

Passenger-Centric Railway Operations

Michel Bierlaire Stefan Binder Yousef Maknoon Tomáš Robenek

Transport and Mobility Laboratory
School of Architecture, Civil and Environmental Engineering
Ecole Polytechnique Fédérale de Lausanne

May 19, 2015



Outline

- 1 Demand and supply
- 2 Measuring satisfaction
- 3 Ideal timetable
- 4 Disposition timetable
- 5 Conclusion

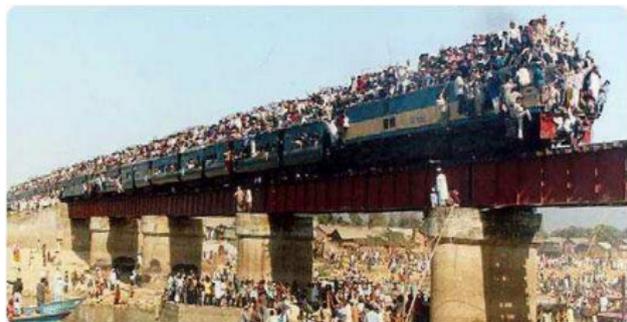


Demand models



- Supply = infrastructure
- Demand = behavior, choices
- Congestion = mismatch

Demand models



- Usually in OR:
- optimization of the supply
- for a given (fixed) demand

Demand-supply interactions

Operations Research

- Given the demand...
- configure the system

Behavioral models

- Given the configuration of the system...
- predict the demand

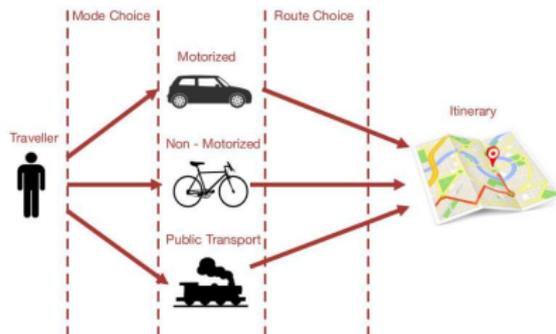
Johnson City Enterprise.
Published Every Saturday,
\$1. per year—Advance Payment.
SATURDAY, APRIL 7, 1883.

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.



Demand-supply interactions

Multi-objective optimization

Minimize costs



Maximize satisfaction

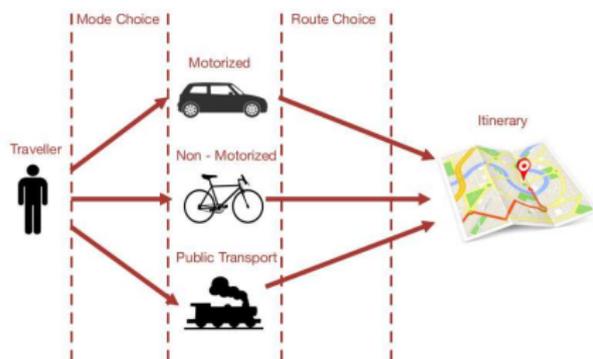


Outline

- 1 Demand and supply
- 2 Measuring satisfaction**
- 3 Ideal timetable
- 4 Disposition timetable
- 5 Conclusion



Measuring satisfaction



Behavioral models

- Demand = sequence of choices
- Choosing means trade-offs
- In practice: derive trade-offs from choice models
- Main concept: utility function
- Common model: logit

Logit model

Utility

$$U_{in} = V_{in} + \varepsilon_{in}$$

- Decision-maker n
- Alternative $i \in \mathcal{C}_n$

Choice probability

$$P_n(i|\mathcal{C}_n) = \frac{e^{V_{in}}}{\sum_{j \in \mathcal{C}_n} e^{V_{jn}}}$$

Variables: $x_{in} = (z_{in}, s_n)$

Attributes of alternative i : z_{in}

- Cost / price
- Travel time
- Waiting time
- Level of comfort
- Number of transfers
- Late/early arrival
- etc.

Characteristics of decision-maker n :

s_n

- Income
- Age
- Sex
- Trip purpose
- Car ownership
- Education
- Profession
- etc.



