

# Transportation networks

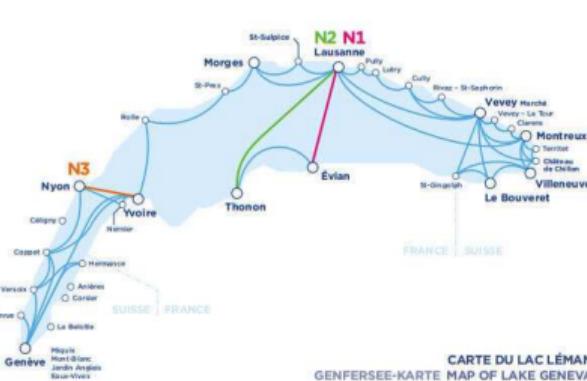
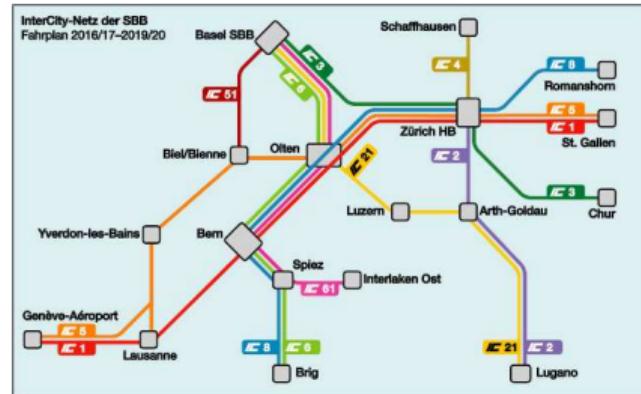
## Modeling assumptions

