CONNECTIVITY AND ACCESSIBILITY APPROACHES TO NETWORK ROBUSTNESS:

THE ALLOCATION OF MOBILITY HUBS

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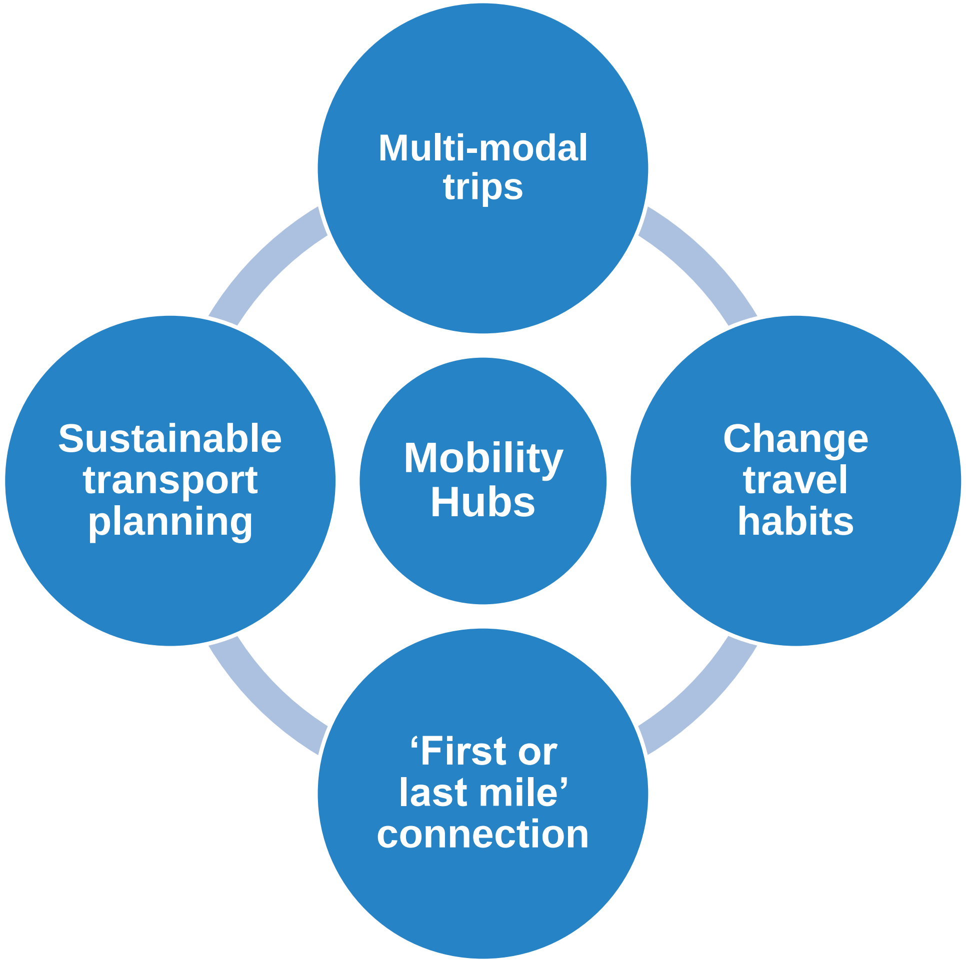
MOBILITY HUBS (MH)

Definition

Dedicated and permanent platforms where **public and shared transport** can be integrated by switching between modes

2005 17 Cities

2019 2.900 Cities



BIKE-SHARING AND PT INTEGRATION

Among the various "sharing" transport services, the most widespread and studied is **bike-sharing**, which is also the one for which the most data are available

Bike sharing can be seen as a stand-alone service to improve the first-last mile problem or in a synergy with the Public Transport Network (PTN) by providing the advantages for **interchanging between public transport stops**

We focus only on station-based Bike-Sharing (BS) and PTN integration

RESEARCH QUESTIONS

Can network robustness metrics and accessibility metrics help with the MH allocation choice?

Network robustness is the ability of networks to resist failures or attacks. MH may contribute to robustness by providing redundancy to PTN (Rose, 2009)

Accessibility refers to the relative ease of reaching a particular area (Hansen,1959)

HOW TO ALLOCATE MOBILITY HUBS?