Willingness to pay

Attributes of alternative i : z_{in}

- Cost / price
- Travel time
- Waiting time
- Level of comfort
- Number of transfers
- Late/early arrival
- etc.

Willingness to pay for alternative i

- Value of travel time
- Value of waiting time
- Value of comfort
- Value of transfers
- Value of not being on time
- etc.

Willingness to pay



Utility

$$U_{in} = \beta_c c_{in} + \beta_t t_{in} + \dots$$

Value of time

$$VOT_{in} = \frac{\partial U_{in} / \partial t_{in}}{\partial U_{in} / \partial c_{in}} = \frac{\beta_t}{\beta_c}$$

Equivalence

Utility

$$U_{in} = \beta_c c_{in} + \beta_t t_{in} + \beta_w w_{in} + \beta_{cft} cft_{in} + \beta_T T_{in} + \beta_e e_{in} + \beta_\ell \ell_{in} + \dots$$

Willingness to pay: cost per unit

- Travel time: β_t/β_c
- Waiting time: β_w/β_c
- Comfort: β_{cft}/β_c
- Transfers: β_T/β_c
- Being early: β_e/β_c
- Being late: β_ℓ/β_c

Travel time equivalent: hours per unit

- Cost: β_c/β_t
- Waiting time: β_w/β_t
- Comfort: β_{cft}/β_t
- Transfers: β_T/β_t
- Being early: β_e/β_t
- Being late: β_ℓ/β_t

Outline

- 1 Demand and supply
- 2 Measuring satisfaction
- 3 Ideal timetable**
- 4 Disposition timetable
- 5 Conclusion



Planning of railway operations



Timetables

Objectives

- Minimize cost
- Maximize satisfaction

Constraints

- Cyclicity
- or not...

Fernverkehr		S - Bahn	
Abfahrtsort	Zugnummer	Abfahrtsort	Zugnummer
Basel	1001	Basel	1001
Basel	1002	Basel	1002
Basel	1003	Basel	1003
Basel	1004	Basel	1004
Basel	1005	Basel	1005
Basel	1006	Basel	1006
Basel	1007	Basel	1007
Basel	1008	Basel	1008
Basel	1009	Basel	1009
Basel	1010	Basel	1010
Basel	1011	Basel	1011
Basel	1012	Basel	1012
Basel	1013	Basel	1013
Basel	1014	Basel	1014
Basel	1015	Basel	1015
Basel	1016	Basel	1016
Basel	1017	Basel	1017
Basel	1018	Basel	1018
Basel	1019	Basel	1019
Basel	1020	Basel	1020
Basel	1021	Basel	1021
Basel	1022	Basel	1022
Basel	1023	Basel	1023
Basel	1024	Basel	1024
Basel	1025	Basel	1025
Basel	1026	Basel	1026
Basel	1027	Basel	1027
Basel	1028	Basel	1028
Basel	1029	Basel	1029
Basel	1030	Basel	1030
Basel	1031	Basel	1031
Basel	1032	Basel	1032
Basel	1033	Basel	1033
Basel	1034	Basel	1034
Basel	1035	Basel	1035
Basel	1036	Basel	1036
Basel	1037	Basel	1037
Basel	1038	Basel	1038
Basel	1039	Basel	1039
Basel	1040	Basel	1040
Basel	1041	Basel	1041
Basel	1042	Basel	1042
Basel	1043	Basel	1043
Basel	1044	Basel	1044
Basel	1045	Basel	1045
Basel	1046	Basel	1046
Basel	1047	Basel	1047
Basel	1048	Basel	1048
Basel	1049	Basel	1049
Basel	1050	Basel	1050
Basel	1051	Basel	1051
Basel	1052	Basel	1052
Basel	1053	Basel	1053
Basel	1054	Basel	1054
Basel	1055	Basel	1055
Basel	1056	Basel	1056
Basel	1057	Basel	1057
Basel	1058	Basel	1058
Basel	1059	Basel	1059
Basel	1060	Basel	1060
Basel	1061	Basel	1061
Basel	1062	Basel	1062
Basel	1063	Basel	1063
Basel	1064	Basel	1064
Basel	1065	Basel	1065
Basel	1066	Basel	1066
Basel	1067	Basel	1067
Basel	1068	Basel	1068
Basel	1069	Basel	1069
Basel	1070	Basel	1070
Basel	1071	Basel	1071
Basel	1072	Basel	1072
Basel	1073	Basel	1073
Basel	1074	Basel	1074
Basel	1075	Basel	1075
Basel	1076	Basel	1076
Basel	1077	Basel	1077
Basel	1078	Basel	1078
Basel	1079	Basel	1079
Basel	1080	Basel	1080
Basel	1081	Basel	1081
Basel	1082	Basel	1082
Basel	1083	Basel	1083
Basel	1084	Basel	1084
Basel	1085	Basel	1085
Basel	1086	Basel	1086
Basel	1087	Basel	1087
Basel	1088	Basel	1088
Basel	1089	Basel	1089
Basel	1090	Basel	1090
Basel	1091	Basel	1091
Basel	1092	Basel	1092
Basel	1093	Basel	1093
Basel	1094	Basel	1094
Basel	1095	Basel	1095
Basel	1096	Basel	1096
Basel	1097	Basel	1097
Basel	1098	Basel	1098
Basel	1099	Basel	1099
Basel	1100	Basel	1100

