

Transportation networks

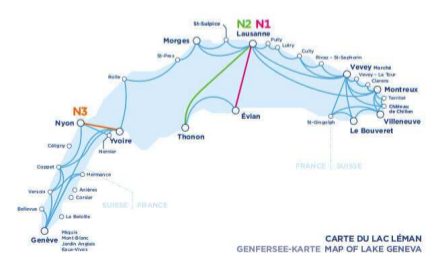
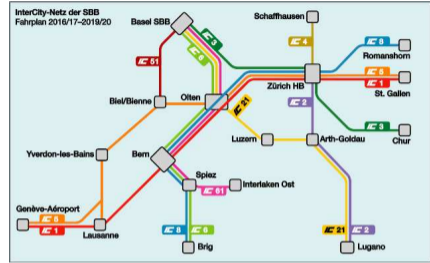
Modeling assumptions

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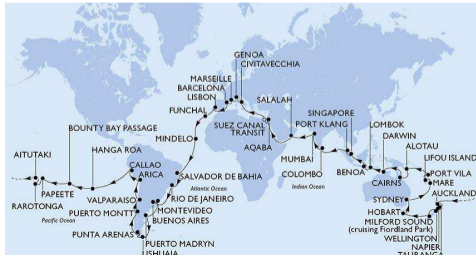
Introduction to transportation systems



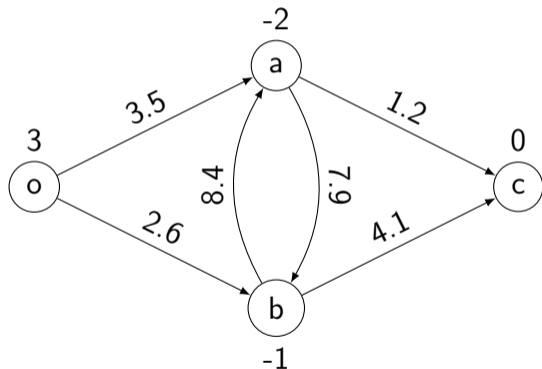
Transportation networks: supply



Transportation networks: supply



Network: mathematical model



Networks

- Nodes: \mathcal{N}
- Arcs: \mathcal{A}
- Incidence function

$$\phi : \mathcal{A} \rightarrow \mathcal{N} \times \mathcal{N}$$

- Quantities on nodes
- Quantities on arcs

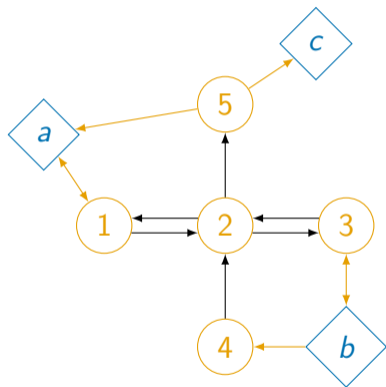
Road networks

Nodes

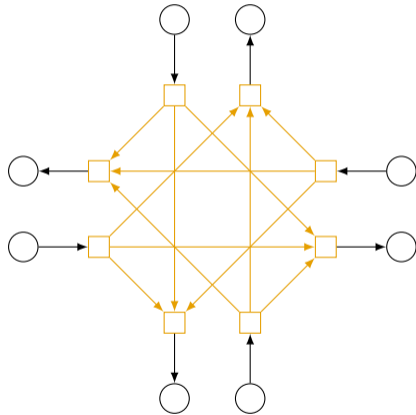
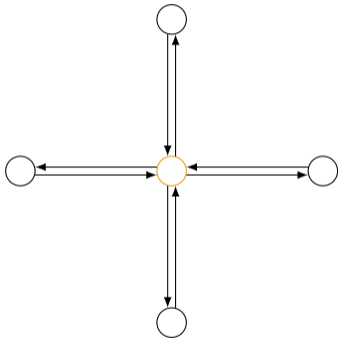
- ▶ Geo-coded.
- ▶ **Centroids**: associated with geographical zones.
- ▶ **Intersections**.
- ▶ Merging points, capacity changes.