Michel Bierlaire

Introduction to transportation systems

**EPFL**

# Transportation networks: supply

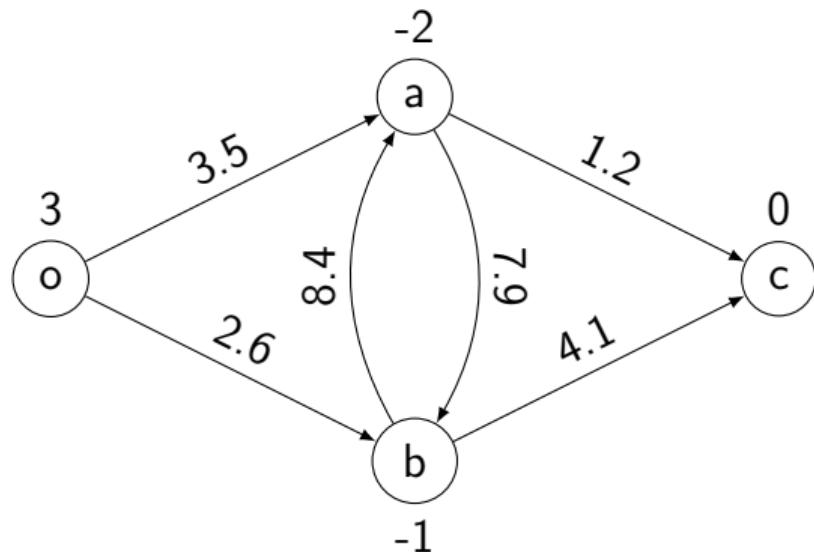


CARTE DU LAC LÉMAN  
GENFERSEE-KARTE MAP OF LAKE GENEVA

# 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

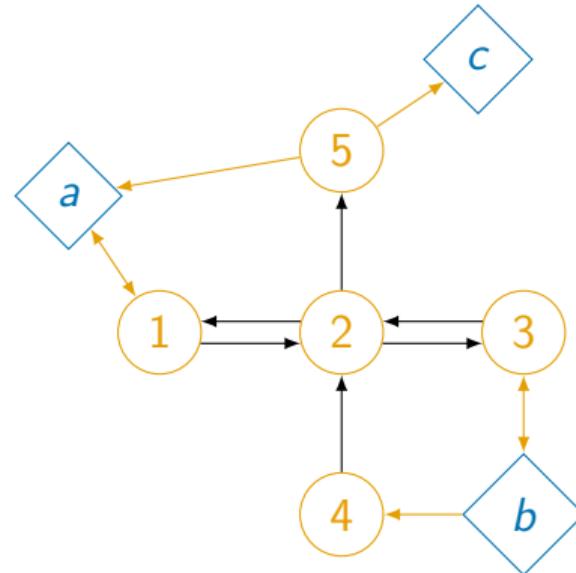
# Road networks

## Nodes

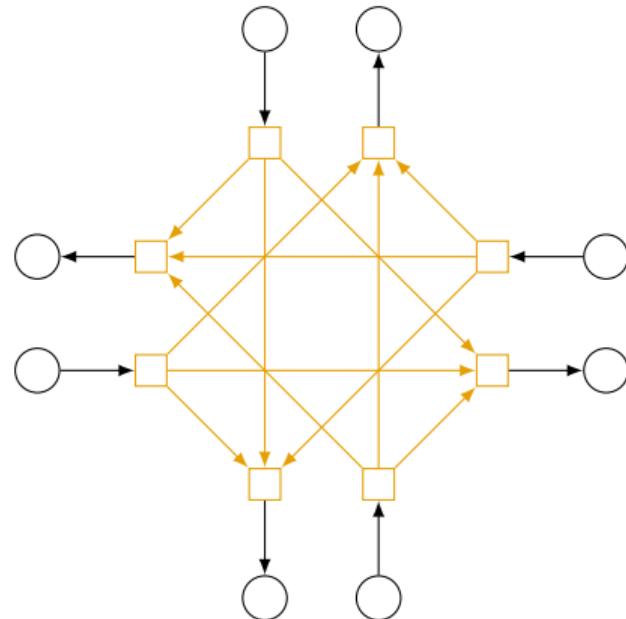
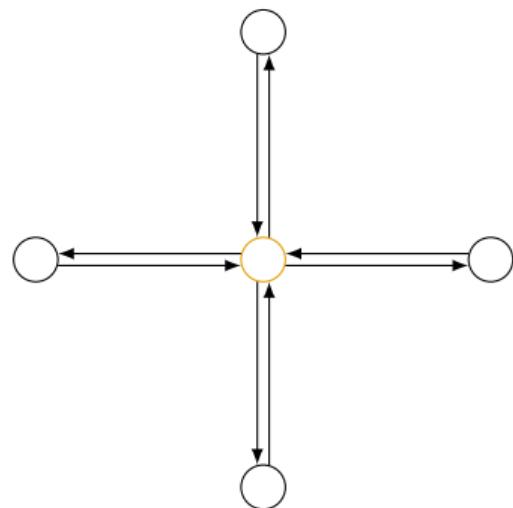
- ▶ Geo-coded.
- ▶ **Centroids**: associated with geographical zones.
- ▶ **Intersections**.
- ▶ Merging points, capacity changes.

## Links

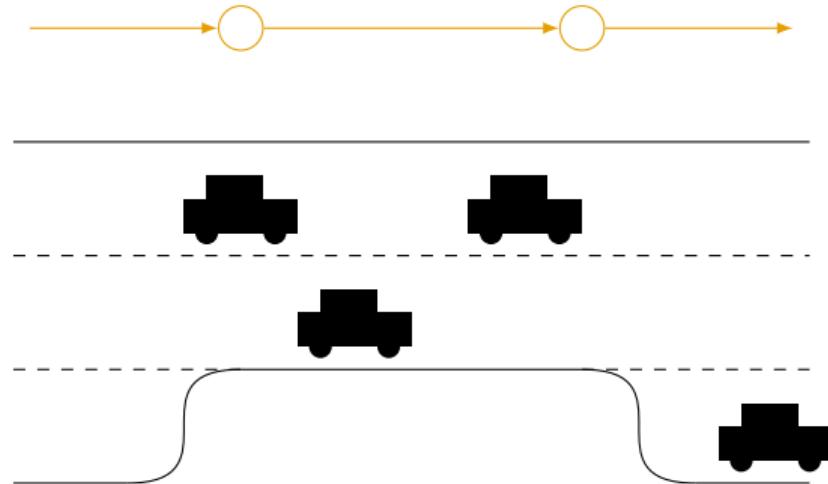
- ▶ Centroid connectors.
- ▶ Homogenous segments of road.