Modeling elements

Supply

- Line ℓ : sequence of stations served by the same train
- Train $v \in V_\ell$: service of a line at a given departure time

Demand

- Origin / destination i
- Ideal arrival time t
- Path $p \in P_i$: sequence of portions of lines to reach d from o
 - Access/egress time for path p (OD i)
 - Travel time for path p
 - Waiting time for path p

Model

Decision variables

- x_i^{tp} : 1 – if passenger with ideal time t between OD pair i chooses path p ; 0 – otherwise
- $y_i^{tp/v}$: 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
- d_v^l : the departure time of a train v on the line l (from its first station)
- 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

Calculation variables

- C_i^t : total cost of a passenger with ideal time t between OD pair i
- w_i^t : total waiting time of a passenger with ideal time t between OD pair i
- s_i^t : value of the scheduled delay of a passenger with ideal time t between OD pair i
- z_v^l : dummy variable modeling the cyclicity corresponding to a train v on the line l
- o_{vg}^l : occupation of train v of line l on segment g



Model

Problem constraints

- passenger cost $\leq \varepsilon$
- everyone uses at most one path
- link between path and trains: everyone boards one train of each line in the path
- cyclicity
- everyone uses only trains that are actually running
- train capacity
- maximum number of train units



Model

Calculation constraints

- Scheduled delay
- Waiting time
- Overall cost



Models

Current model

Departure times of trains are fixed, current values are used (cyclic).

Cyclic model

Departure times are optimized, cyclicity is enforced.

Non-cyclic model

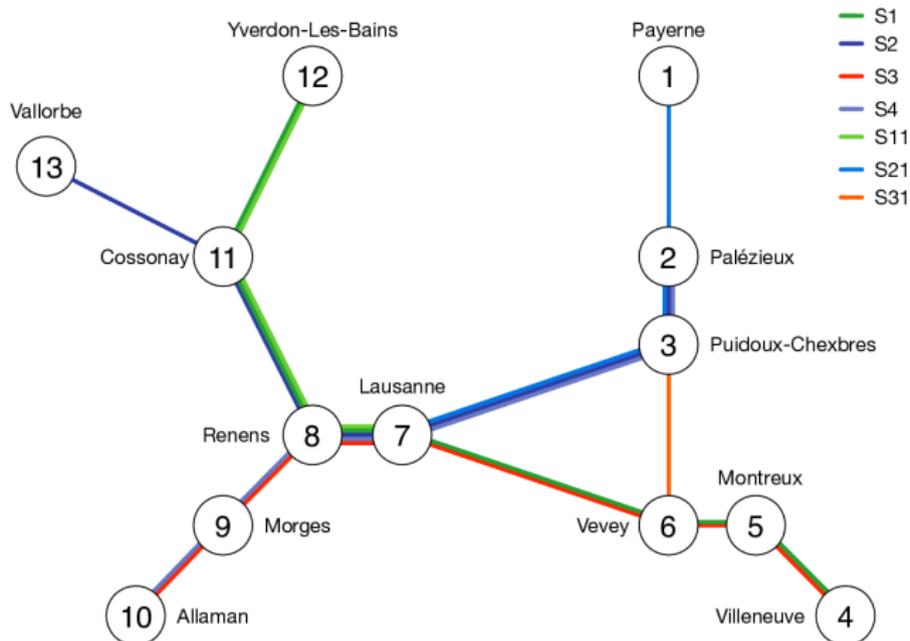
Departure times are optimized, cyclicity is not enforced.



