Integrating Supply-Demand Relationship in the Design of Ideal Railway Timetables

Tomáš Robenek   Yousef Maknoon   Shadi Sharif Azadeh
Michel Bierlaire   Jianghang Chen

Decision-Aid Methodologies in Transportation

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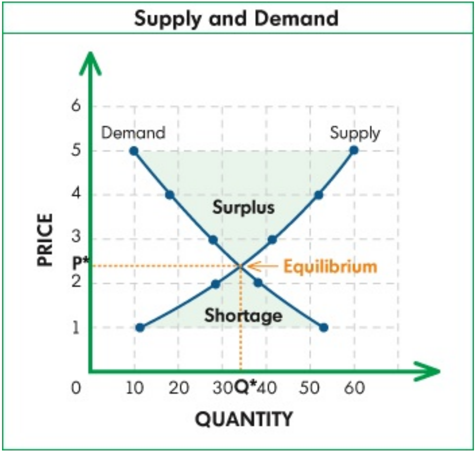
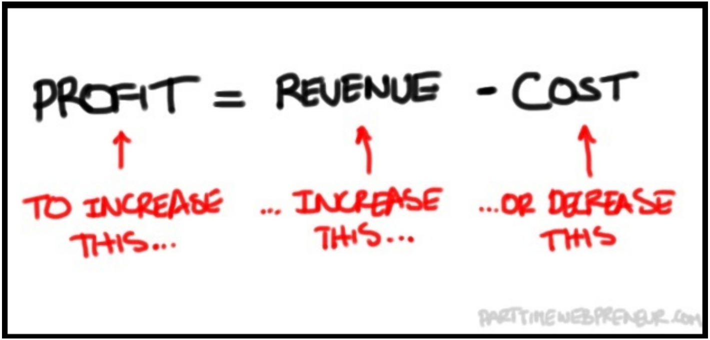
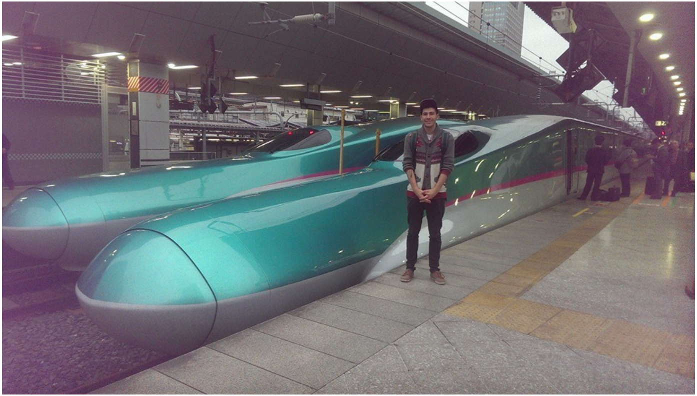
Economics 101



