Evaluating the Quality of Railway Timetables

Tomáš Robenek Yousef Maknoon
Shadi Sharif Azadeh Michel Bierlaire

4th symposium of European Association for Research in Transportation
September 9 – 11, 2015

September 10, 2015

TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Supply x Demand

Figure : Calvin and Hobbes by Bill Watterson

Liberalisation – 01.01.2010

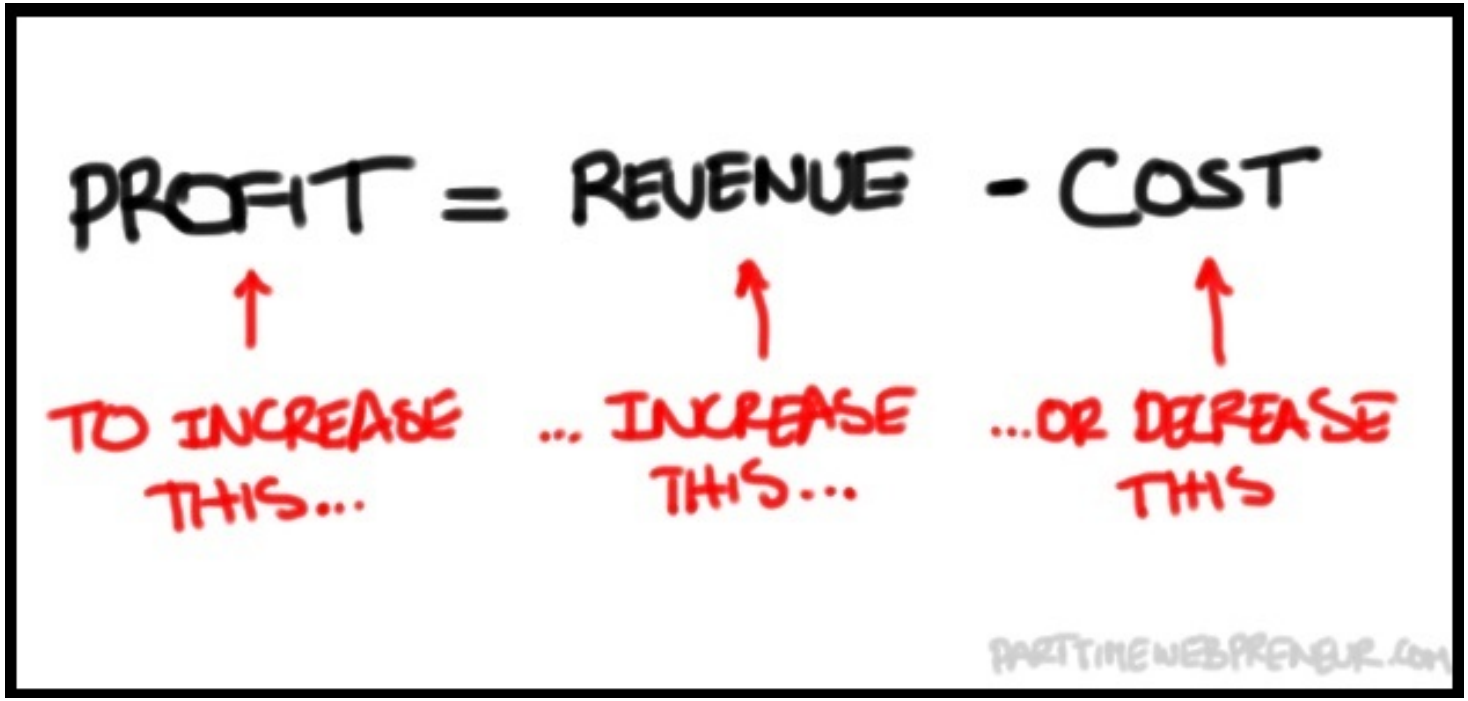
Purely commercial rail passenger services in Europe

	Market closed for commercial national rail passenger services.
	Open access, but no external RUs providing commercial national rail passenger services .
	Open access with external RUs providing commercial national rail passenger services.
	AT and CZ: commencing end of 2011, external RUs providing purely commercial national rail passenger services.