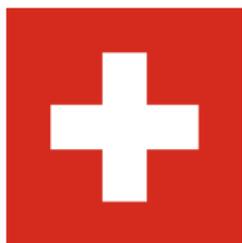
Case Study – Switzerland



S-Train Network Canton Vaud, Switzerland



Case study: Switzerland



Context

- 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

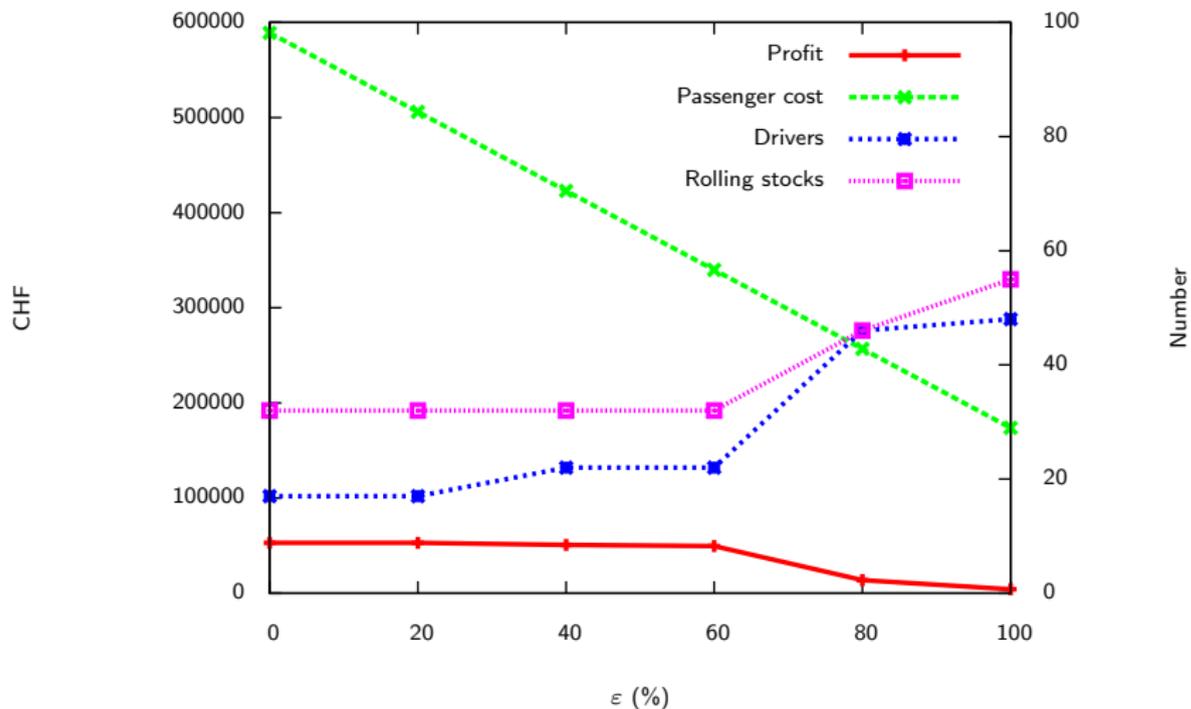
Case study: Switzerland

Willingness to pay from the literature