## Road networks: intersections



## Road networks: capacity changes



# Road networks: data

## Nodes

- ▶ Demand: in-flow, out-flow

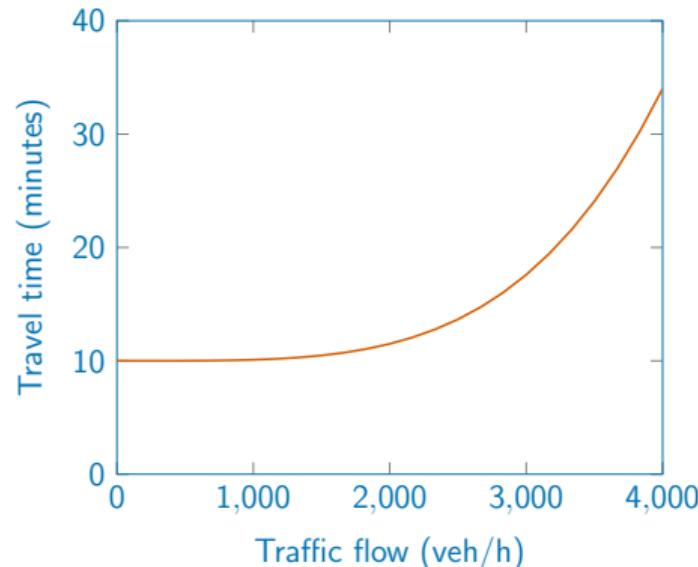
## Links

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

# Link performance functions

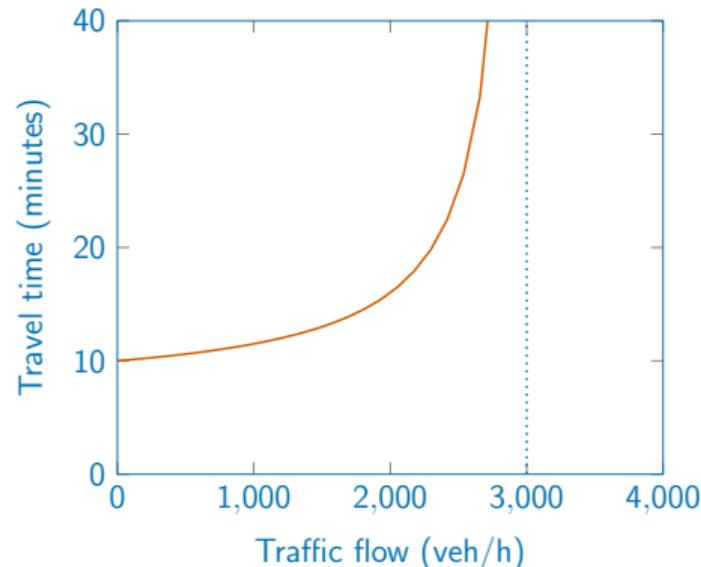
Without upper limit

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



With upper limit

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



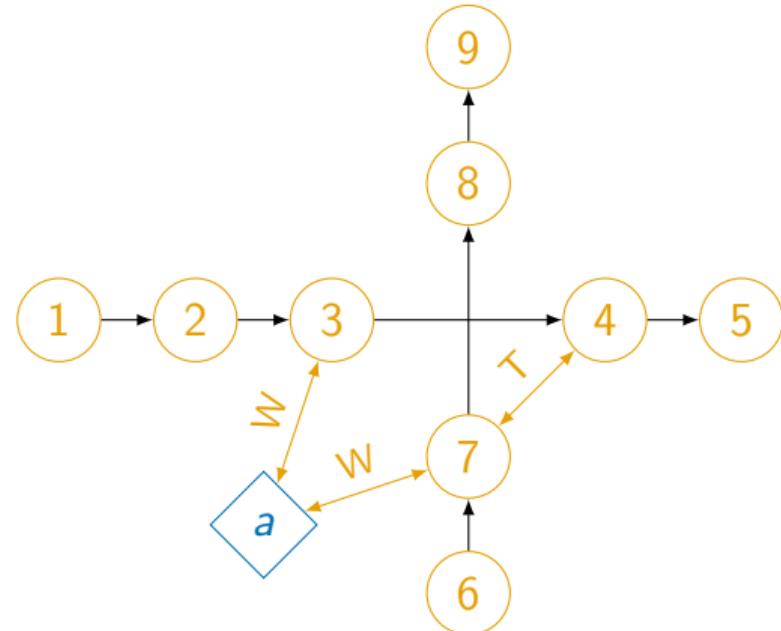
# Public transportation

## Nodes

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

