Passenger-Centric Railway Operations

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Outline

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

Demand models

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

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

Operations Research
- Given the demand...
- configure the system

Behavioral models
- Given the configuration of the system...
- predict the demand
Demand-supply interactions

Multi-objective optimization

Minimize costs

Maximize satisfaction
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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 \( i \in C_n \)

Choice probability

\[ P_n(i|C_n) = \frac{e^{V_{in}}}{\sum_{j \in C_n} e^{V_{jn}}} \]
Measuring satisfaction

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

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

Value of time

\[ VOT_{in} = \frac{\partial U_{in}/\partial t_{in}}{\partial U_{in}/\partial c_{in}} = \frac{\beta_t}{\beta_c} \]
Measuring satisfaction

Equivalence

Utility

\[ U_{in} = \beta_c c_{in} + \beta_t t_{in} + \beta_w w_{in} + \beta_{cft} c_{ft_{in}} + \beta_T T_{in} + \beta_e e_{in} + \beta_\ell \ell_{in} + \cdots \]

Willingness to pay: cost per unit
- Travel time: \( \beta_t / \beta_c \)
- Waiting time: \( \beta_w / \beta_c \)
- Comfort: \( \beta_{cft} / \beta_c \)
- Transfers: \( \beta_T / \beta_c \)
- Being early: \( \beta_e / \beta_c \)
- Being late: \( \beta_\ell / \beta_c \)

Travel time equivalent: hours per unit
- Cost: \( \beta_c / \beta_t \)
- Waiting time: \( \beta_w / \beta_t \)
- Comfort: \( \beta_{cft} / \beta_t \)
- Transfers: \( \beta_T / \beta_t \)
- Being early: \( \beta_e / \beta_t \)
- Being late: \( \beta_\ell / \beta_t \)
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Planning of railway operations

STRATEGIC - several years

Demand → Line Planning → Lines → Ideal Train Timetabling → Ideal Timetables

TACTICAL - >= 1 year

Ideal Timetables → Train Timetabling

OPERATIONAL - < 1 year

Train Timetables → Actual Timetables → Train Platforming → Platform Assignments

Actual Timetables → Rolling Stock Planning → Train Assignments

Actual Timetables → Crew Planning → Crew Assignments
Timetables

Objectives
- Minimize cost
- Maximize satisfaction

Constraints
- Cyclicity
  - or not...
Modeling elements

Supply
- Line $\ell$: 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 $p$
Ideal timetable

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 $\ell$; 0 – otherwise
- $d_{\ell}^{v}$: the departure time of a train $v$ on the line $\ell$ (from its first station)
- $u_{\ell}^{v}$: number of train units of a train $v$ on the line $\ell$
- $\alpha_{\ell}^{v}$: 1 – if a train $v$ on the line $\ell$ is being operated; 0 – otherwise
Model

Calculation variables

- $C^t_i$: total cost of a passenger with ideal time $t$ between OD pair $i$
- $w^t_i$: total waiting time of a passenger with ideal time $t$ between OD pair $i$
- $s^t_i$: value of the scheduled delay of a passenger with ideal time $t$ between OD pair $i$
- $z^ℓ_ν$: dummy variable modeling the cyclicity corresponding to a train $ν$ on the line $ℓ$
- $o^ℓ_νg$: occupation of train $ν$ 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
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
Ideal timetable

Pareto: non cyclic

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**Figure:**

- **Profit** (red line)
- **Passenger cost** (green dashed line)
- **Drivers** (blue dotted line)
- **Rolling stocks** (purple dash-dotted line)

**Axes:**
- **CHF** on the y-axis
- **Number** on the x-axis

**Legend:**
- Profit
- Passenger cost
- Drivers
- Rolling stocks

**Graph Description:**

- The graph illustrates the trade-offs between different cost categories and profit as a function of the parameter \( \varepsilon \) (percentage).
- Profit decreases as \( \varepsilon \) increases, while passenger cost and rolling stocks costs show an increasing trend.
- Drivers costs remain relatively stable across different values of \( \varepsilon \).

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**Table:**

<table>
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<th>( \varepsilon ) (%)</th>
<th>Profit</th>
<th>Passenger cost</th>
<th>Drivers</th>
<th>Rolling stocks</th>
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**Source:**

Bierlaire et al. (EPFL) - Passenger-Centric Railway Operations

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Impact of congestion

![Graph showing the impact of congestion on passenger cost. The graph has two curves: one for current operations and another for cyclic operations. The graph shows that the non-cyclic operations have a lower passenger cost compared to the cyclic operations.](image)
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Motivation

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

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

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?
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Conclusions

Importance of demand
- Passenger satisfaction
- Choice behavior
- Willingness to pay
- Heterogeneity

Railway applications
- Ideal timetables
- Disposition timetables