The location of BS stations is mainly an optimization problem

Multi-Criteria Decision Methods (MCDM)

Criteria

Including

- **Robustness**
- **Sustainability**
- **Accessibility**

MCDM

Using "easily" accessible Data

The most suitable PT stop for mobility hubs: Multidimensional analysis					
Potential Location / Criteria / *Sub-criteria*	Connectivity *Stop centrality measures* *PTN efficiency loss after stop removal*	Accessibility *Area accessibility loss after stop removal*	Sustainability *No. of sustainable modes in the stop*	Other *Demand points/zones* *Points of interest* *Population density* …	*Score*
Stop 1					
Stop 2					
…					
Stop N					

NODE CENTRALITY MEASURES AND NETWORK ROBUSTNESS

Node Centrality

Betweenness

Degree

Connectivity - Efficiency

$$E = \frac{1}{N(N-1)} \sum_{i \neq j} \frac{1}{d_{ij}}$$

Unweighted

$$E_p = \frac{1}{N(N-1)} \sum_{i \neq j} \frac{w_{ij}}{d_{ij}}$$

Weighted by the flow of "passengers"

<u>Applied to:</u>

Aggregated single-mode networks (**SMNs**): metro, tram, and bus network (**PTN**)

PTN including travel time (**PTNt**)

PTNt weighted by passenger flows (**WPTNt**)

Aggregated PTN stops and sharing-bike stations including travel time by bike (**PTNBt**)

PTNB weighted by passenger flows (**WPTNBt**)

AREA ACCESSIBILITY MEASURES

Doubly constrained spatial interaction model (SIM)

The flow between the origin (O_i) and destination (D_j) is a function of the **potential** at each origin, the **attractiveness** of each destination, and the **cost** (d_{jj}) of overcoming the separation between them:

$$T_{ij} = A_i B_j O_i D_j exp(\beta d_{ij})$$

$$A_i = \left(\sum_j B_j D_j exp(\beta d_{ij})\right)^{-1}$$

$$B_j = \left(\sum_i A_i O_i exp(\beta d_{ij})\right)^{-1}$$

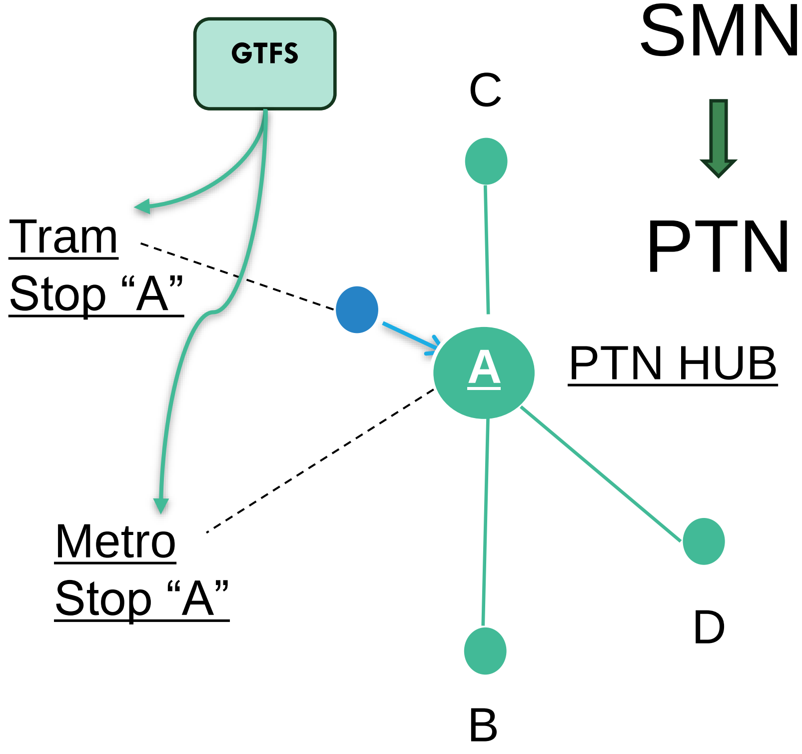
The parameter β may be calibrated (estimated) and used to calculate the indicator of Accessibility for each area

