Passenger-Centric Railway Operations

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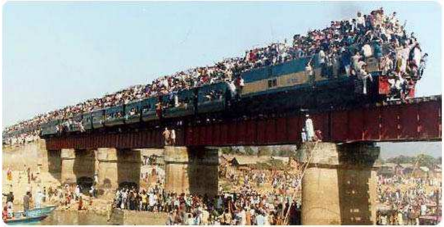
Outline

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

Johnson City Enterprise.

Published Every Saturday,

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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.

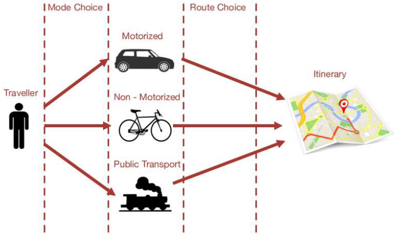
E. T. & W. N. C. R. R.

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

J. C. HARDIN, Agent.

Behavioral models

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



Demand-supply interactions

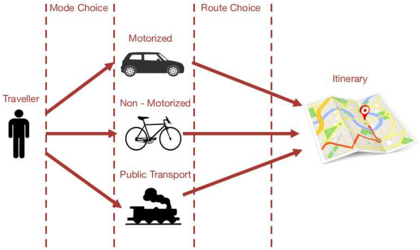
Multi-objective optimization

Minimize costs

Maximize satisfaction

Outline

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

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

Choice probability

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

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

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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.

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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

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

Value of time

$$\mathrm{VOT}_{in} = \frac{\partial U_{in}/\partial t_{in}}{\partial U_{in}/\partial c_{in}} = \frac{\beta_t}{\beta_c}$$

Equivalence

Utility

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

Willingness to pay: cost per unit

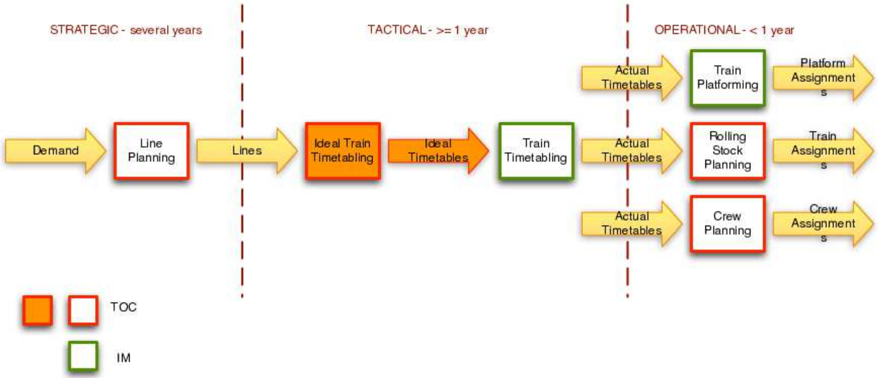
- Travel time: β_t/β_c
- Waiting time: β_w/β_c
- Comfort: $\beta_{\text{cft}}/\beta_c$
- Transfers: β_T/β_c
- Being early: β_e/β_c
- Being late: β_ℓ/β_c

Travel time equivalent: hours per unit

- Cost: β_c/β_t
- Waiting time: β_w/β_t
- Comfort: $\beta_{\text{cft}}/\beta_t$
- Transfers: β_T/β_t
- Being early: β_e/β_t
- Being late: β_ℓ/β_t

Outline

Planning of railway operations



Timetables

Objectives

- Minimize cost
- Maximize satisfaction

Constraints

- Cyclicity
- or not...

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^{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
- 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

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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

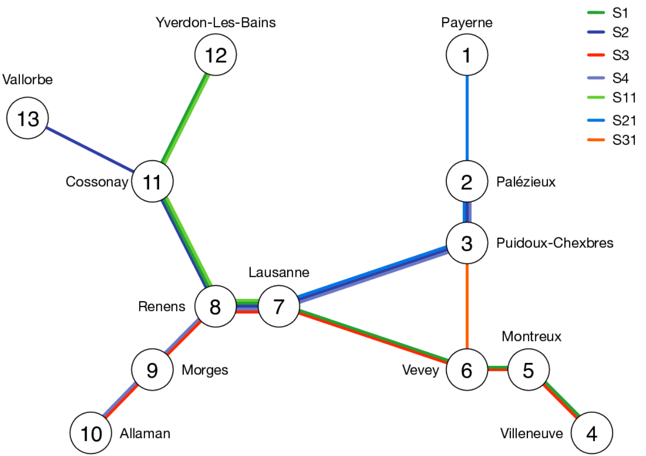
Departure times are optimized, cyclicity is enforced.

Non-cyclic model

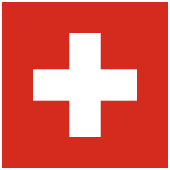
Departure times are optimized, cyclicity is not enforced.

