Applying Traffic Assignement to a railway network

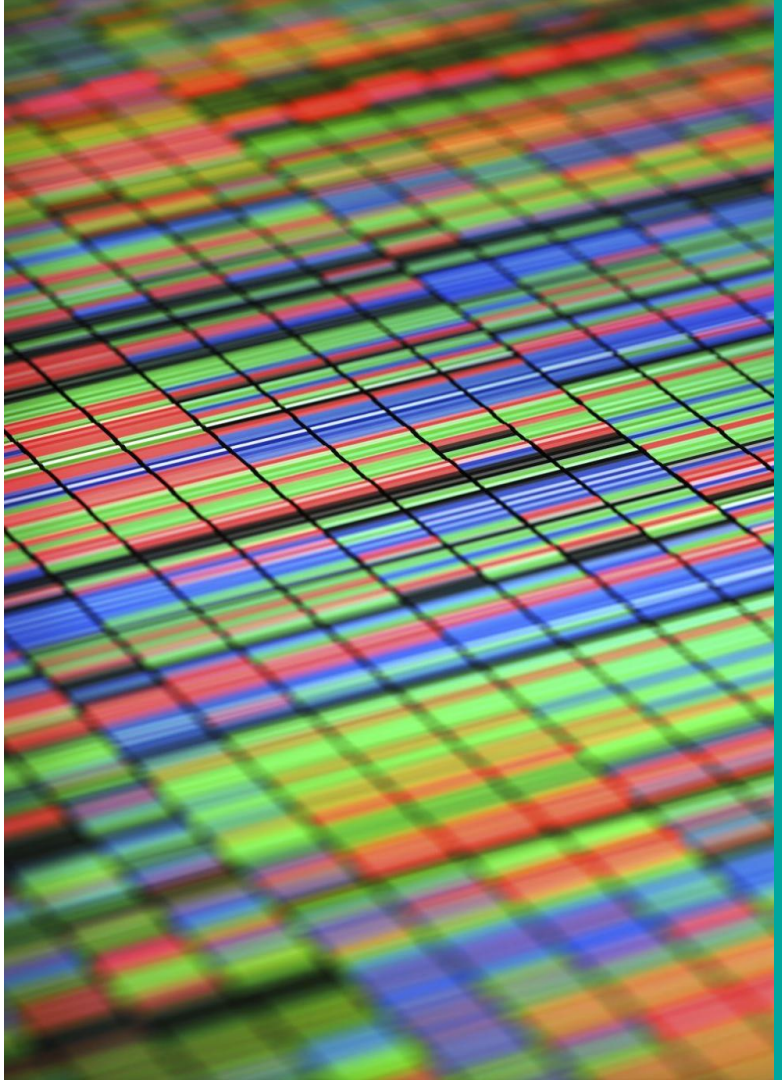
Luca Liuzzi

Fletcher Collis

Project Motivation

Main motivations

Understanding	Comparison	Feasibility	Flexibility
Explore the various challenges of a railway network and learn to model one	Uncover the fundamental differences in a road vs rail networks	See if it is possible to create framework to easily apply traffic assignment to any real railway network	Make the approach very flexible and modular to be able to use for different use cases



Initial Raw Data Overview

Data sources and Challenges

Passenger data

Data found on the SBB data portal : *anzahl-sbb-bahnhofbenutzer.csv*

→ Average passenger counts / year / day for the biggest stations in Switzerland

Bahnhof_Gare_Stazione	Unité	Jahr	Anzahl Bahnhofbenutzer
Bern	DP/jour ouvré	2016	318000
Bern	DP/jour ouvré	2020	227600
Bern	DP/jour ouvré	2021	228800
Bern	DP/jour ouvré	2023	296500
Bern	DP/jour	2013	
Bern	DP/jour	2015	
Bern	DP/jour	2020	211000
Bern	DP/jour	2022	261500
Bern	DP/jour	2024	281900
Basel SBB	DP/jour ouvré	2013	134000
Basel SBB	DP/jour ouvré	2014	135000
Basel SBB	DP/jour ouvré	2021	95700
Basel SBB	DP/jour	2015	126400
Basel SBB	DP/jour	2016	126400
Basel SBB	DP/jour	2019	128400

NO INFORMATION ON ORIGIN OR DESTINATION

Data sources and Challenges

- **Network data**

Data found on the SBB data portal : *linie-mit-polygon.csv*

→ Complete Swiss rail infrastructure as polylines (strings of coordinates)