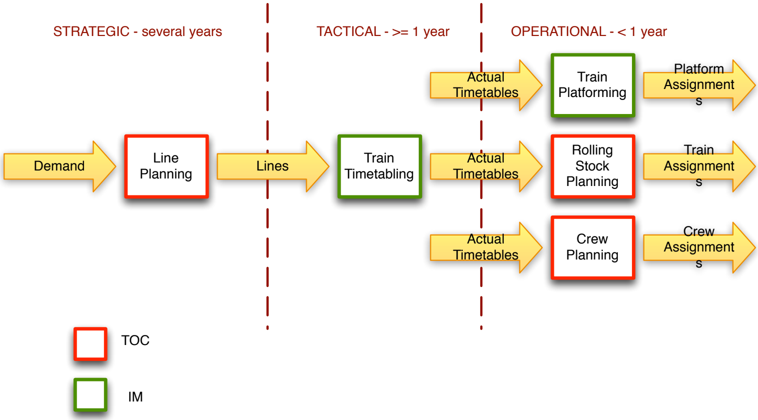
The Objective



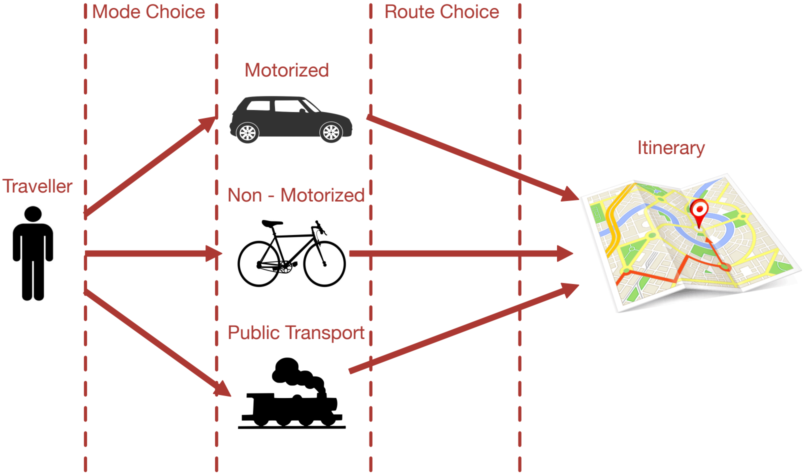
We Focus on Railway



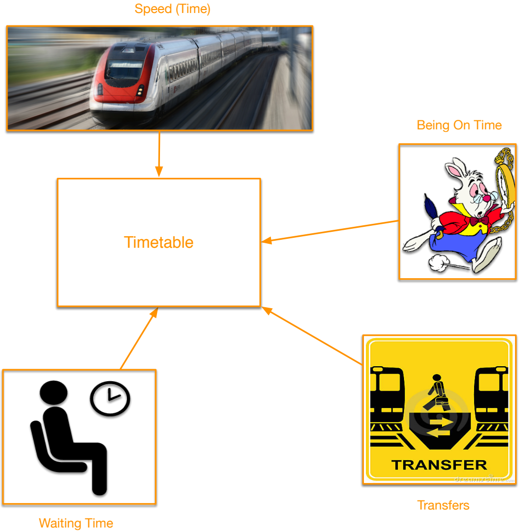
Supply Planning



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)

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

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

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

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

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

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

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

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

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

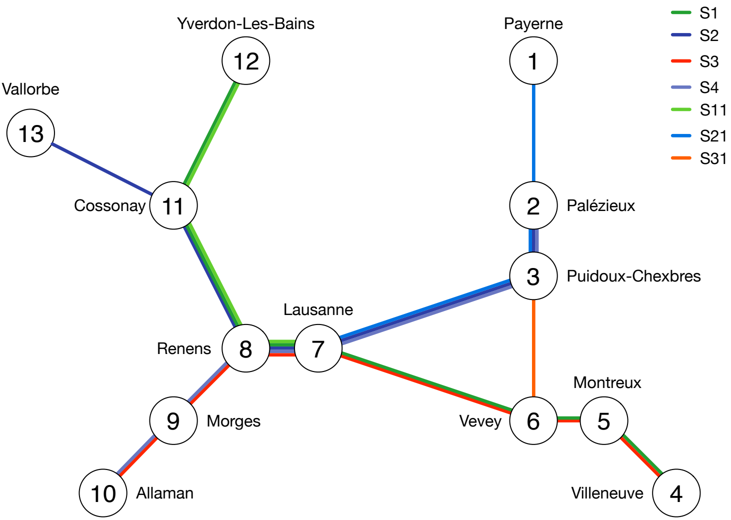
$$\textit{scheduled delay} \tag{9}$$

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

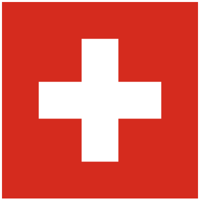
Case Study – Switzerland

[0]source: www.myswitzerland.com

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
- 3 models – current (SBB), cyclic (60 min cycle optimal), non-cyclic