$$ACC_i = \sum_j D_j f(\beta, d_{ij})$$

From 2. PTN including travel time

FROM SMNS TO PTN

1 **SMNs_Stop Aggregation (by stop name)**



SMNs

↓

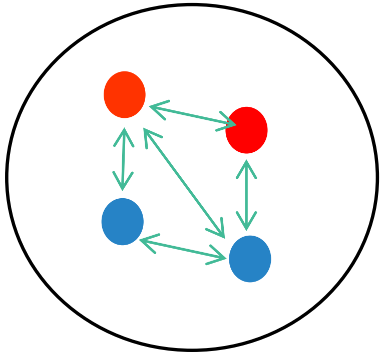
PTN

→

PTNt

2 **Adding Travel Time Graph Expansion**

A

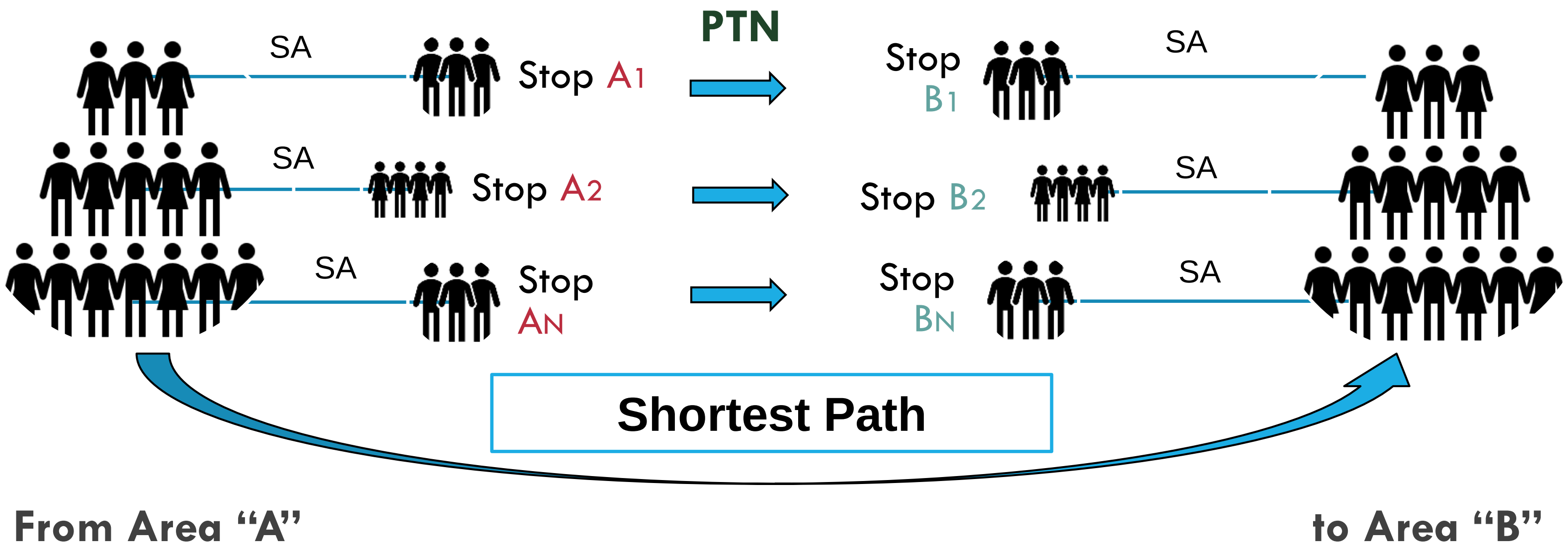


Intra-Inter links

Travel Time =
In-vehicle Time + Waiting Time + Transfer Penalty

ADDING PASSENGERS FLOWS ③

- Demand per O/D **areas** → demand per i/j **stop**
- Static assignment (SA; deterministic)

