \forall t \in T_i, \tag{18}$$

$$s_i^{tp} \geq 0, \qquad \forall i \in I, \forall t \in T_i, \forall p \in P_i. \tag{19}$$

Waiting Time

$$
\begin{aligned}
w_i^t &\geq w_i^{tp} - M \cdot \left(1 - x_i^{tp}\right), && \forall i \in I, \forall t \in T_i, \forall p \in P_i, && (20)\\
w_i^{tp} &= \sum_{l \in L^p \setminus 1} w_i^{tpl}, && \forall i \in I, \forall t \in T_i, \forall p \in P_i, && (21)\\
w_i^{tpl} &\geq \left(\left(d_v^l + h_i^{pl}\right) - \left(d_{v'}^{l'} + h_i^{pl'} + r_i^{pl'} + m\right)\right) && \forall i \in I, \forall t \in T_i, \forall p \in P_i, \forall l \in L^p : && \\
&\quad - M \cdot \left(1 - y_i^{tpl'v'}\right) - M \cdot \left(1 - y_i^{tplv}\right), && l > 1, l' = l - 1, \forall v \in V^l, \forall v' \in V^{l'}, && (22)\\
w_i^{tpl} &\leq \left(\left(d_v^l + h_i^{pl}\right) - \left(d_{v'}^{l'} + h_i^{pl'} + r_i^{pl'} + m\right)\right) && \forall i \in I, \forall t \in T_i, \forall p \in P_i, \forall l \in L^p : && \\
&\quad + M \cdot \left(1 - y_i^{tpl'v'}\right) + M \cdot \left(1 - y_i^{tplv}\right), && l > 1, l' = l - 1, \forall v \in V^l, \forall v' \in V^{l'}, && (23)\\
w_i^t &\geq 0, && \forall i \in I, \forall t \in T_i, && (24)\\
w_i^{tp} &\geq 0, && \forall i \in I, \forall t \in T_i, \forall p \in P_i, && (25)\\
w_i^{tpl} &\geq 0, && \forall i \in I, \forall t \in T_i, \forall p \in P_i, \forall l \in L^p. && (26)
\end{aligned}
$$

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Breaking the symmetry

Cyclic

$$
\begin{aligned}
d_v^l - d_{v-1}^l = z_v^{l1} \cdot 60 + z_v^{l2} \cdot 120, \qquad & \forall l \in L, \forall v \in V : v > 1, \\
z_v^{l1} + z_v^{l2} = 1, \qquad & \forall l \in L, \forall v \in V : v > 1,
\end{aligned}
$$

Non-Cyclic

$$
d_v^l < d_{v+1}^l, \qquad \forall l \in L, \forall v \in V : v < V,
$$

Case Study – Canton Vaud, Switzerland

[0] source: www.myswitzerland.com

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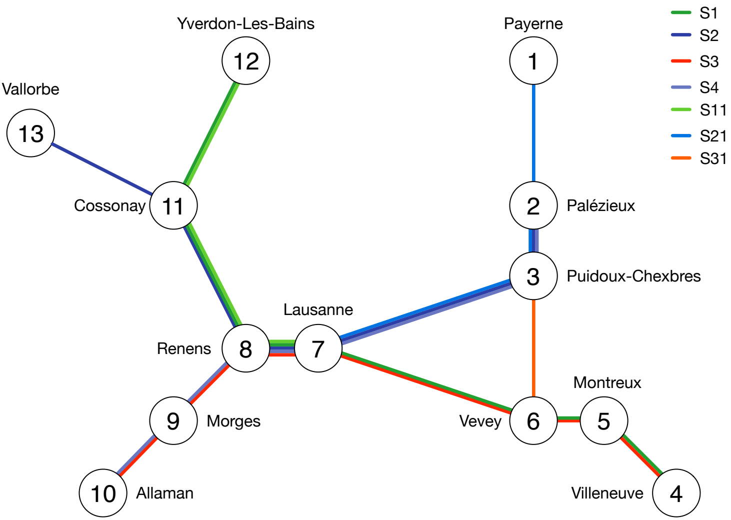
S-Train Network

Réseau Express Régional Vaud.

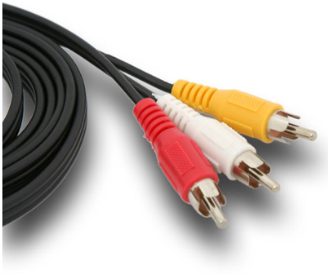
Reduced Network



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

General Inputs



- $\alpha = 27.81$ CHF/hour
- $\beta = 2.5 \cdot \alpha$
- $\gamma = \alpha/6 = 4.635$ CHF
- $\epsilon = 0.5 \cdot \alpha$
- $\eta = \alpha$
- minimum transfer = 4 min

RABe 523 — FLIRT

- 180 seats
- 200 standing
- op. expenses per train/km = 30.4 CHF

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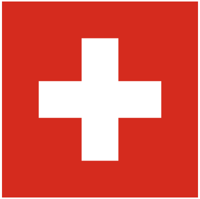
Demographics



cca 8 million inhabitants

cca 750'000 inhabitants

Demographics

- on average 1 million passenger journeys per day in 2013 in CH
- from previous slide – Canton Vaud cca $1/10$ of Switzerland $\rightarrow$ 100'000 Passenger Journeys

- 5 to 6 – 1'000 PJ
- 6 to 7 – 6'000 PJ
- 7 to 8 – 14'000 PJ
- 8 to 9 – 8'000 PJ

- Passenger Flow is a defined OD pair with a desired arrival time to a destination
- Lausanne gare S-trains : other trains ration = 40:60 %
- 1 000 PF multiplied by the size of the demand group → 11 000 PJ
  - 5 to 6 – 42 PF
  - 6 to 7 – 208 PF
  - 7 to 8 – 475 PF
  - 8 to 9 – 275 PF
- OD – uniform distribution F(13, 1, 14)
- Demand group – F(22, 1, 23)

Summary

- New planning Phase
- Multi – Objective:
  - Minimize Passenger Cost
  - Maximize TOC Profit
  - Pareto Frontier
- Can Produce Cyclic and Non-Cyclic Timetables

Thank you for your attention.