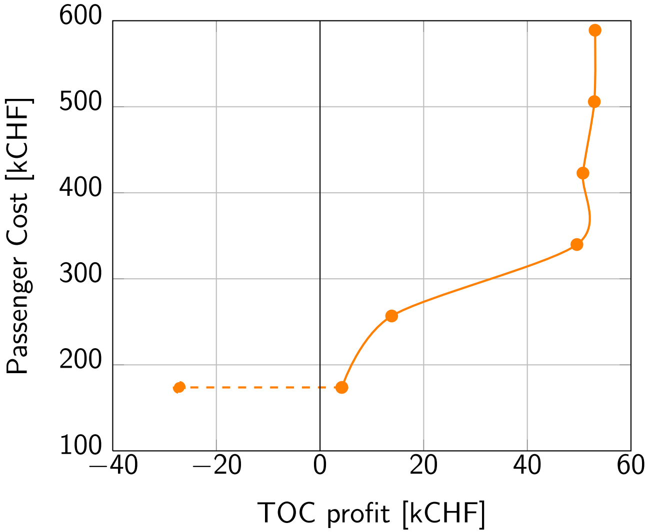
Current Timetable (Morning Peak)

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

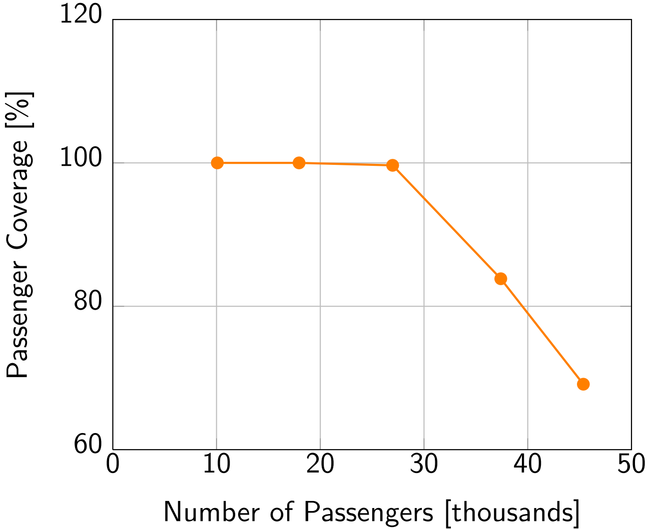
Results of the Current Model for the Base Case

ϵ [%]	0	20	40	60	80	100	100*
profit [CHF]	53 067	52 926	50 730	49 564	13 826	4 211	-27 168
cost [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

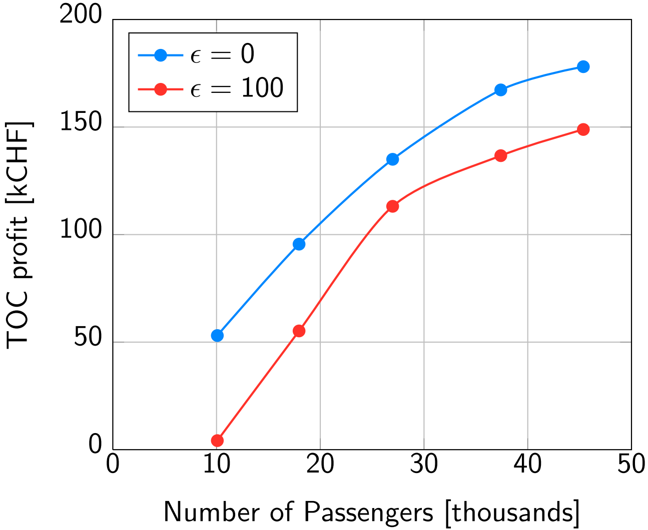
Pareto Frontier of the Current Model for the Base Case