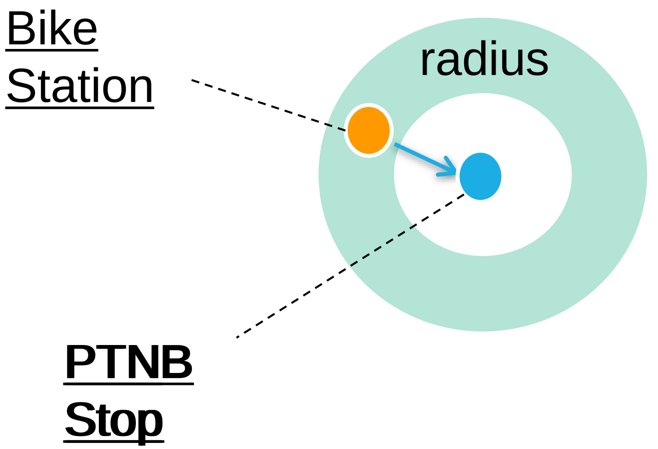


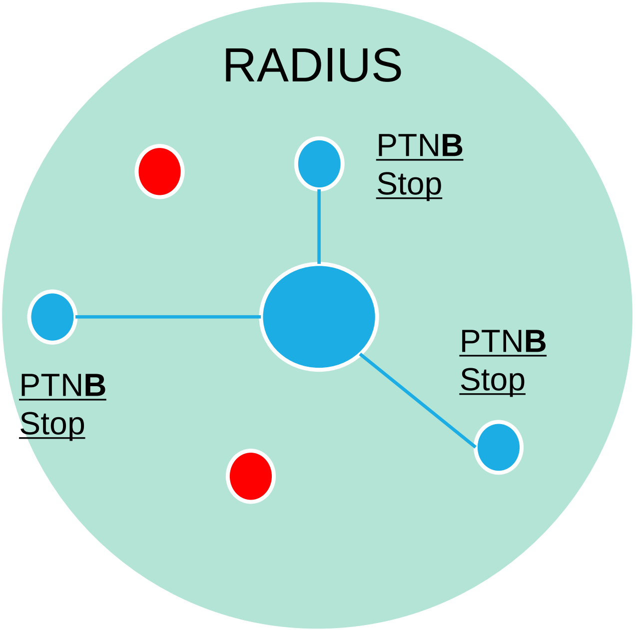
ADDING THE BIKE-SHARING MODE 4

Bike Station – PTN Aggregation

Bike Network as a new transport mode to use after a disruption affecting the PTN

PTN ⇨ PTNB





Travel Time by bike between PTNB

DISRUPTION: STOP REMOVAL

We simulate disruptive events removing nodes (Stops) and calculate the **efficiency loss** following three different strategies:

- Betweenness rank
- Degree Rank
- Random

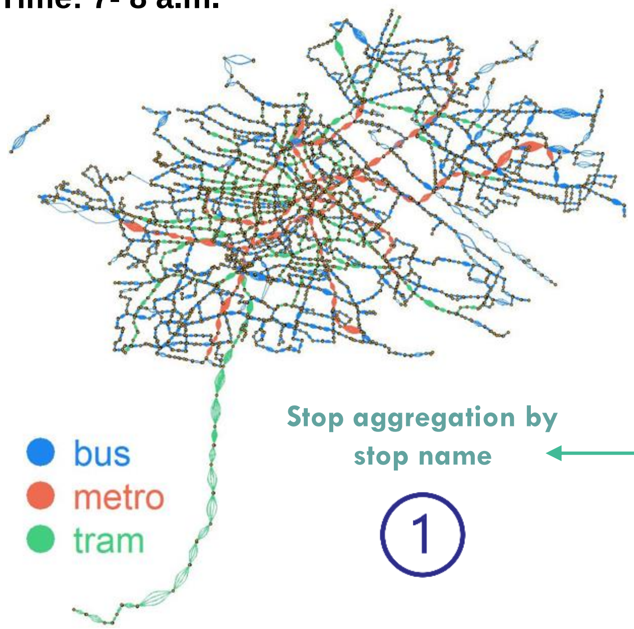
After each stop removal, the flow of passengers at other stops is redistributed!

CASE STUDY: VIENNA

Vienna benefits from the services of a unique PT provider, namely Wiener Linien GmbH (WL). Vienna's PTN consists of **5 metro, 29 tram, and 127 bus routes.** WienMobil Rad is the public bicycle rental service fully operational from fall 2022 with **233** fixed bike-stations 3,000 bicycles

PTN

Time: 7- 8 a.m.