Geo point	Geo shape	TRACK GAUGE	KM START	KM END	START_OP	START_OP	END_OP	END_OP	Linie	Line
47.21976912299228, 8.808646167429176	{"coordinates": [[8.816764778632129, 47.224802852486135], [8.816634416211253, 47.22478858845543], [8.81650405385998, 47.224774324277], [8.816373691578317, 47.22476005995085], [8.81624332936631, 47.22474	N	21.012	1744.514	RW	Rapperswil SG	HUR	Hurden	671	Rapperswil - Pfäffikon Ost (SOB)
47.18557904508911, 6.91404312078451	{"coordinates": [[6.905882565188336, 47.17683910785227], [6.9222036760380684, 47.19431898232596]], "type": "LineString"}	M	27771.0	30177.0	BOEC	Le Boéchet	BOIS	Les Bois	235	Tavannes - Le Noirmont
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47.51164288195099, 8.368444732796242	{"coordinates": [[8.369558383296539, 47.511128780333334], [8.369448684599812, 47.51117941944303], [8.369338985851348, 47.51123006744106], [8.369229286736243, 47.51128070634102], [8.369119574295665, 47.51	N	25185.864	25388.895	NW	Niederweningen	NWGE	Niederweningen (Gleisende)	761	Oberglatt - Niederweningen Gleisende
46.980134078491794, 6.827839530302453	{"coordinates": [[6.813550934223624, 46.96842108330804], [6.813621891995827, 46.96849678087256], [6.813686775890433, 46.96857499091224], [6.813748149105447, 46.96865452204868], [6.8138080709122, 46.966	N	10584.9	14060.0	CHNN	Chambrelien Nord (bif)	MML	Montmollin-Montezillon	224	Chambrelien Nord - Le Locle frontière
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47.46332270594999, 7.1560329148141911	{"coordinates": [[7.15547801824391, 47.4740917350635], [7.1565878113284471, 47.4525536768364694]], "type": "LineString"}	N	8377.0	10893.0	VEND	Vendlincourt	BONF	Bonfol	238	Porrentruy - Bonfol
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47.06130091603083, 7.1917906321569 27	{"coordinates": [[7.1982497100931 28, 47.06646439286938], [7.185331554220726, 47.05613743919229]], "type": "LineString"}	M	7780.0	9150.0	TAEU	Täuffelen	HECK	Hagneck	261	Biel - Täuffelen - Ins
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47.01101540758756, 6.997660046346841	{"coordinates": [[7.010613975227288, 47.00921234821 7126], [7.010483573912471, 47.00922390469786], [7.010353336222334, 47.00923637015928], [7.010223288522631, 47.00924973570566], [7.010093457107 36, 47.0	N	36726.171	38742.49	MEP	Marin-Epagnier	SBLB	St-Blaise-Lac	220	Bern - Neuchâtel Est (bif)
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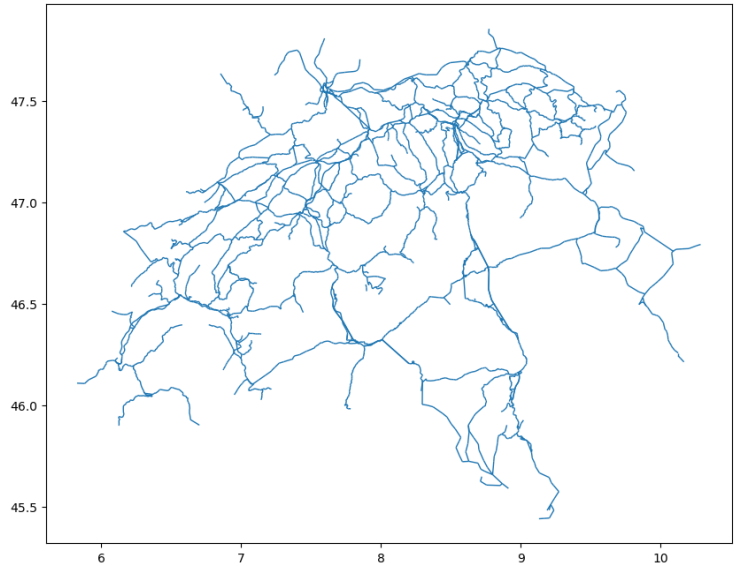
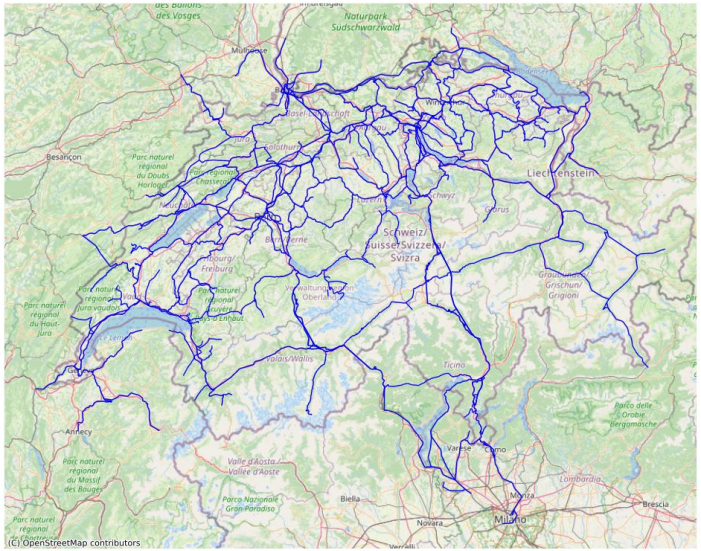
NO INFORMATION ON IC LINES AND WHICH TRACKS THEY USE

Data sources and Challenges





How do we go from messy geographic and marginal data to something we can plug into a traffic assignment model?