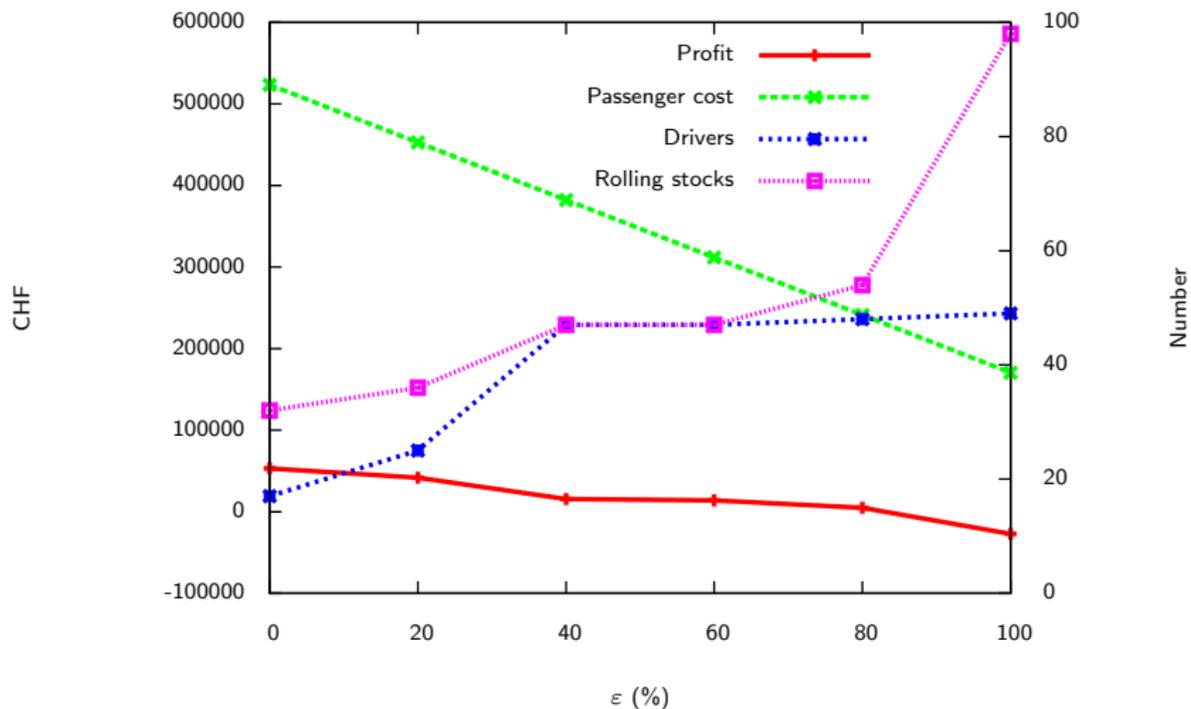
- Value of travel time: 27.81 CHF / hour
- Value of waiting time: 69.5 CHF /hour
- Value of comfort: —
- Value of transfers: 4.6 CHF / hour (10 min. travel time)
- Value of being late: 27.81 CHF / hour
- Value of being early: 13.9 CHF / hour
- etc.