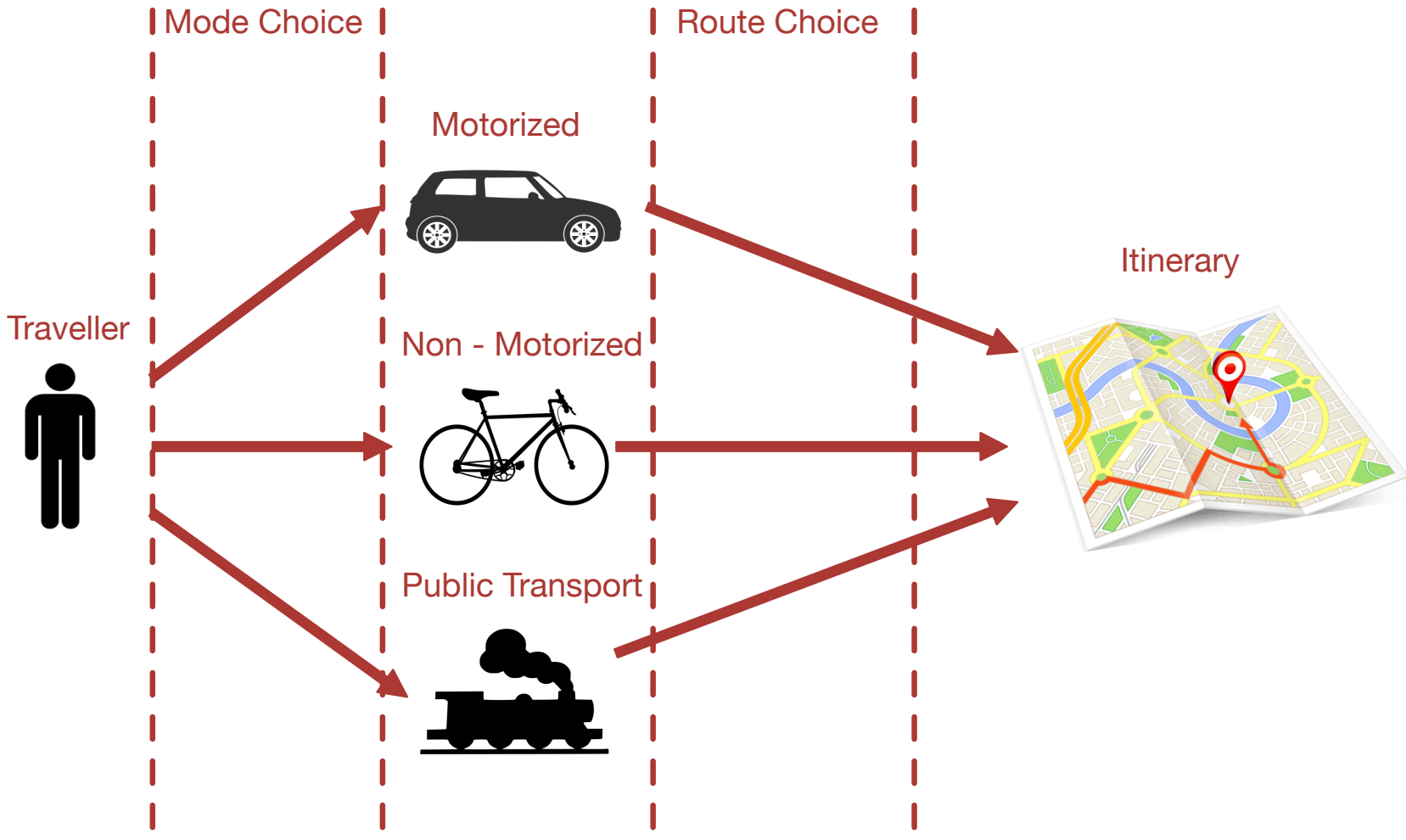
TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

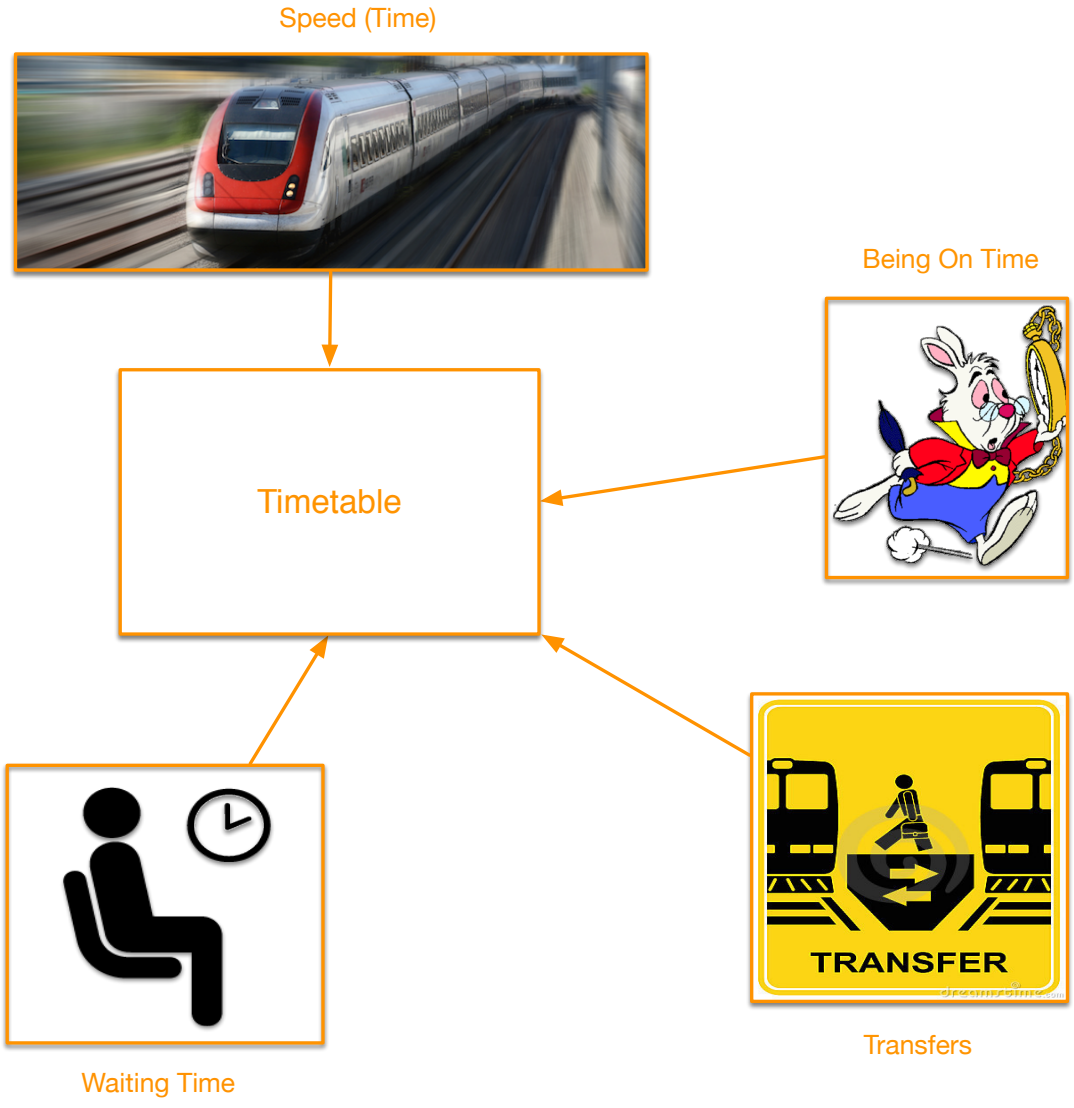
TOC Point of View



Transport Demand



Passenger Point of View



Passenger Satisfaction

Satisfaction of a passenger (i, t) for a given alternative/path p:

$$\mathcal{U}_i^t = -\sum_{\ell \in L^p} r_i^{p\ell} + \beta_W \cdot w_i^{tp} + \beta_T \cdot (|L^p| - 1) + \beta_E \cdot \delta_i^{tp} + \beta_L \cdot \gamma_i^{tp} \, [\text{min}]$$

where:

L^p	–	set of lines in path p
$r_i^{p\ell}$	–	in-vehicle-time of a train line ℓ
w_i^{tp}	–	total waiting time along path p
$\|L^p\|$	–	number of lines in path p
δ_i^{tp}	–	early scheduled delay
γ_i^{tp}	–	late scheduled delay

β_W	=	-2.5 (Wardman (2004))
β_T	=	-10 (de Keizer et al. (2012
β_E	=	-0.5 (Small (1982))
β_L	=	-1 (Small (1982))

Monetarization

We can mulitply the whole equation by the Value of Time:

$\beta_{time}/\beta_{value} = 27.81$ Chf/hour (Axhausen et al. (2008))

References

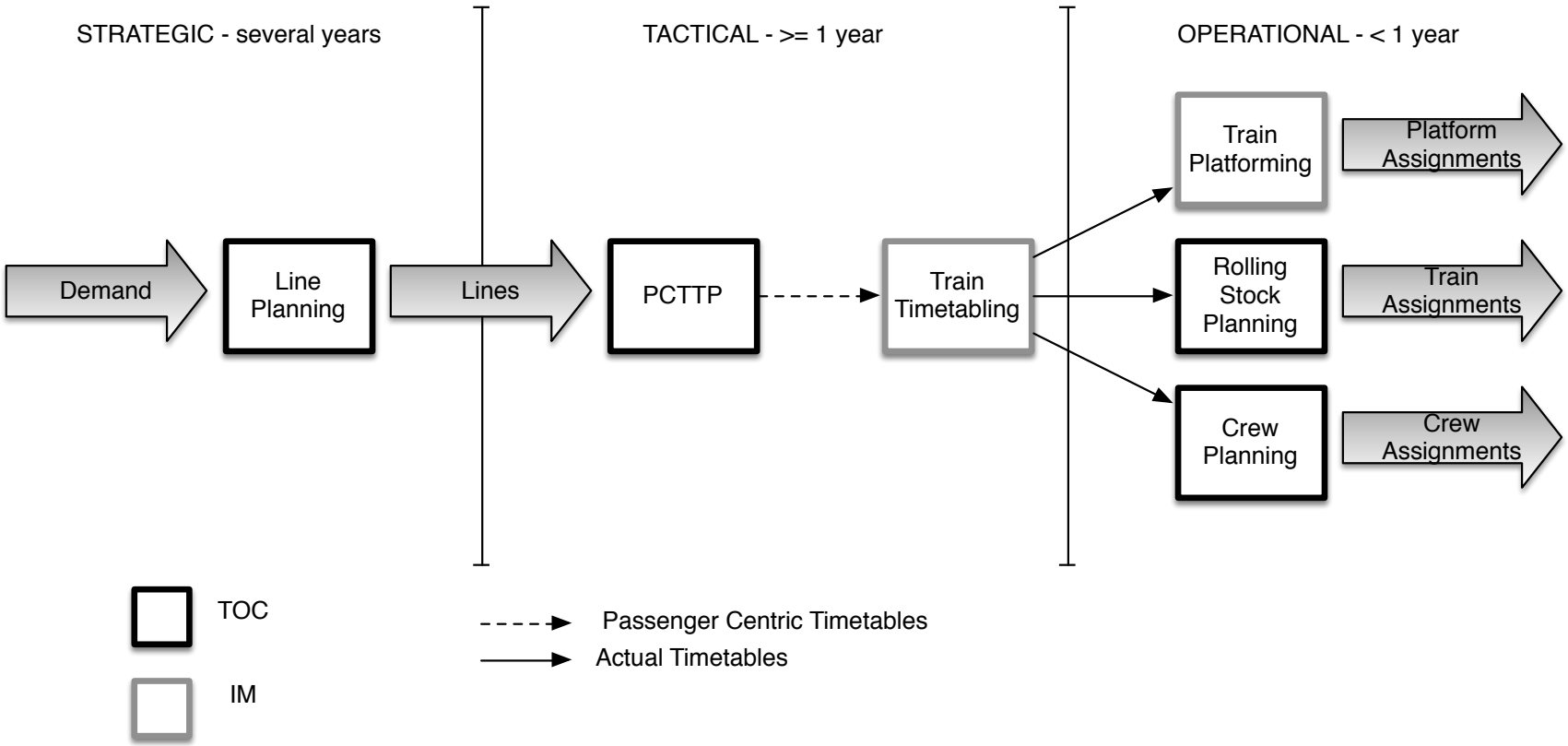
Axhausen, K. W., Hess, S., König, A., Abay, G., Bates, J. J. and Bierlaire, M. (2008). Income and distance elasticities of values of travel time savings: New Swiss results, *Transport Policy* **15**(3): 173 – 185.

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

Small, K. A. (1982). The Scheduling of Consumer Activities: Work Trips, *The American Economic Review* **72**(3): pp. 467–479.

Wardman, M. (2004). Public transport values of time, *Transport Policy* **11**(4): 363 – 377.