Links

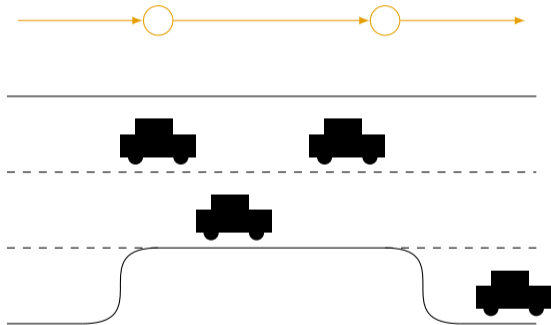
- ▶ Centroid connectors.
- ▶ Homogenous segments of road.



Road networks: intersections



Road networks: capacity changes



Road networks: data

Nodes

- ▶ Demand: in-flow, out-flow

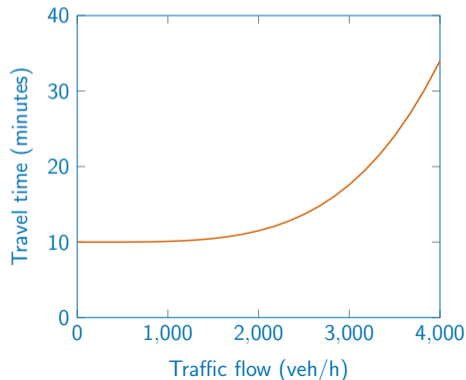
Links

- ▶ Flow, capacity (veh/min).
- ▶ Travel time, free-flow travel time (min).
- ▶ Travel cost, toll (CHF, €).
- ▶ Density, jam density (veh/km).

Link performance functions

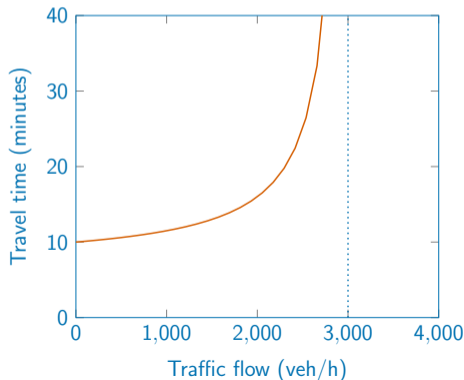
Without upper limit

$$t(x) = t_0 \left(1 + \alpha \left(\frac{x}{\ell} \right)^\beta \right)$$



With upper limit

$$t(x) = t_0 \left(1 + \alpha \left(\frac{x}{\ell - x} \right) \right)$$



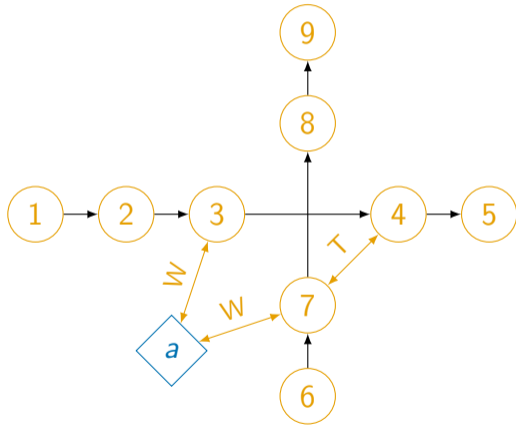
Public transportation

Nodes

- ▶ Geo-coded.
- ▶ Centroids: associated with geographical zones.
- ▶ Stations / stops.

Links

- ▶ Line segments.
- ▶ Walking, waiting [W].
- ▶ Transfer [T].