## Links

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



# Public transportation: data

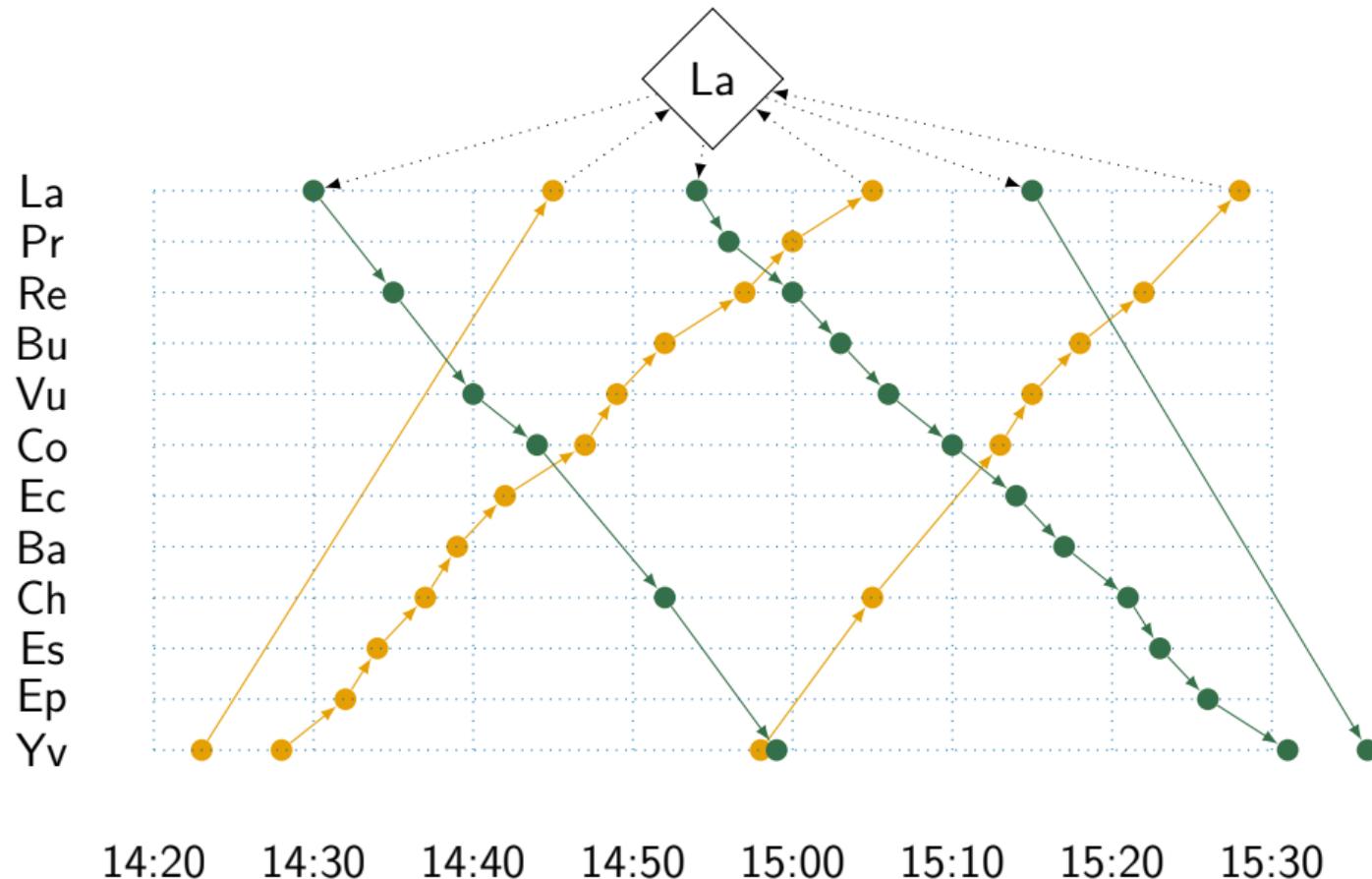
## Nodes

- ▶ 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	■■5	St. Gallen via Neuchâtel – Biel/Bienne – Zürich HB – Zürich Flughafen ■		1
14:18	S30	Fribourg/Freiburg via Yverdon-Champ Pittet – Yverdon – Cheyres – Payerne		3
14:22	■■5	Lausanne ■		2
14:28	S1	Lausanne via Epenes VD – Essert-Pittet – Chavornay – Baulmes		2
14:32	S1	Grandson		1
■ 14:39	■■5	St. Gallen via Neuchâtel – Biel/Bienne – Zürich HB – Zürich Flughafen ■		1