Update of Planning



Inputs

Passenger

- OD Matrix
- Desired arrival time to D
- All paths
- Behavior

Operator

- Network
- Fare structure
- Cost structure
- Rolling stock

Decision Variables I

- $\mathcal{U}_i^t$ – passenger satisfaction (utility)
- 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
- λ_i^t – the scheduled delay of a passenger (i, t)
- d_v^ℓ – the departure time of a train v on the line ℓ (from its first station)

Decision Variables II

$y_i^{tp\ell v}$ – 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

ω_{vs}^l – train occupation of a train v of the line ℓ on a segment s

μ_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

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

$$\textit{passenger satisfaction} \geq \varepsilon \tag{2}$$

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

$$\textit{at most one path per passenger} \tag{4}$$

$$\textit{link trains with paths} \tag{5}$$

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

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

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

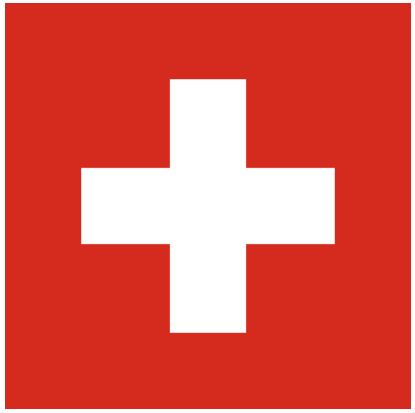
$$\textit{scheduled delay} \tag{9}$$

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

Case Study – Switzerland

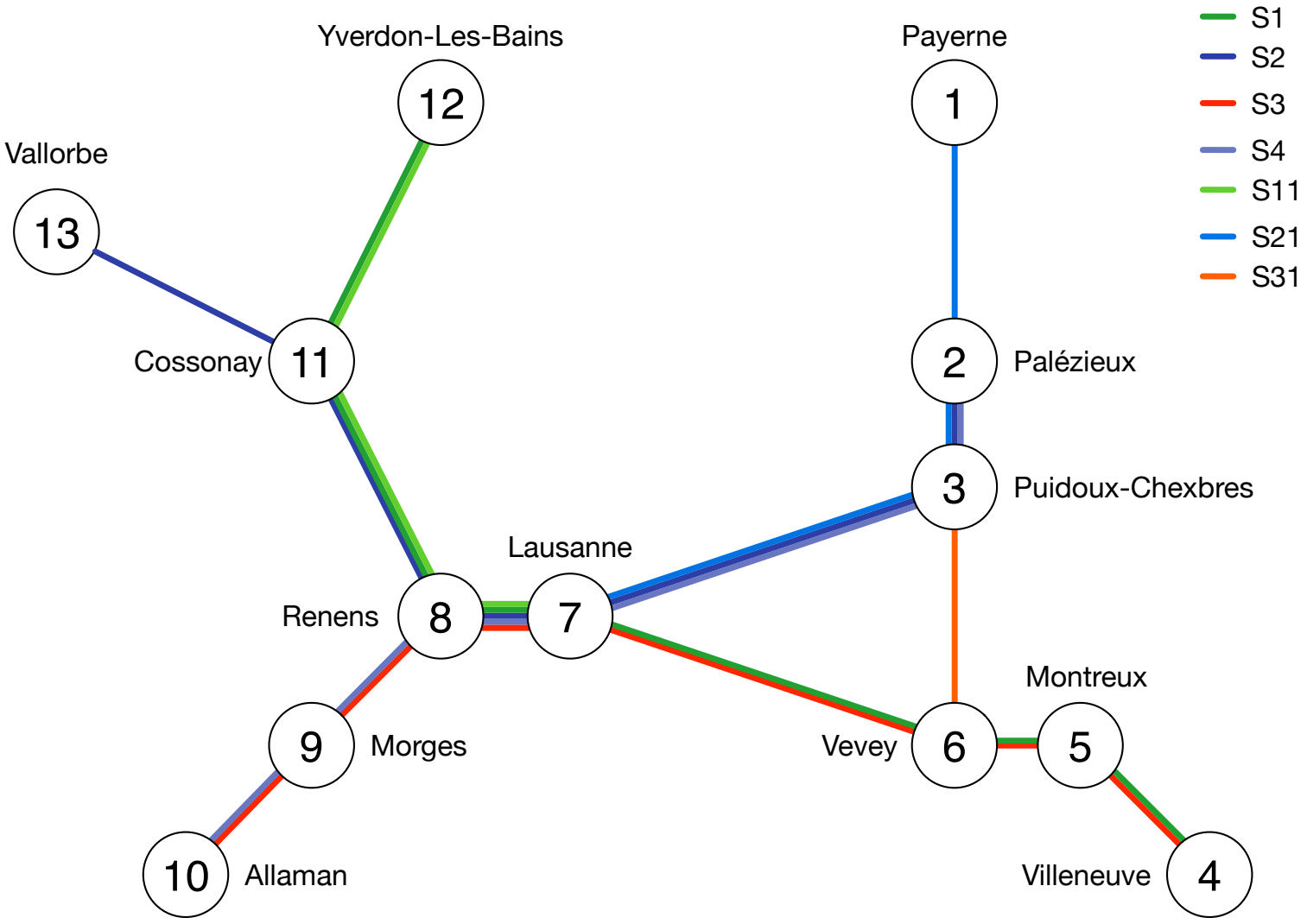
[0] source: www.myswitzerland.com

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
- 3 scenarios – SBB 2014, cyclic PCTTP, non-cyclic PCTTP