Constructing the OD matrix

Attraction and Gravity model

- **Generate synthetic destination:**
  - The number of passengers is considered as the production of each station
  - Compute weight based on population and production

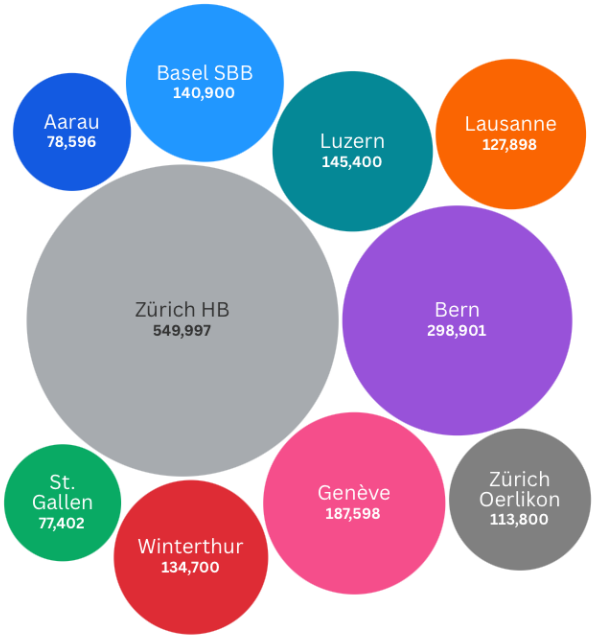
$$\omega_i = \frac{Population_i + Production_i}{Total\ Population + Total\ Production}$$

$$Attraction_i = \omega_i \times Total\ Production$$

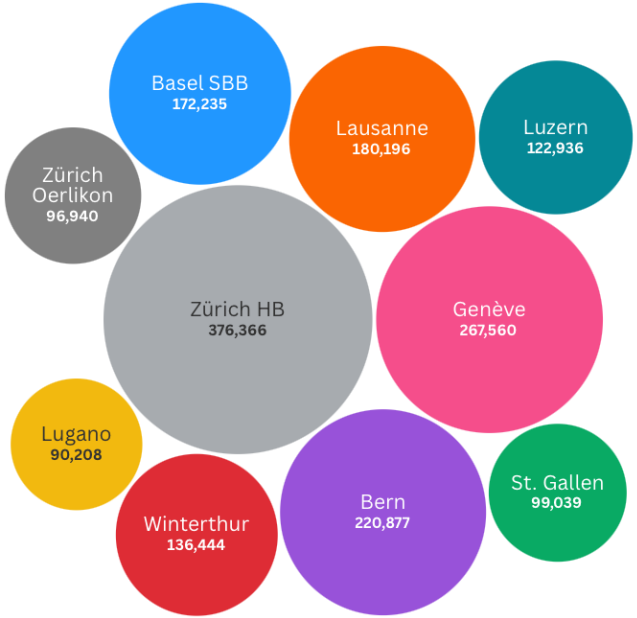
- **Gravity Model:**
  - Doubly constrained
  - Cost function only based on the distance between cities
  - Internal trips: zero demand
- **Comments**
  - simple and quick to implement
  - does not consider attractive features of a city (e.g. jobs, activities, services)