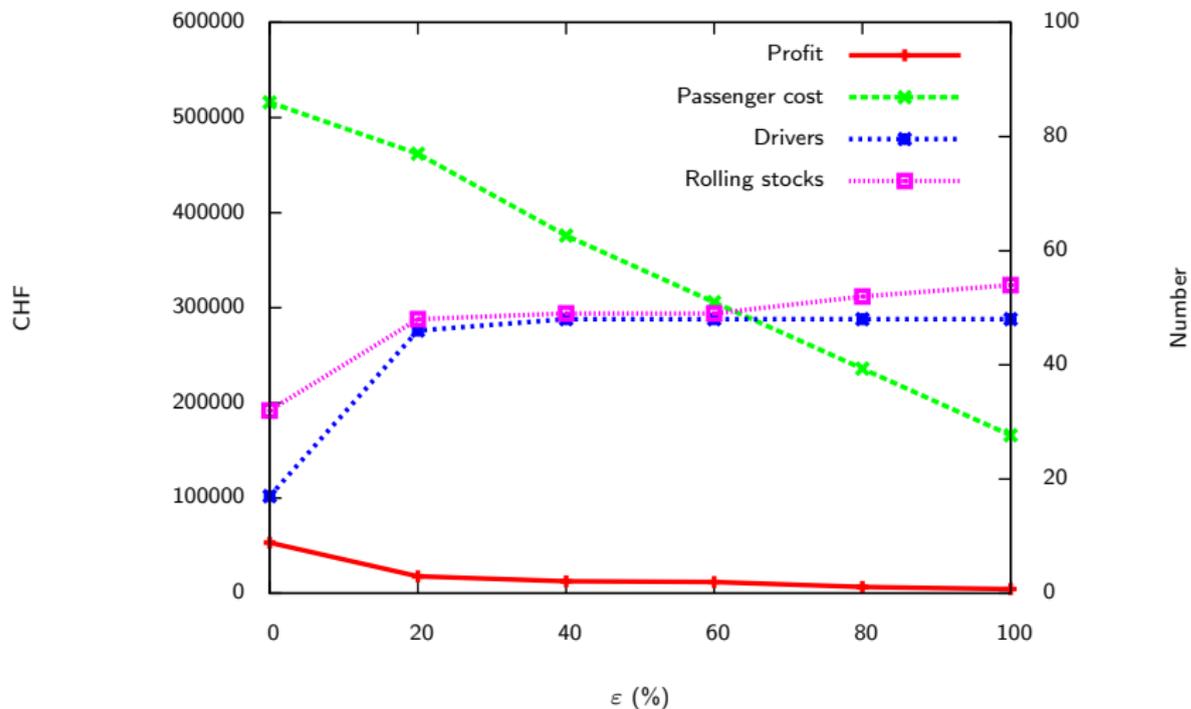
Pareto: current model



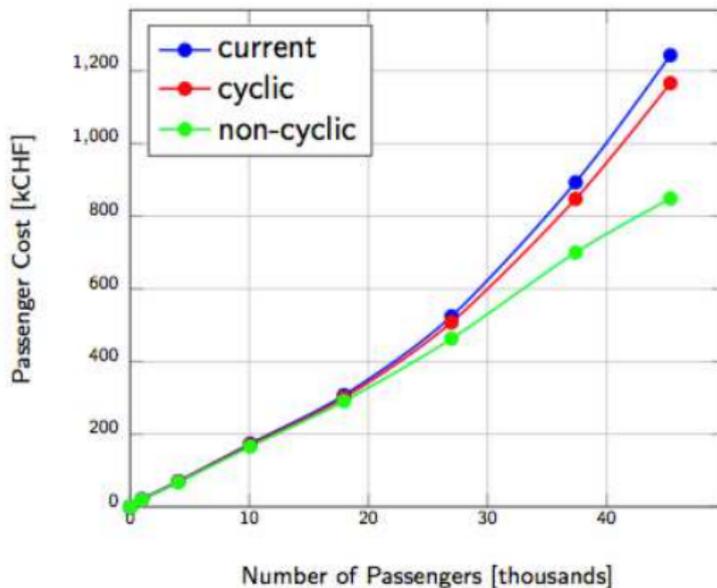
Pareto: cyclic model



Pareto: non cyclic



Impact of congestion



Outline

- 1 Demand and supply
- 2 Measuring satisfaction
- 3 Ideal timetable
- 4 Disposition timetable**
- 5 Conclusion



Motivation



Figure: Bray Head, Railway Accident, Ireland, 1867. The Liszt Collection.

Recovery

Research question

What are the impacts, in terms of passenger (dis-)satisfaction, of different recovery strategies in case of a severe disruption in a railway network?

Recovery strategies

- Train cancellation
- Partial train cancellation
- Global re-routing of trains
- Additional service (buses/trains)
- “Direct train”
- Increase train capacity



Outline

- 1 Demand and supply
- 2 Measuring satisfaction
- 3 Ideal timetable
- 4 Disposition timetable
- 5 Conclusion



Conclusions

Importance of demand

- Passenger satisfaction
- Choice behavior
- Willingness to pay
- Heterogeneity

Railway applications

- Ideal timetables
- Disposition timetables