S-Train Network Canton Vaud, Switzerland



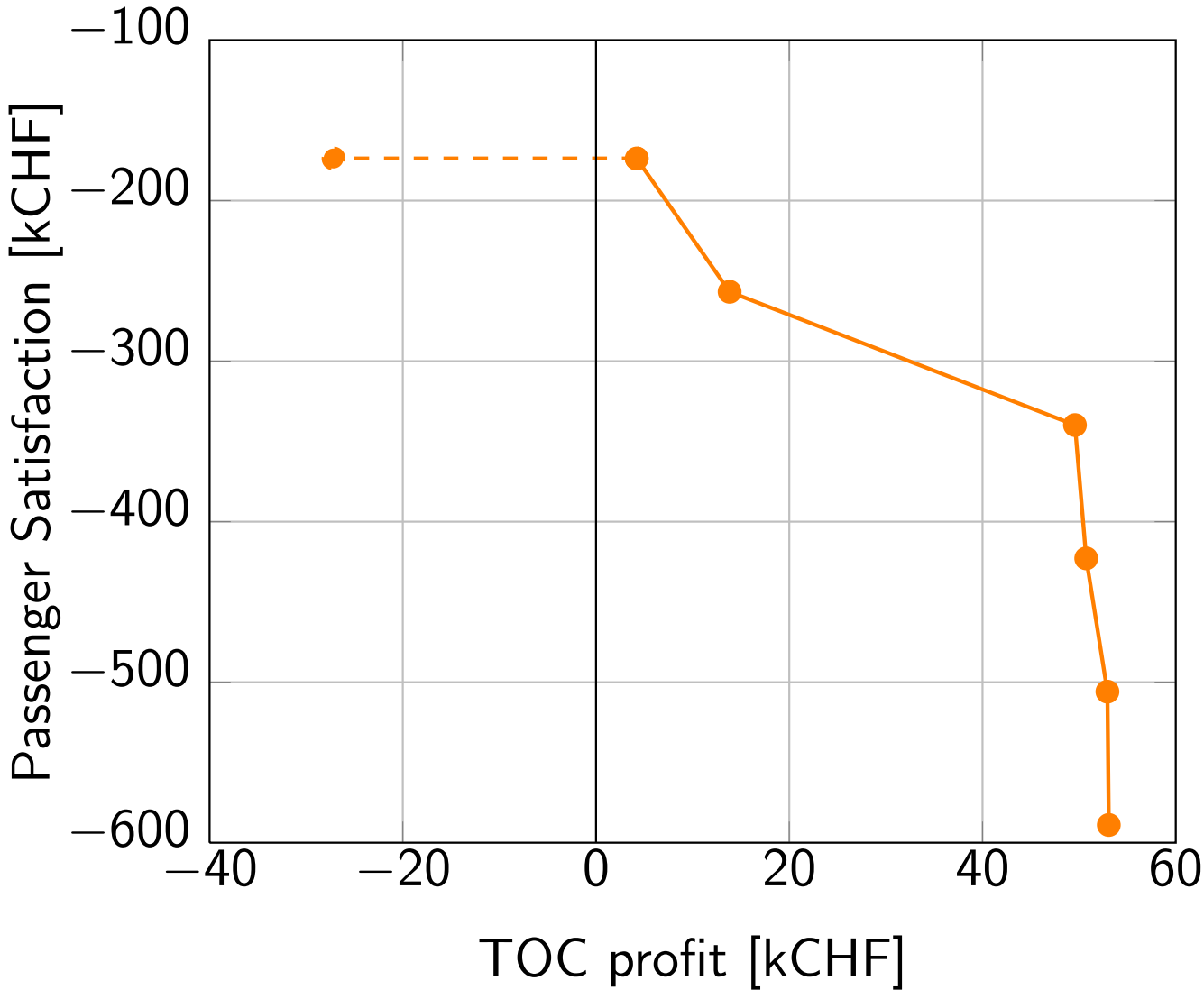
Current Timetable (Morning Peak)

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

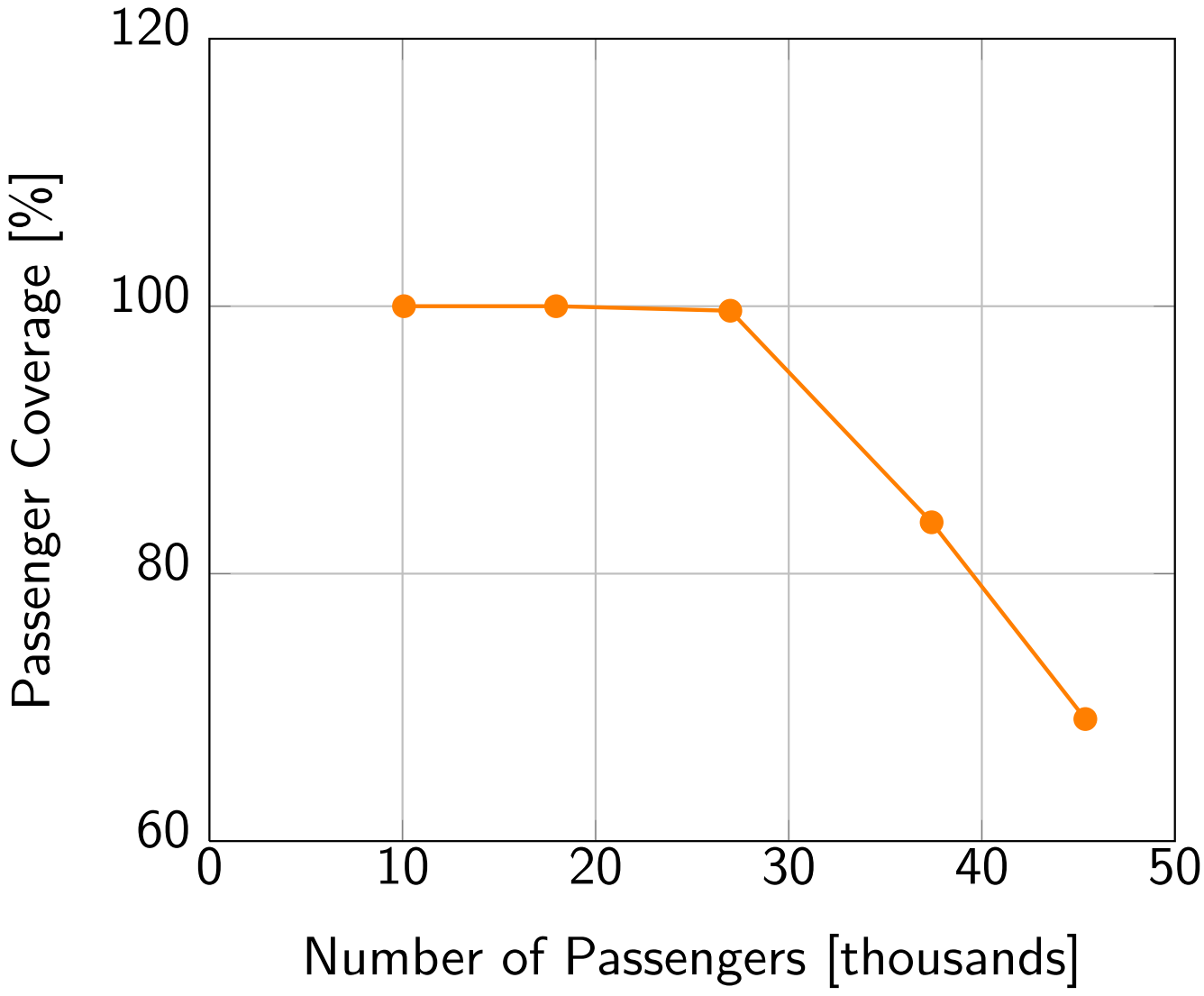
Results – Current Demand SBB 2014 (cca. 11 000 pax)