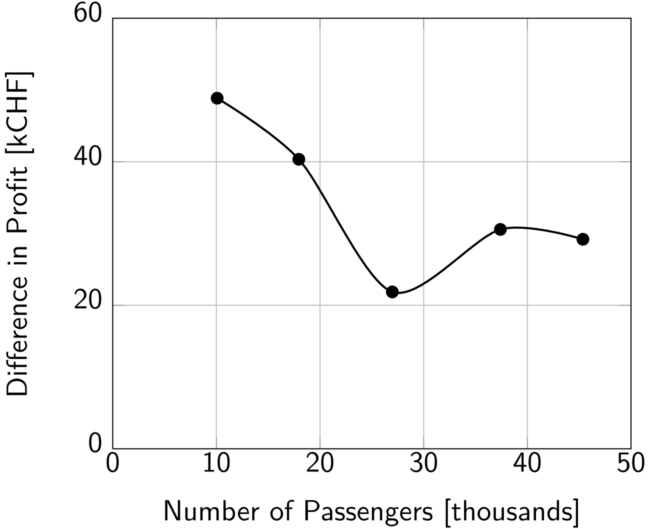
Passenger Congestion



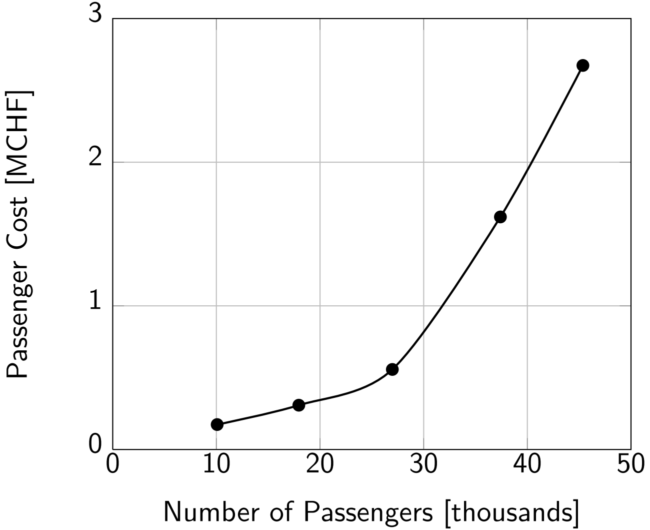
TOC Profit as a Function of the Demand



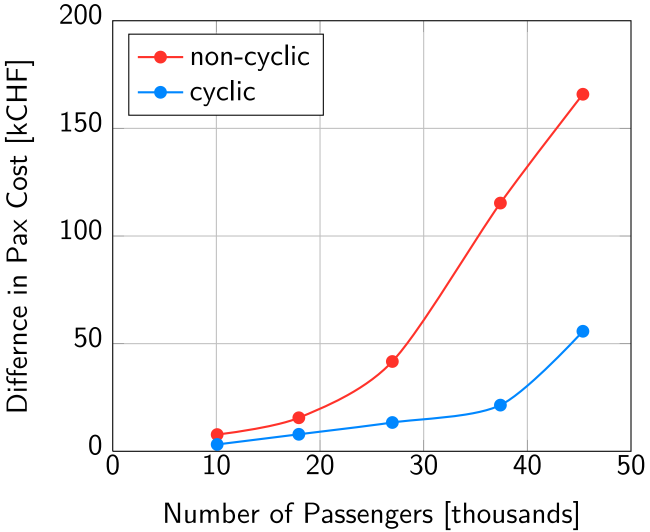
Difference in profit as a function of the demand for the current model



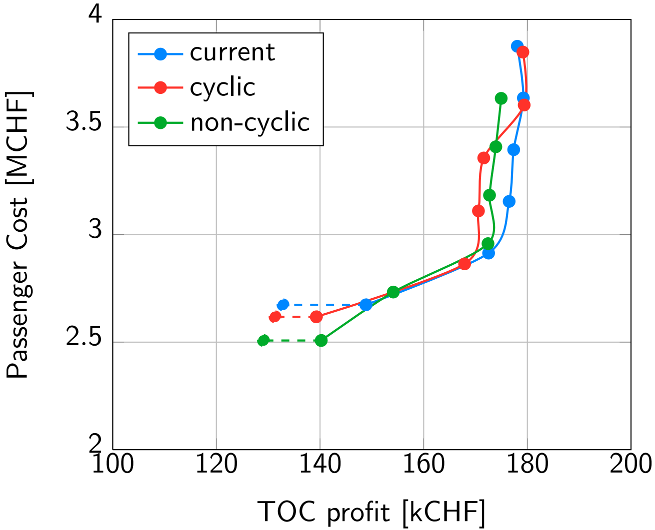
Passenger Cost as a Function of the Demand



Passenger Cost Difference as Compared to the Current Model



Pareto Frontiers of the Congested Case



Conclusions

- We formulate the ITTP problem
  - max profit or min pax cost
  - cyclic or non-cyclic timetables
  - pax flows (connections)
- TOC can choose the best trade-off between cost and profit
- Non-cyclic timetable is more flexible

Future Work

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

Thank you for your attention.