GTFS

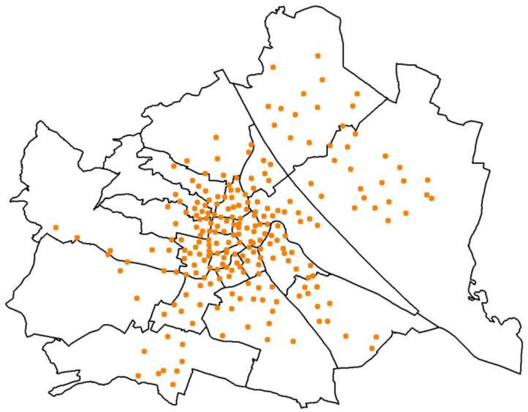
1

Stop aggregation by stop name

stop_name	route_short_name	mode
Praterstern S+U	5	tram
Praterstern S+U	5B	bus
Praterstern S+U	82A	bus
Praterstern	U2	metro
Praterstern S+U	O	tram
Praterstern	U2	metro
Praterstern	U1	metro
Praterstern	U1	metro
Praterstern S+U	80A	bus
Praterstern S+U	O	tram

2

Aggregation by distance: radius = 150mt



Bike-sharing stations

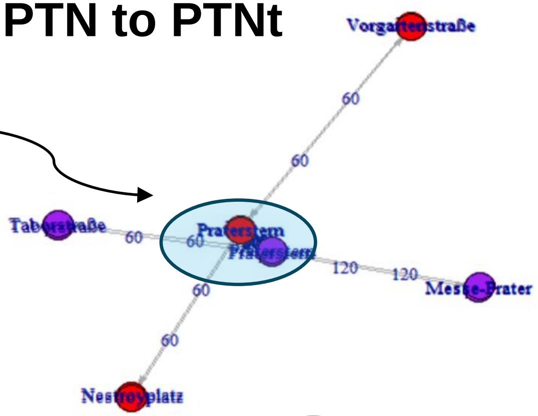
GIS

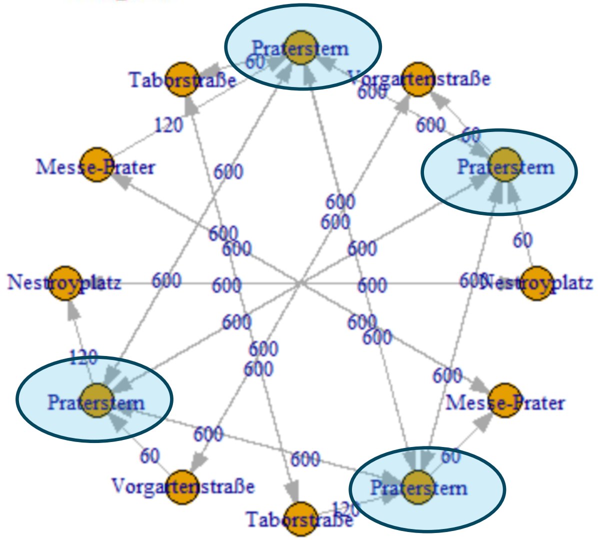
ADDING THE SHARE-BIKE SERVICE

From SMs to PTN
(Aggregation by stop name)