Results

Top 10 Producers



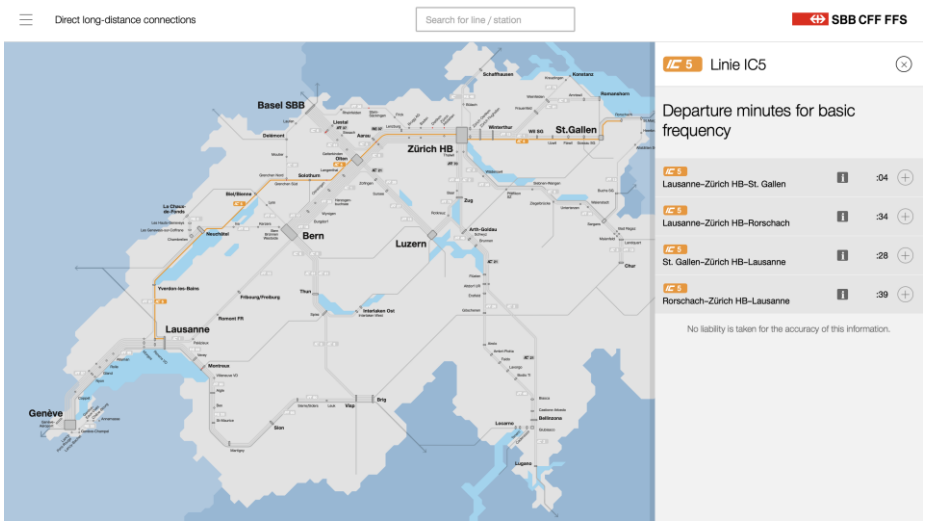
Top 10 Attractors

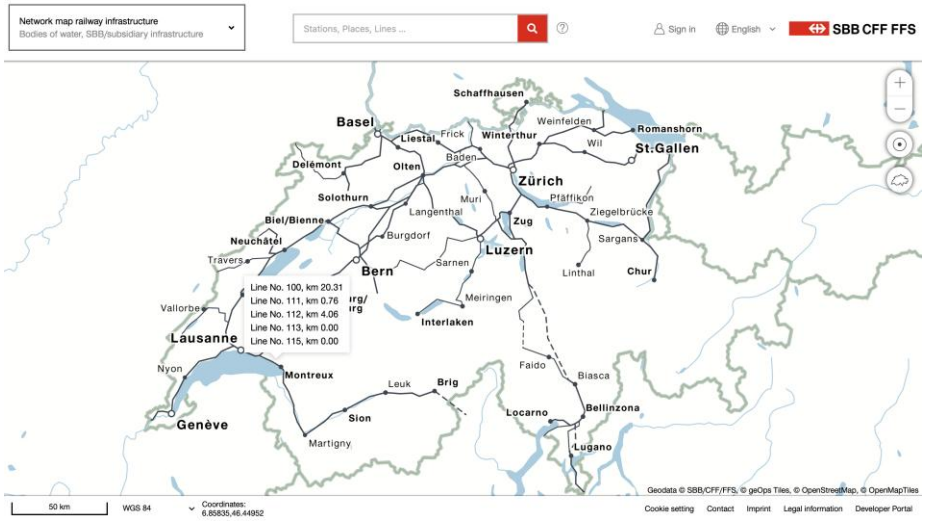


Modeling the railway network

Filtering + Adding Essential Information

Decision : Concentrate on InterCity (IC) lines

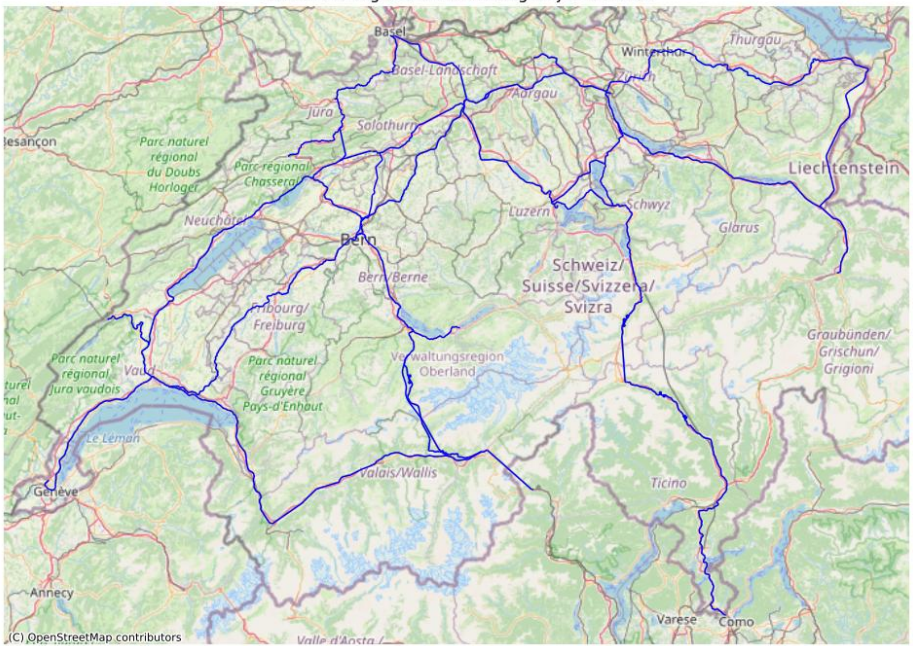


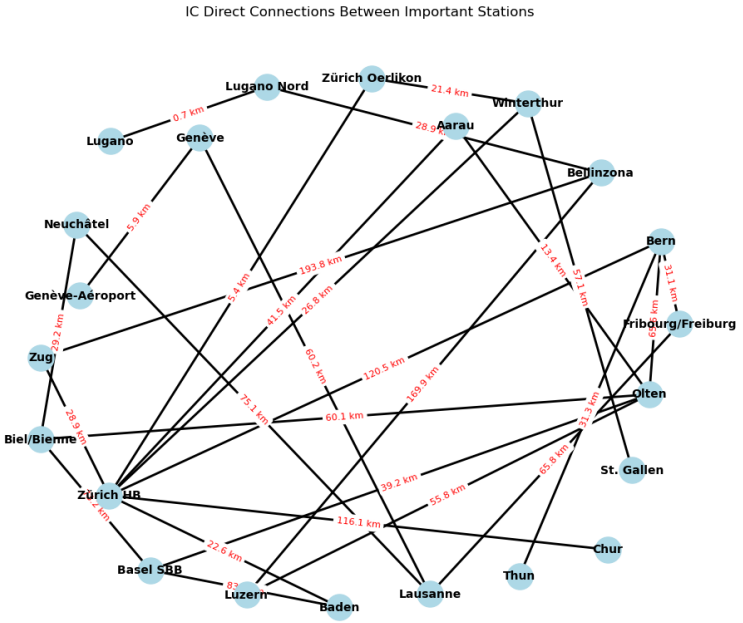


- Get the IC network info
- Get the IC line headways

- Manually map SBB “lines” to the ones used by the IC network

Filtering + Adding Essential Information





General Modeling Aproach

	start_node	end_node	distance [m]	IC_lines
0	Fribourg/Freiburg	Bern	31109.895	IC1
1	Fribourg/Freiburg	Lausanne	65778.350	IC1
2	Chur	Zürich HB	116075.402	IC3
3	St. Gallen	Winterthur	57139.042	IC1, IC5
4	Neuchâtel	Lausanne	75087.957	IC5
5	Neuchâtel	Biel/Bienne	29200.120	IC5