Public transportation: data

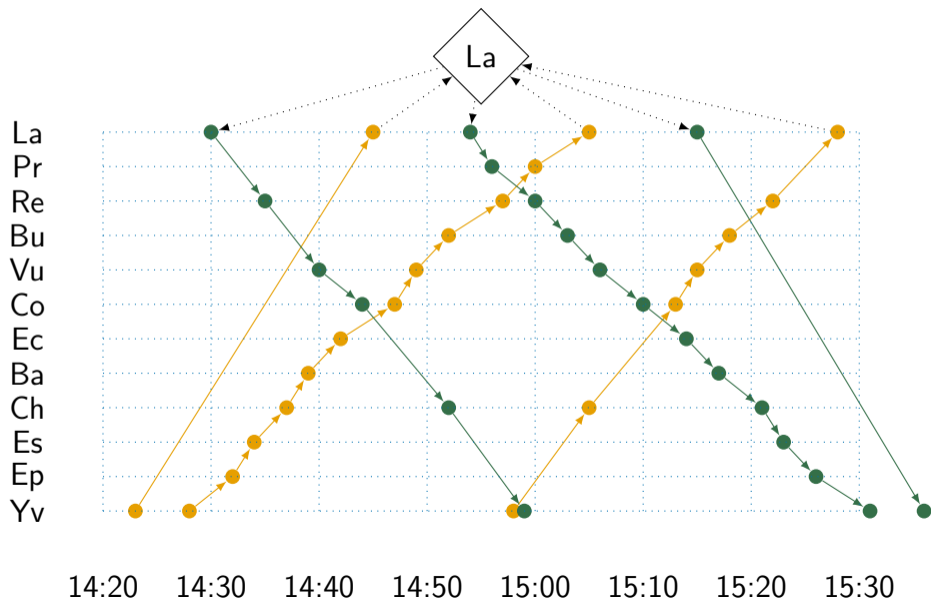
Nodes

- ▶ Demand: in-flow, out-flow

Links

- ▶ Frequency (veh/hour), headway (min).
- ▶ Travel time (min).
- ▶ Walking time (min).
- ▶ Waiting time (min).
- ▶ Transfer time (min).
- ▶ Capacity (number of seats).

Scheduled public transportation



Scheduled public transportation

14 00			Voie	Sect.
14 00	S5	Grandson		1
14 06	 S5	St. Gallen via Neuchâtel – Biel/Bienne – Zürich HB – Zürich Flughafen 		1
14 18	S30	Fribourg/Freiburg via Yverdon-Champ Pittet – Yvonand – Chéryes – Payerne		3
14 22	 S5	Lausanne 		2
14 28	S1	Lausanne via Ependes VD – Essert-Pittet – Chavornay – Bavois		2
14 32	S1	Grandson		1
 14 39	 S5	St. Gallen via Neuchâtel – Biel/Bienne – Zürich HB – Zürich Flughafen 		1
 14 39	 S5	Zürich HB via Neuchâtel – Biel/Bienne – Solothurn – Olten 		1
 14 46	R	Ste-Croix via Yverdon William Barbey – La Bréaz – Vuilleboeuf – Baulmes		B3
14 53	 S5	Genève-Aéroport via Morges – Genève 		2
14 57	S5	Aigle via Chavornay – Cossonay-Ponthalaz – Bussigny – Lausanne		2

Nodes

- ▶ Space and time.
- ▶ Centroids.
- ▶ Time-table.

Links

- ▶ Line segments.
- ▶ Walking, waiting.
- ▶ Transfer.
- ▶ Departure time choice.

Scheduled public transportation: data

Nodes

- ▶ Demand: in-flow, out-flow

Links

- ▶ Travel time (min).
- ▶ Walking time (min).
- ▶ Waiting time (min).
- ▶ Transfer time (min).
- ▶ Capacity (number of seats).

Pedestrians



Difficulties

- ▶ Level of granularity (door-to-door).
- ▶ No physical network, lane, etc.
- ▶ Strong interactions with other modes (feeding mode)

Multi-modal networks

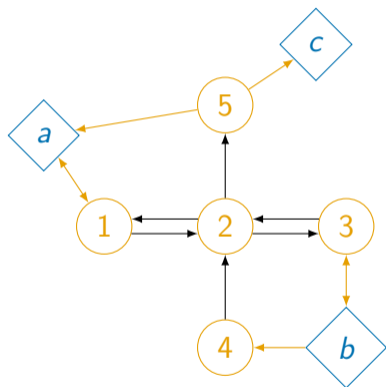


Difficulties

- ▶ Superposition of networks for each mode.
- ▶ All possible transfers: parkings, stations, airports, etc.