From PTN to PTNt

From
GTFS





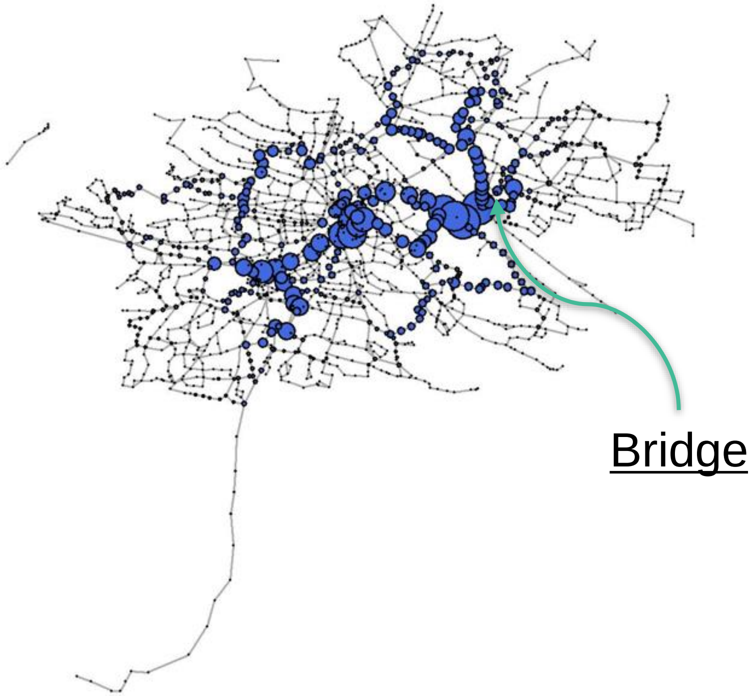
Expansion

Example: **Pratestern (Metro)**
Penalty = 600 sec

NODE CENTRALITY

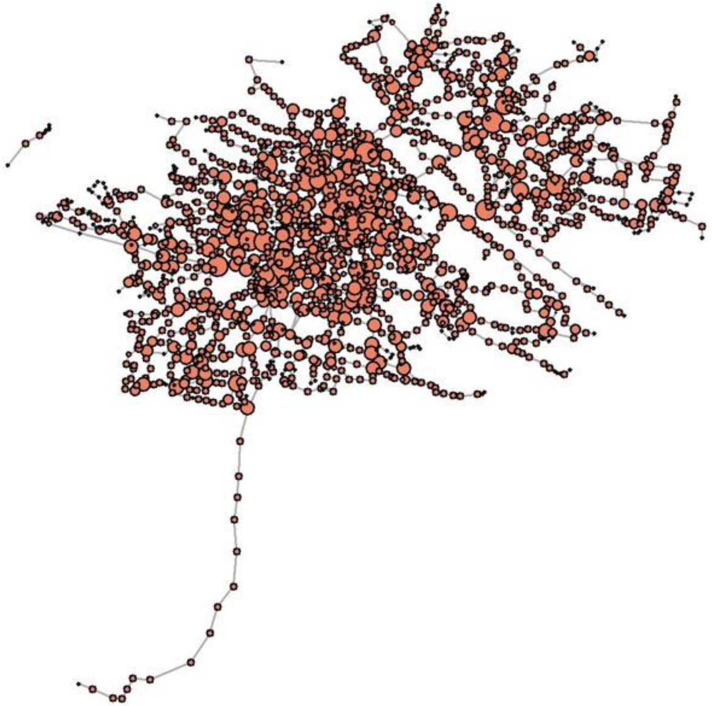
Betweenness

(Aggregated Stops)



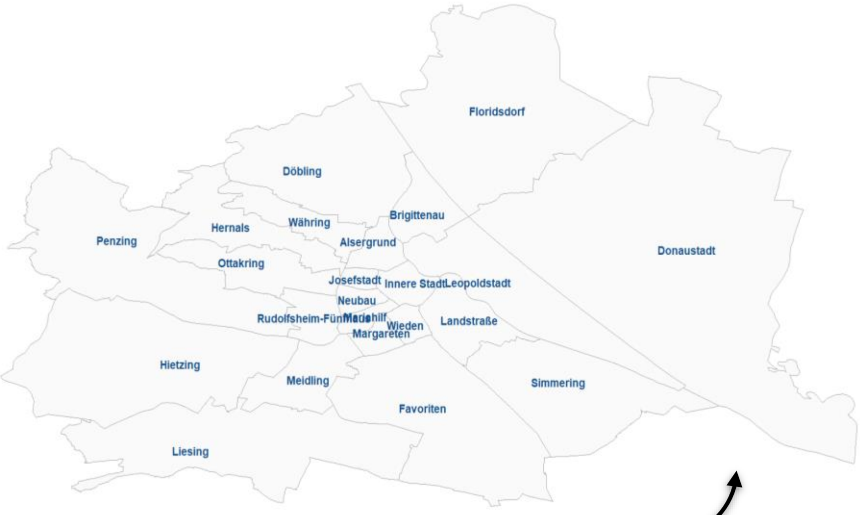
Degree

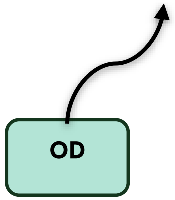
(Aggregated Stops)