6	Lugano	Lugano Nord	659.934	IC2, IC21
7	Lugano Nord	Bellinzona	28895.062	IC2, IC21
8	Basel SBB	Baden	83614.363	IC3
9	Basel SBB	Olten	39172.397	IC21, IC6, IC61
10	Basel SBB	Biel/Bienne	73186.658	IC51
11	Winterthur	Zürich Oerlikon	21418.950	IC1
12	Winterthur	Zürich HB	26787.367	IC5, IC81
13	Bellinzona	Luzern	169866.354	IC21
14	Bellinzona	Zug	193790.225	IC2
15	Zürich Oerlikon	Zürich HB	5368.417	IC1
16	Aarau	Olten	13373.404	IC5
17	Aarau	Zürich HB	41492.905	IC5
18	Genève	Genève-Aéroport	5918.188	IC1
19	Genève	Lausanne	60226.630	IC1
20	Baden	Zürich HB	22587.175	IC3
21	Luzern	Olten	55768.093	IC21
22	Olten	Bern	65626.280	IC6, IC61
23	Olten	Biel/Bienne	60070.608	IC5
24	Thun	Bern	31264.012	IC6, IC61, IC8, IC81
25	Bern	Zürich HB	120492.589	IC1, IC8, IC81
26	Zug	Zürich HB	28929.698	IC2