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

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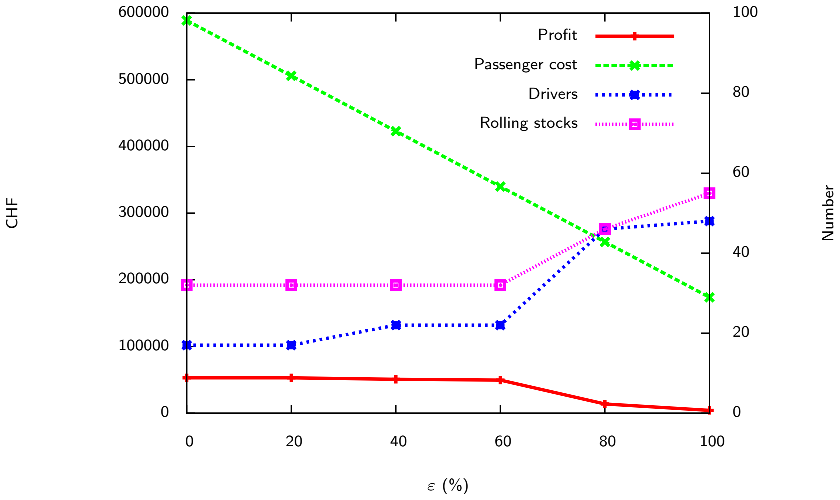
Case study: Switzerland

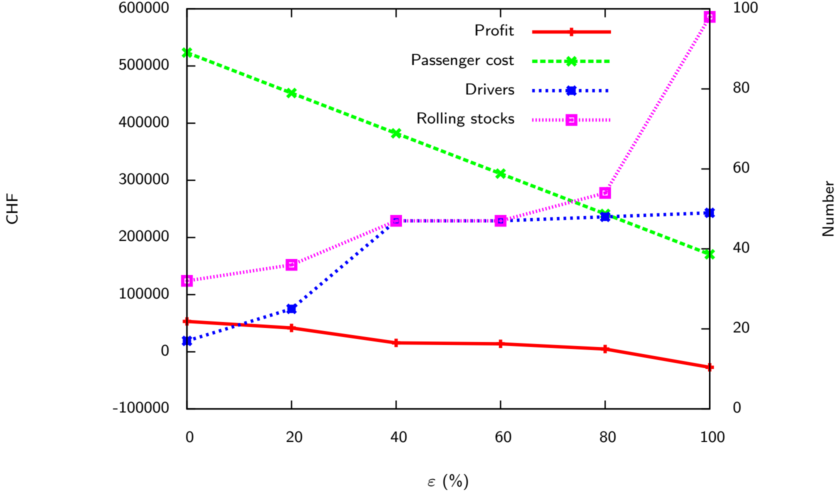
Willingness to pay from the literature

- 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.

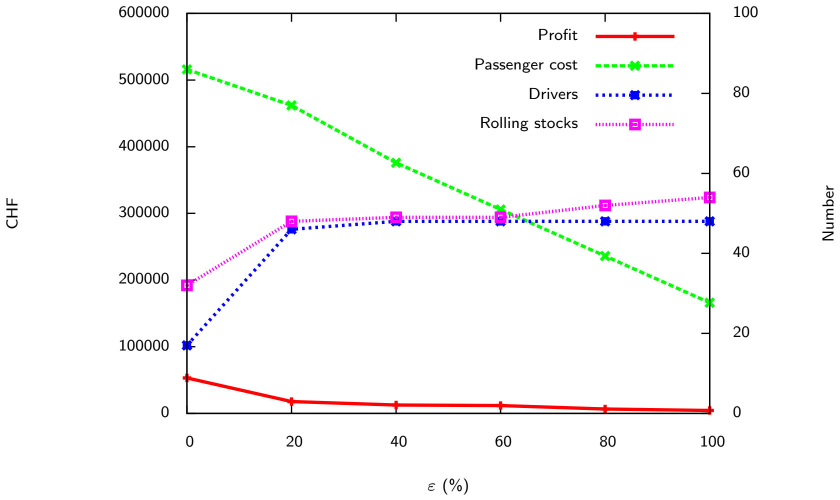
Pareto: current model



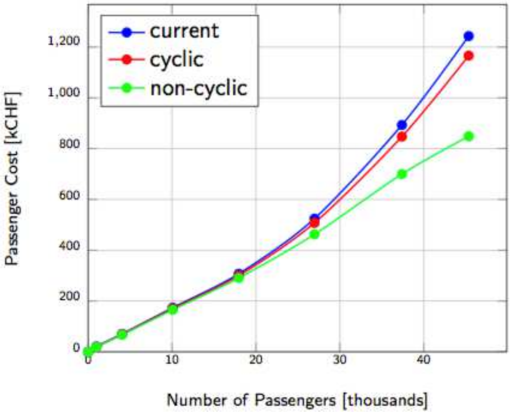
Pareto: cyclic model



Pareto: non cyclic



Impact of congestion



Outline

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

Conclusions

Importance of demand

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

Railway applications

- Ideal timetables
- Disposition timetables