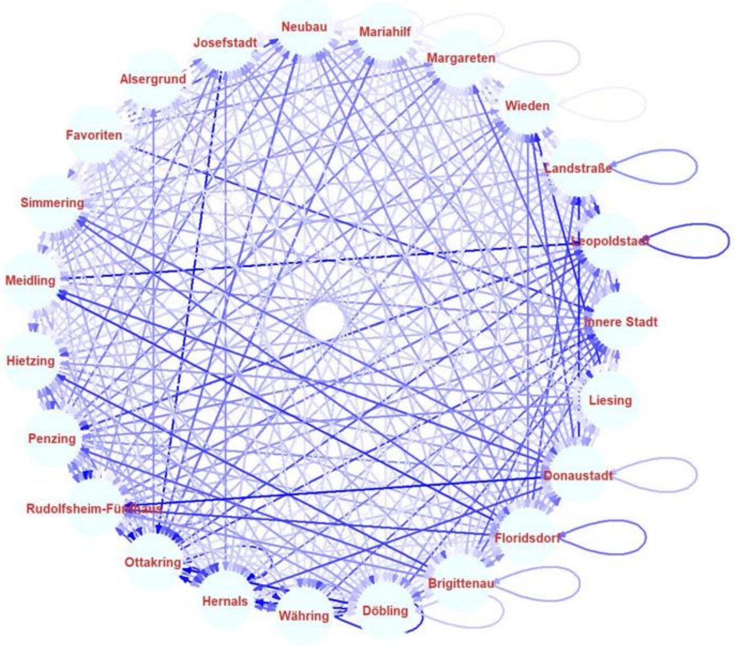
ORIGIN-DESTINATION FLOWS

The composition of flows is very heterogeneous with some peaks (blue lines) such as between **Favoriten**, a highly populated urban area with many residential buildings, and the central district **Innere Stadt**