1) Lines to Stations

Manually map which lines pass though which stations

2) Node-Line Duplication

Each station becomes **multiple nodes,** one for each line that stops there

Why? *To separate different train line paths at shared stations*

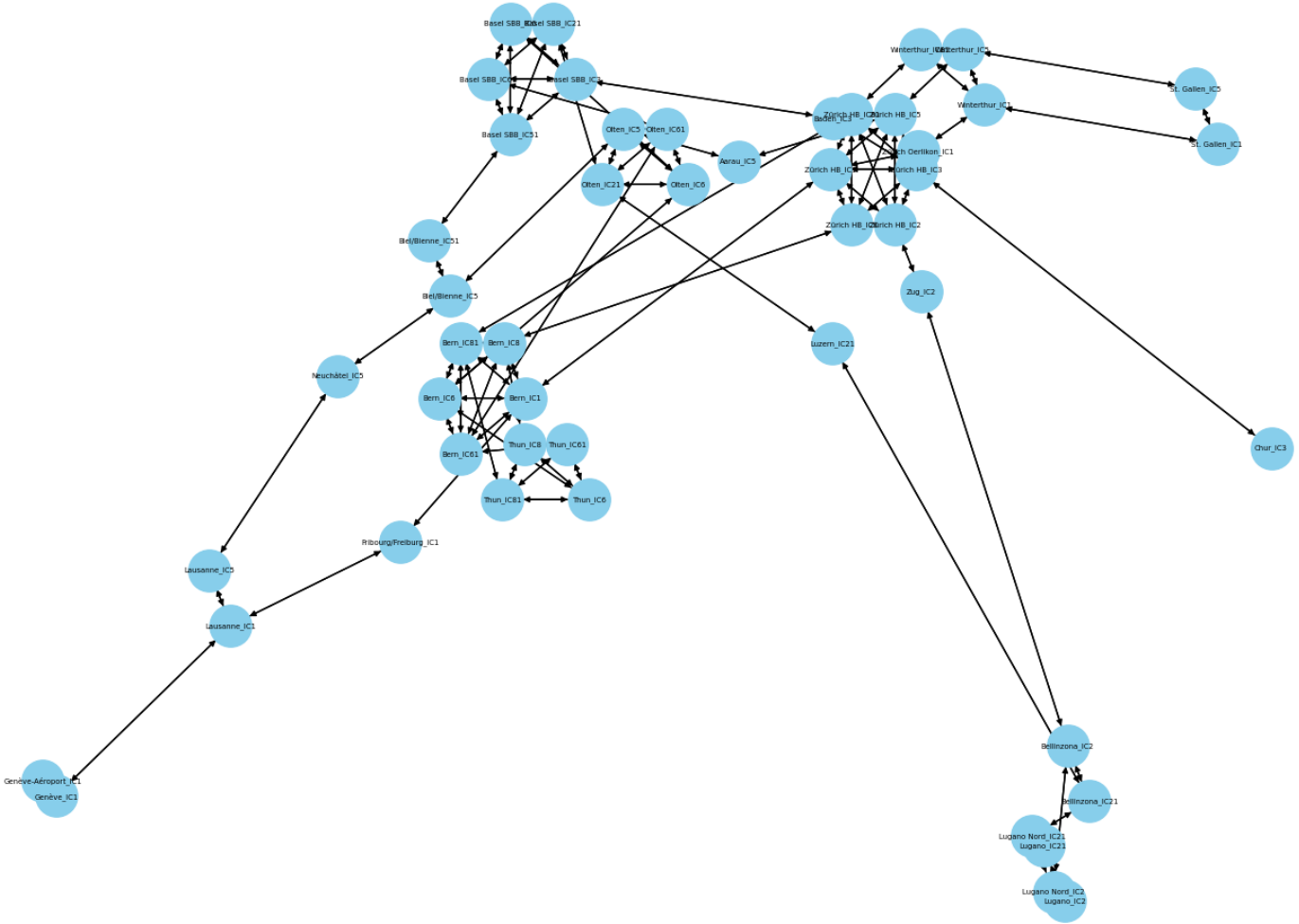
3) Transfer Modeling

At each station: connect the duplicated node-line pairs using **transfer links**

Transfer arcs only exist **within the same station**

Add fixed transfer penalty (5 minutes + ½ headway)

This modeling choice made transfers explicit and penalizable in shortest path calculations


Basel SBB_IC21
Basel SBB_IC2
Basel SBB_IC51
Olten_IC5
Olten_IC61
Olten_IC21
Olten_IC6
Aarau_IC5
Winterthur_IC1
Winterthur_IC2
St. Gallen_IC5
St. Gallen_IC1
Zürich HB_IC5
Zürich HB_IC1
Zürich HB_IC3
Zürich HB_IC2
Zug_IC2
Luzern_IC21
Chur_IC3
Biel/Bienne_IC51
Biel/Bienne_IC5
Neuchâtel_IC5
Bern_IC81
Bern_IC8
Bern_IC6
Bern_IC1
Bern_IC61
Thun_IC8
Thun_IC61
Thun_IC81
Thun_IC6
Fribourg/Freiburg_IC1
Lausanne_IC5
Lausanne_IC1
Genève-Aéroport_IC1
Genève_IC1
Bellinzona_IC2
Bellinzona_IC21
Lugano Nord_IC21
Lugano_IC21
Lugano Nord_IC2
Lugano_IC2

The Model

Cost function, Crowdedness

- Link Cost Funciton – BPR function

$$t_a = (TT + \tau)\left[1 + 0.15\left(\frac{x}{C}\right)^4\right]$$

$Where$:

- $TT : Travel\ Time\ [min]$
- $\tau : transfer\ time\ [min]$
- $x : link\ flow\ [pax]$
- $C : line\ capacity\ [pax]$

- Crowding amplifies travel time perception
- Each transfer results in a travel time penalty

Traffic Assignment Model

- Used the standard **Frank-Wolfe** algorithm seen in class
- Static assignment solved under **UE** condition

- At iteration k,
  - Step 1: Find descent direction $\mathbf{d}^k = \mathbf{y}^k - \mathbf{x}^k$
    - Solve auxiliary problem with linear approximated objective
      - **All-or-nothing assignment:** assign all demand to shortest paths to get $\mathbf{y}^k$
  - Step 2: Find optimal step size α
    - Solve line search problem
      - **Bisection search:** reduce half of search space per iteration
  - Step 3: Update link flow $\mathbf{x}^{k+1} = \mathbf{x}^k + \alpha \mathbf{d}^k$
  - Step 4: Check convergence
    - Compute gap $g = \langle \mathbf{t}^k, -\mathbf{d}^k \rangle$
    - If $g \leq \varepsilon$ for some gap threshold ε, terminate and return $\mathbf{x}^* = \mathbf{x}^k$

Objective – Beckmann's Formulation

$$\int_0^{x_a} t_a(u)du = x(TT + \tau)\left[1 + 0.03\left(\frac{x}{C}\right)^4\right]$$