Paths

- ▶ $a \rightarrow 1 \rightarrow 2 \rightarrow 3 \rightarrow b$
- ▶ $a \rightarrow 1 \rightarrow 2 \rightarrow 5 \rightarrow c$
- ▶ $b \rightarrow 3 \rightarrow 2 \rightarrow 5 \rightarrow a$
- ▶ $b \rightarrow 3 \rightarrow 2 \rightarrow 1 \rightarrow a$
- ▶ $b \rightarrow 4 \rightarrow 2 \rightarrow 5 \rightarrow a$
- ▶ $b \rightarrow 4 \rightarrow 2 \rightarrow 1 \rightarrow a$
- ▶ $b \rightarrow 3 \rightarrow 2 \rightarrow 5 \rightarrow c$
- ▶ $b \rightarrow 4 \rightarrow 2 \rightarrow 5 \rightarrow c$

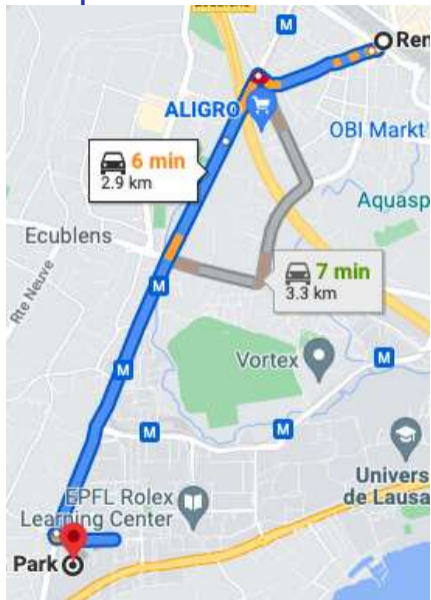


Link-path incidence matrix

1. $a \rightarrow 1 \rightarrow 2 \rightarrow 3 \rightarrow b$
2. $a \rightarrow 1 \rightarrow 2 \rightarrow 5 \rightarrow c$
3. $b \rightarrow 3 \rightarrow 2 \rightarrow 5 \rightarrow a$
4. $b \rightarrow 3 \rightarrow 2 \rightarrow 1 \rightarrow a$
5. $b \rightarrow 4 \rightarrow 2 \rightarrow 5 \rightarrow a$
6. $b \rightarrow 4 \rightarrow 2 \rightarrow 1 \rightarrow a$
7. $b \rightarrow 3 \rightarrow 2 \rightarrow 5 \rightarrow c$
8. $b \rightarrow 4 \rightarrow 2 \rightarrow 5 \rightarrow c$

	1	2	3	4	5	6	7	8
$(a, 1)$	1	1	0	0	0	0	0	0
$(b, 3)$	0	0	1	1	0	0	1	0
$(b, 4)$	0	0	0	0	1	1	0	1
$(1, a)$	0	0	0	1	0	1	0	0
$(1, 2)$	1	1	0	0	0	0	0	0
$(2, 1)$	0	0	0	1	0	1	0	0
$(2, 3)$	1	0	0	0	0	0	0	0
$(2, 5)$	0	1	1	0	1	0	1	1
$(3, b)$	1	0	0	0	0	0	0	0
$(3, 2)$	0	0	1	1	0	0	1	0
$(4, 2)$	0	0	0	0	1	1	0	1
$(5, a)$	0	0	1	0	1	0	0	0
$(5, c)$	0	1	0	0	0	0	1	1

Path performance



Main assumption

Must be link additive

Examples

- ▶ Travel time.
- ▶ Distance.
- ▶ Travel cost.
- ▶ Generalized costs.

Counter-examples

- ▶ Speed.
- ▶ Flow.

Summary

Networks

- ▶ Transportation supply.
- ▶ Interface with the demand.

Network models

- ▶ Nodes and links.
- ▶ Data.

Complexity

- ▶ Must be consistent with the needs.
- ▶ Too simple: useless.
- ▶ Too complex: intractable