■ 14:39	■■5	Zürich HB via Neuchâtel – Biel/Bienne – Solothurn – Olten ■		1
■ 14:46	R	Ste-Croix via Yverdon William Barbey – La Brinaz – Vuiteboeuf – Baulmes	B3	
14:53	■■5	Genève-Aéroport via Morges – Genève ■		2
14:57	S5	Aigle via Chavornay – Cossonay-Penthalaz – 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

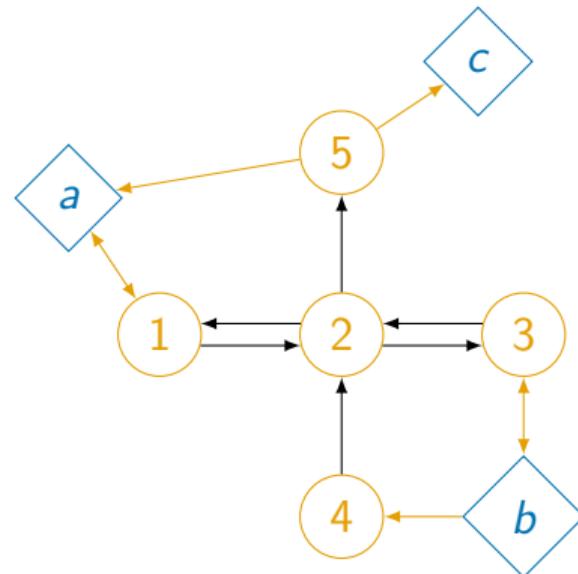


## Difficulties

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

# Paths

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

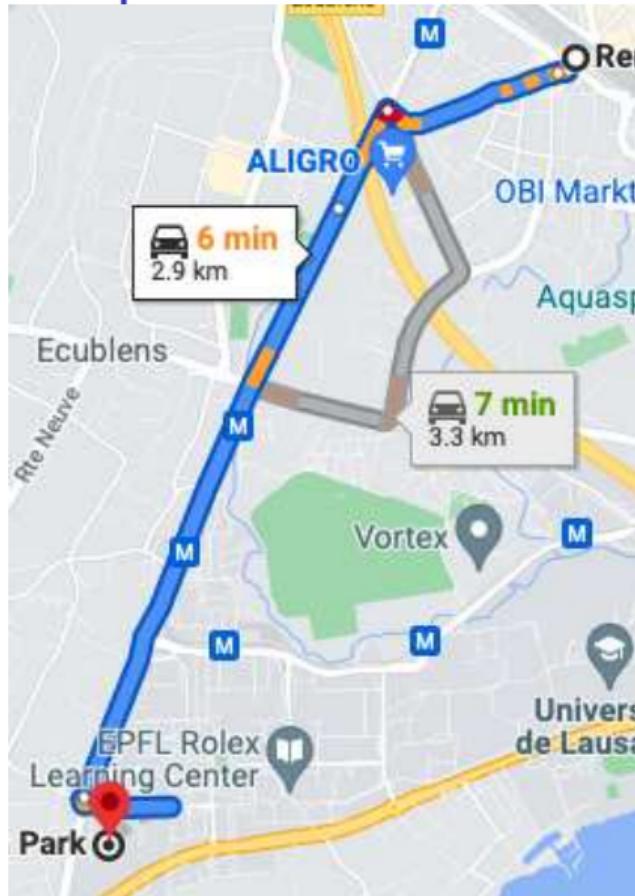


## Link-path incidence matrix

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