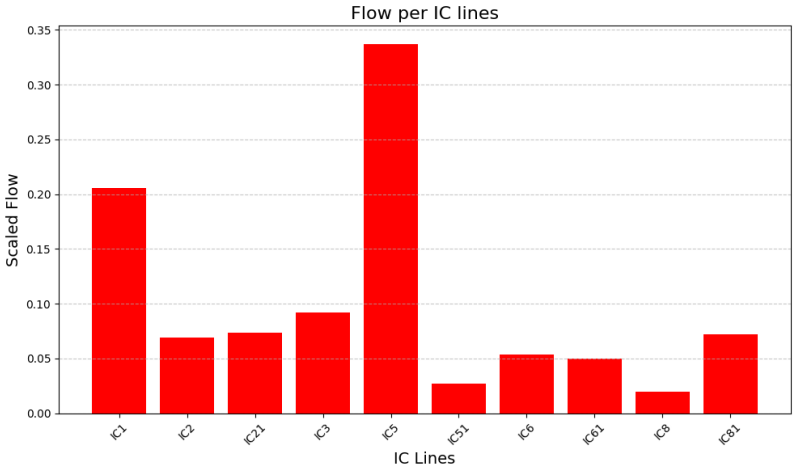
$Where$:

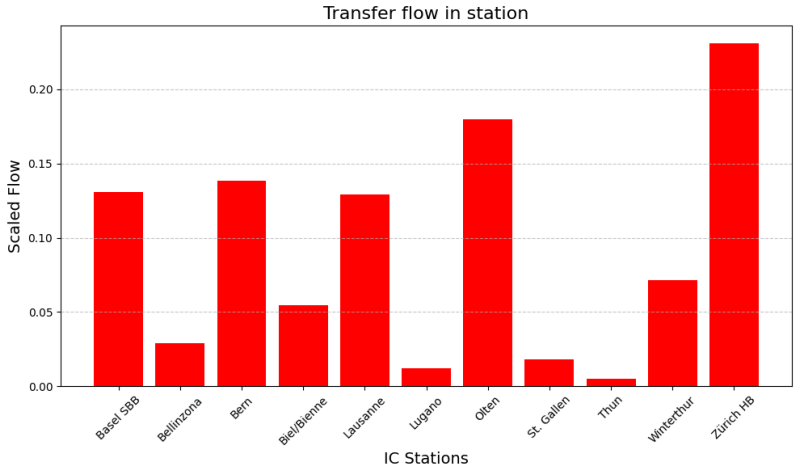
- $\delta : crowding\ multiplier$
- $TT : Travel\ Time\ [min]$
- $\tau : transfer\ time\ [min]$
- $x : link\ flow\ [pax]$
- $C : line\ capacity\ [pax]$