ε [%]	0	20	40	60	80	100	100*
profit [CHF]	53 067	52 926	50 730	49 564	13 826	4 211	-27 168
satisfaction [CHF]	-588 934	-505 899	-422 864	-339 828	-256 793	-173 759	-173 758
ub/lb [CHF]	54 046	54 598	54 776	54 394	54 600	51 195	168 016
gap [%]	1.84	3.16	7.98	9.74	294.91	1115.74	3.30
gap [CHF]	979	1 672	4 046	4 830	40 774	46 984	5 742
drivers [-]	17	17	22	22	46	48	49
rolling stock [-]	32	32	32	32	46	55	98
covered [%]	99.35	99.34	100.00	100.00	100.00	100.00	100.00

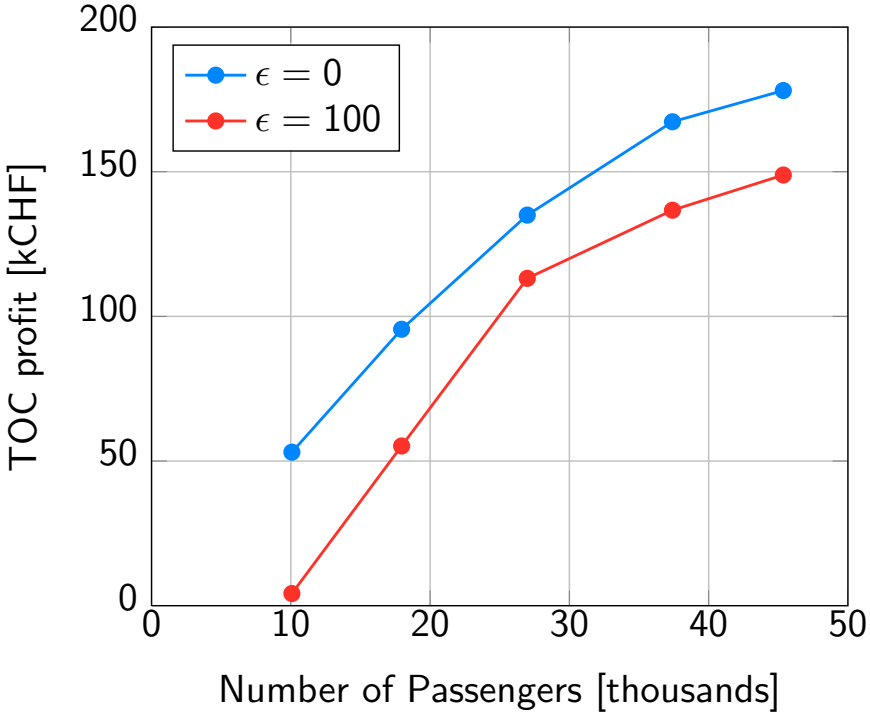
Pareto Frontier

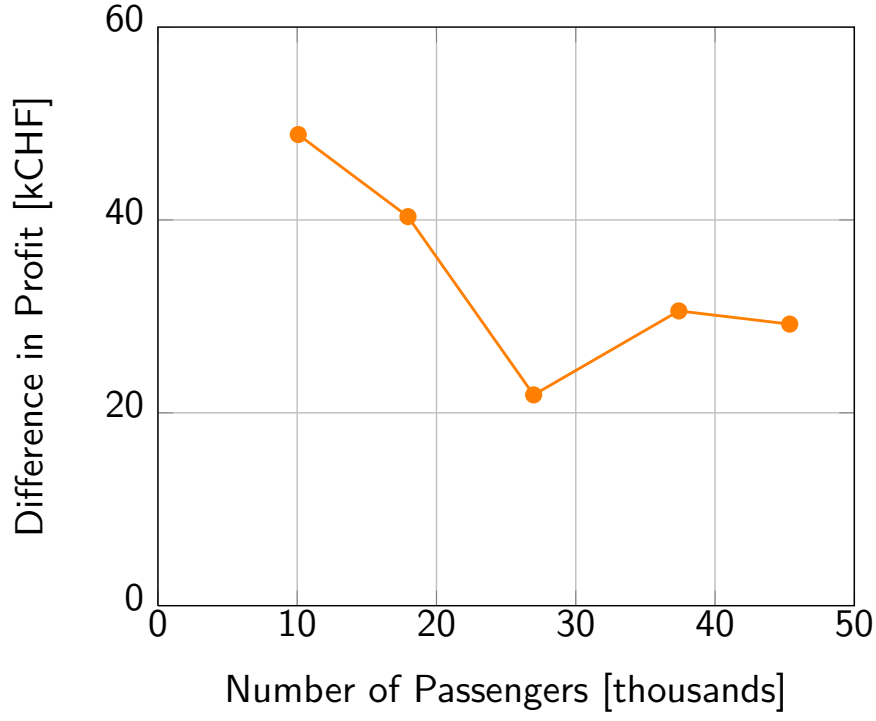


Sensitivity Analysis on Passenger Congestion

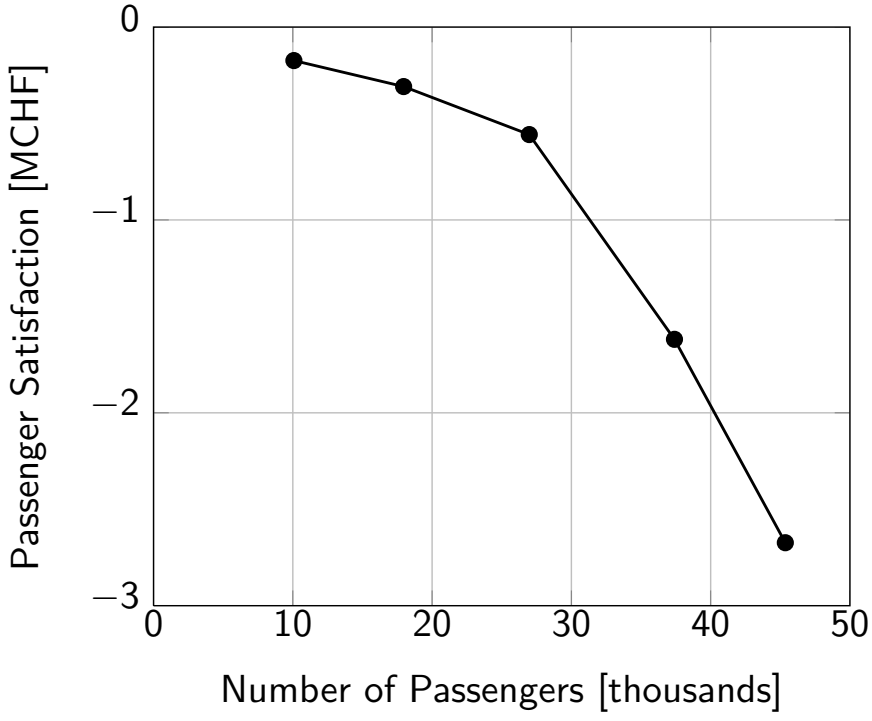