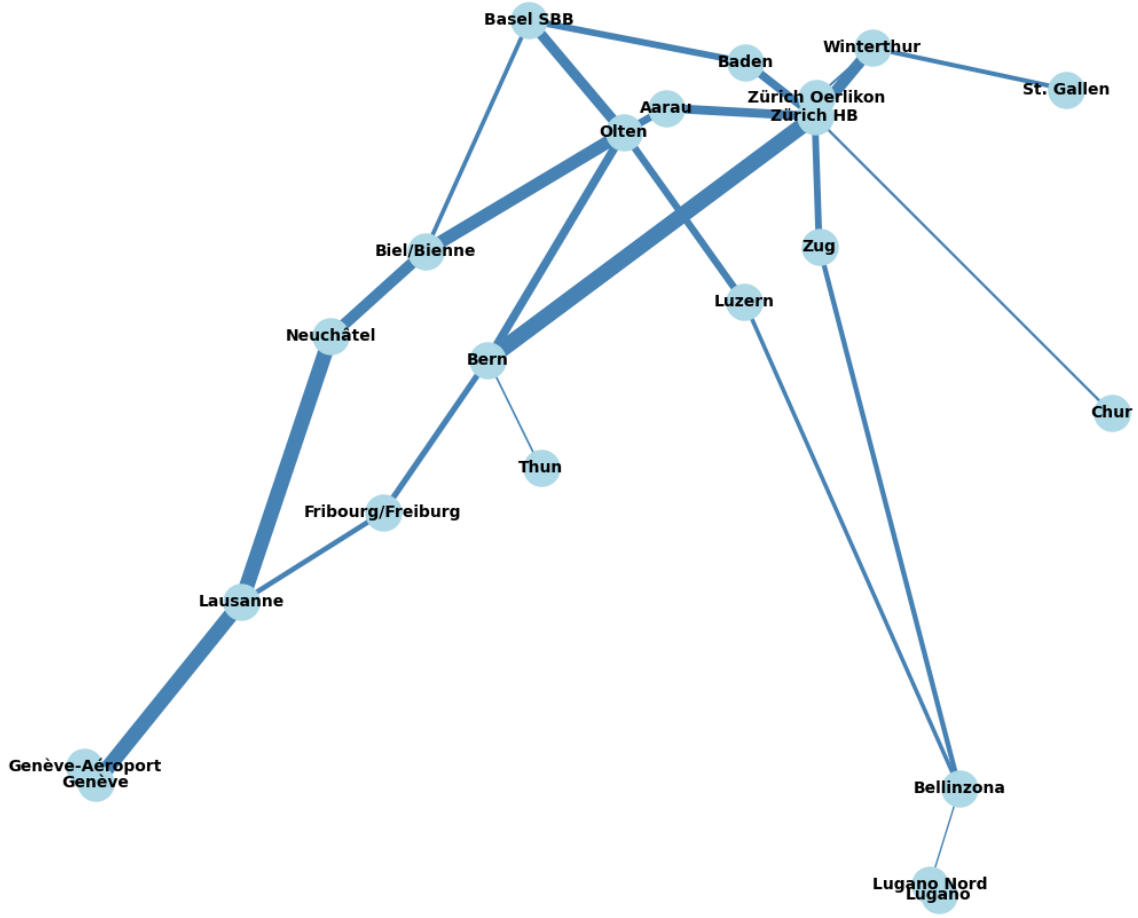
Results Overview

What kind of results we can obtain

- The stations where most transfers take place
- Which lines have the most passengers
- The most used links
- The generalised cost of each line






Basel SBB
Baden
Winterthur
St. Gallen
Zürich Oerlikon
Zürich HB
Aarau
Olten
Biel/Bienne
Zug
Luzern
Neuchâtel
Bern
Chur
Thun
Fribourg/Freiburg
Lausanne
Genève-Aéroport
Genève
Bellinzona
Lugano Nord
Lugano

How can the model be used?

- Assessing future projects and scenarios:
  - consider new OD pairs
  - new major projects (e.g. alptransit, Leman 2030)
  - new types of trains (speed, capacity, comfort)
  - new stations in the intercity network (e.g. Renens in 12.24)

Infrastructure ferroviaire

La nouvelle ligne Lausanne-Genève fait carton plein à Berne

ts en décembre, le Natio

n nouveau tracé CFF ent

Nouvel horaire CFF

12'000 voyageurs de plus par jour en gare de Renens

Dès le 15 décembre, les trains «grandes lignes» s'arrêteront dans le chef-lieu de l'Ouest lausannois. Décryptage d'une nouvelle très attendue.

Chloé Din
Publié: 27.11.2024, 07h30

63

Use case Example

- Analysis of the impact of a new line

→ Inspired by an actual project «SwissMetro»

→ Additional high speed link between Lausanne and Zürich

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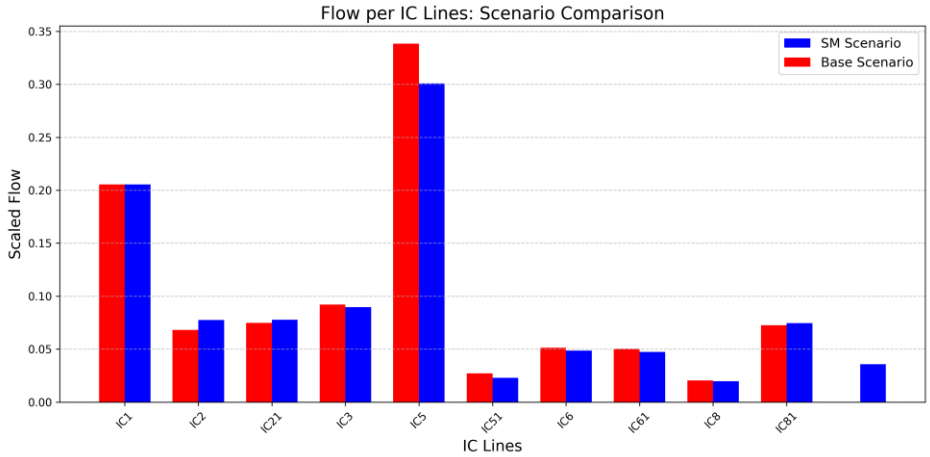
Le projet Swissmetro abandonné faute d'argent

Sciences-Tech.
Modifié le 28 juin 2010 à 14:07

Partager

Le train à sustentation magnétique devait relier la Suisse d'Est en Ouest.

Le projet de train souterrain à grande vitesse ne se concrétisera sans doute jamais. Faute de soutien financier et politique suffisant, la société Swissmetro SA va être liquidée et les droits reviendront à l'EPFL. Pro Swissmetro voit au contraire de bonnes chances de concrétiser cette idée.



The new line reduces total system costs by around 14%.

Limitations & Takeaways

Limitations

- Lack of data

→ Very limited network data (only IC lines and not all stations)

→ Very little passenger data (fixed demand not taking into account time also)

- Simplifying assumptions

→ Links are modeled in a simple way (example same speed everywhere)

→ Simplistic generalised cost (no cost of the ticket, no period of the day, no purpose of the trip, …)

Takeaways

- Modular approach

→ All assumptions can be easily modified if more data were available

→ Depending on use case highly modifyable approach

→ **Overall goal reached**

THANK YOU FOR YOUR ATTENTION!!!

References

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- Images : CFF website