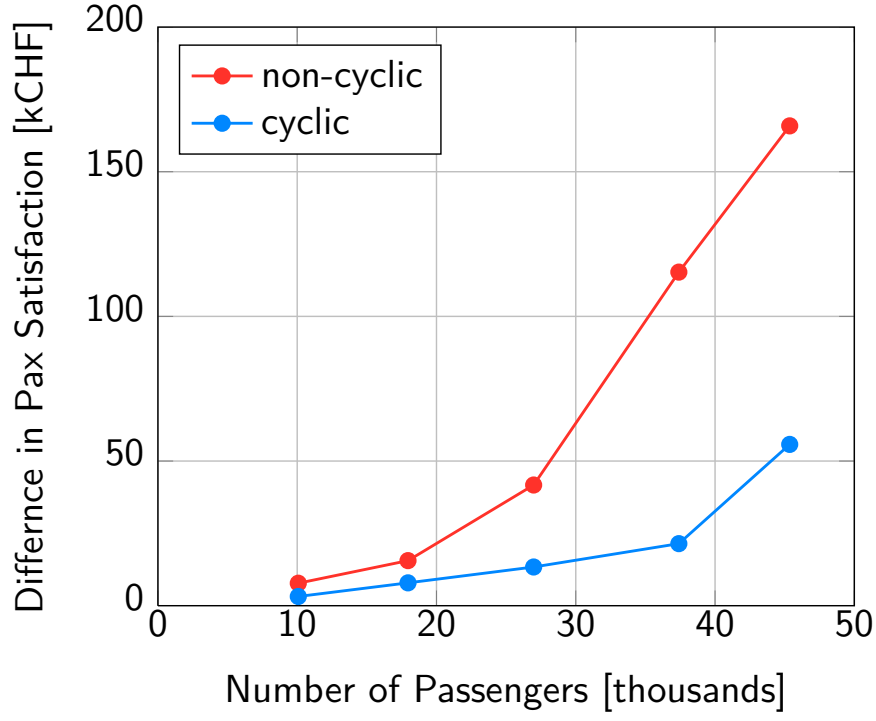
Sensitivity Analysis – Operator



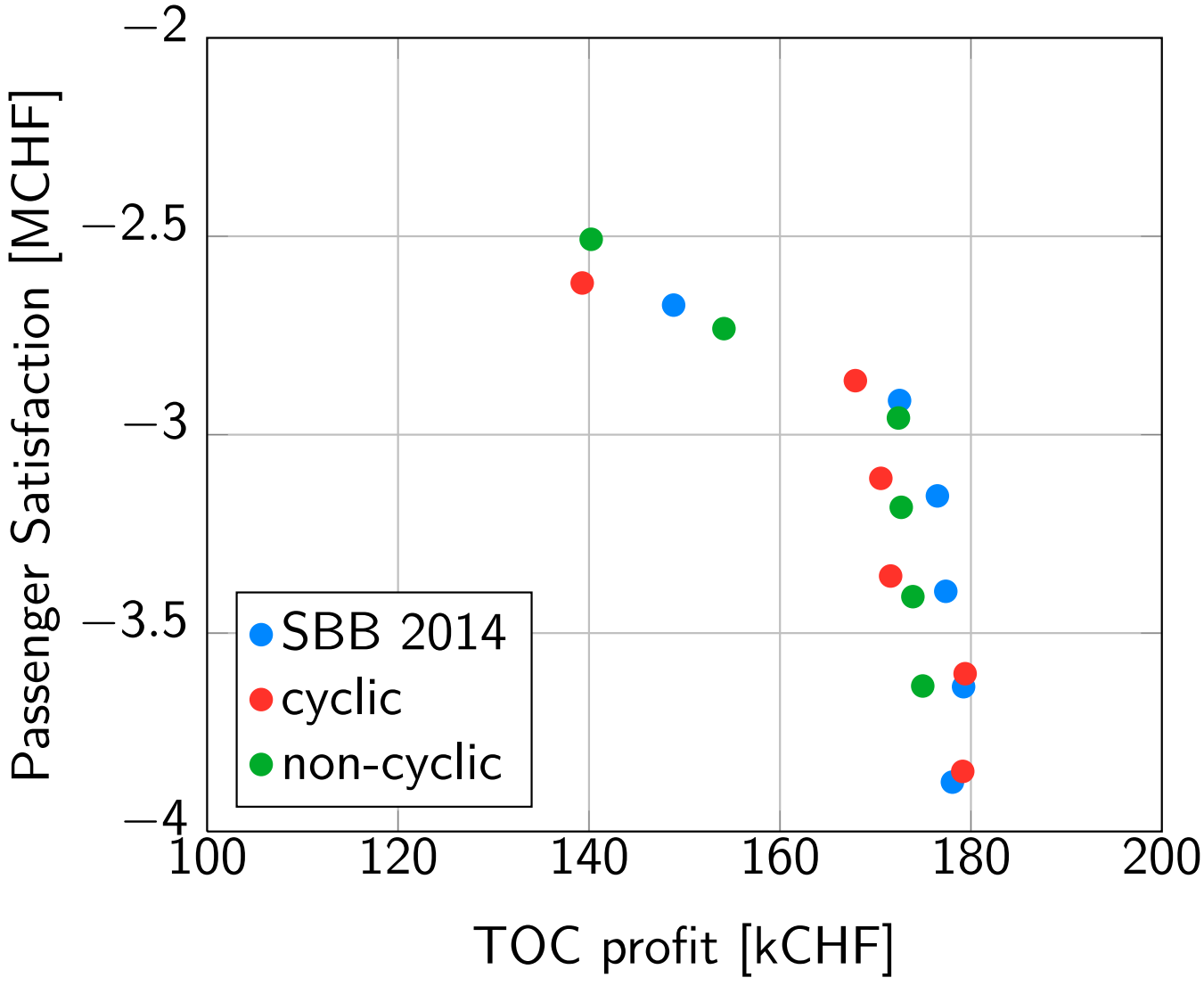


Sensitivity Analysis – Passenger





Sensitivity Analysis – Pareto Frontiers



Summary

- Current demand
  - cyclic timetable is by 3 000 CHF better than the SBB 2014 timetable
  - the non-cyclic timetable is by 4 000 CHF better than the cyclic timetable
- Most congested
  - cyclic timetable is by 55 000 CHF better than the SBB 2014 timetable
  - the non-cyclic timetable is by 110 000 CHF better than the cyclic timetable

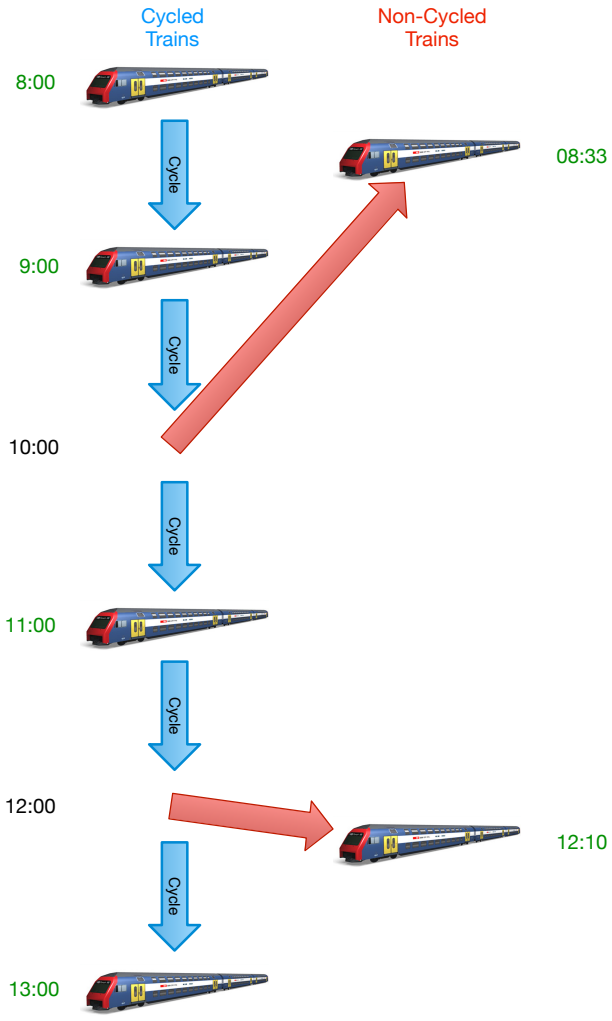
Conclusions

- It is possible to find a good trade-off between the operator and the passengers (around $\varepsilon = 40\%$)
- Even at $\varepsilon = 100\%$ the improvement is so large, that running this timetable with an increased ticket price can be justified
- The non-cyclic timetable is more flexible and can account better for high demand in high density network than the cyclic timetable

Future Work

- Heuristics to solve for a full day
- Estimate the cost of cyclicity

Cost of the Cyclicity



$$\mathcal{U}_i^t = \cdots + \beta_C \cdot \mathit{cyclic}$$

where:

cyclic	–	distance from cyclicity in %
β_C	–	cost of additional planning

$$\beta_C = \frac{27.81}{60/5} = 2.3175$$

Thank you for your attention.