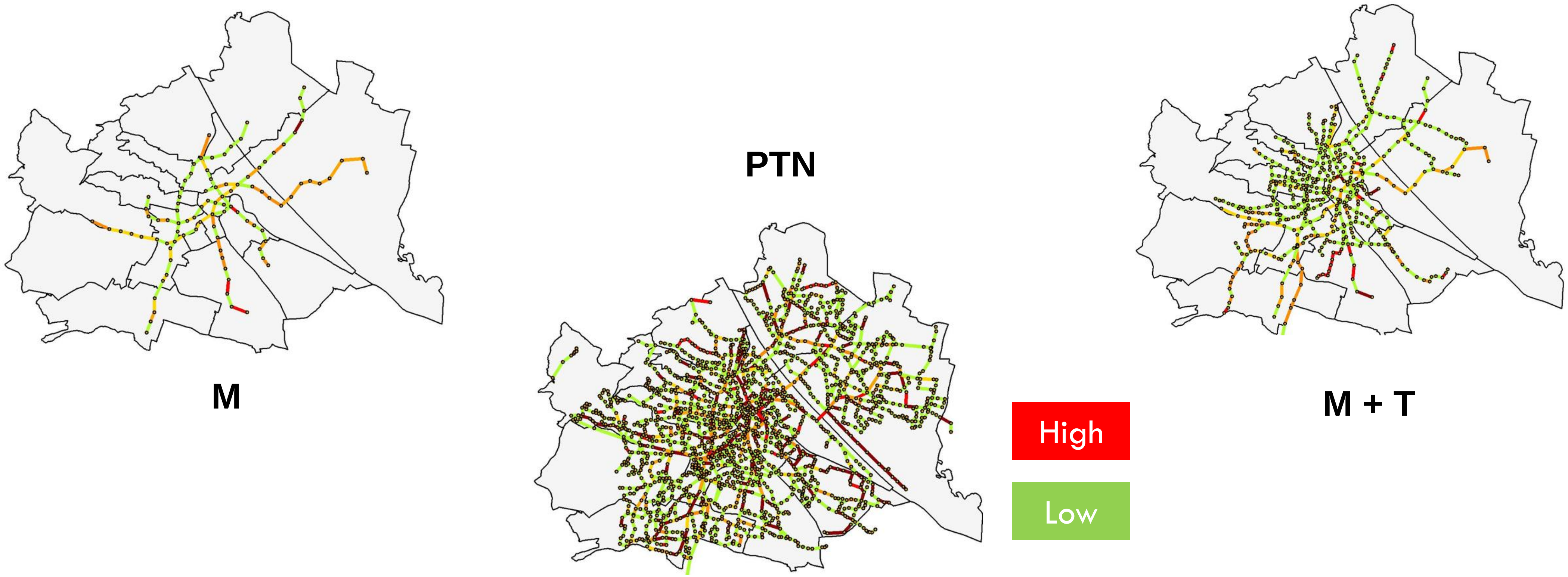


Commuting destination
Data from statistik.at

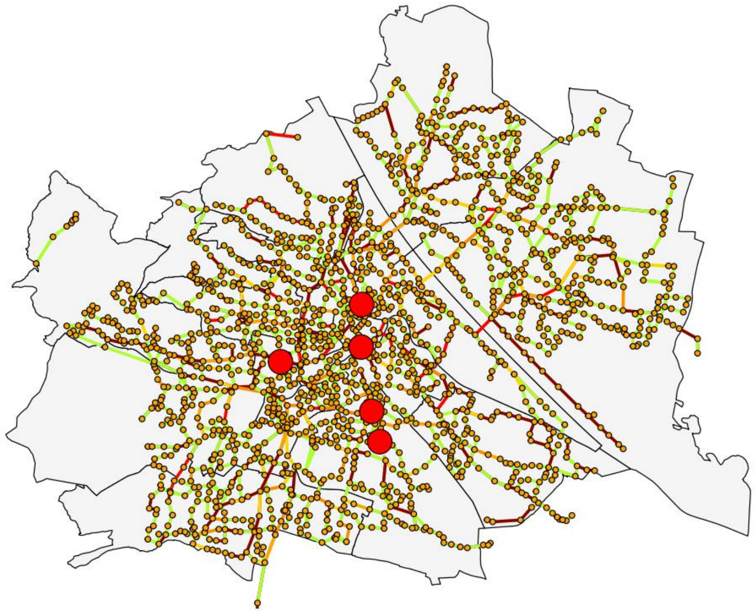


FLOWS ASSIGNMENT

Non-adaptive assignment: Metro (M), metro+tram (M+T), metro+tram+bus (PTN) considering the waiting time (1/frequency) and the 10-min penalty for line changes (also in route choice)



ANALYSIS



Remove N based on different strategies

flows re-distribution

- Recalculate travel time d_{ij} → Compute the loss of area accessibility

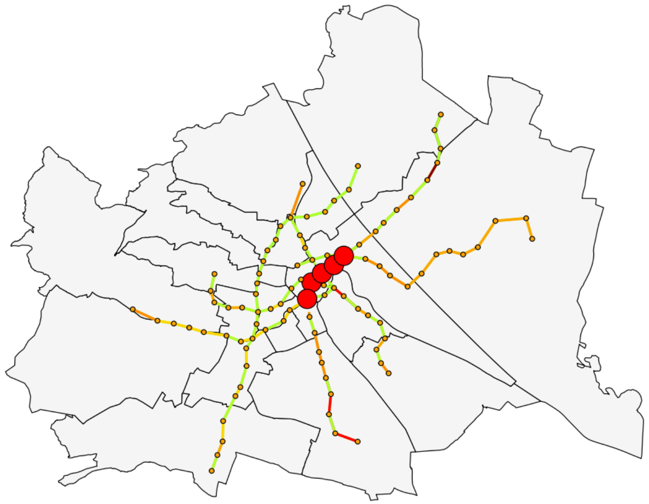
$$ACC_i = \sum_j D_j f(\beta, d_{ij})$$

- Recalculate Passenger-based efficiency E_p → Compute the loss of network efficiency

$$E_p = \frac{1}{N(N-1)} \sum_{i \neq} \frac{w_{ij}}{d_{ij}}$$

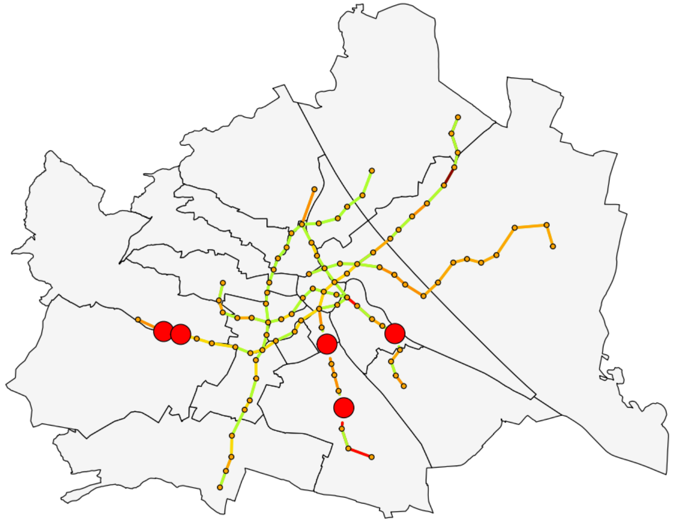
wij passenger flows

PRELIMINARY SIMULATIONS: METRO



Remove 5 nodes with
highest betweenness
with
flows re-distribution

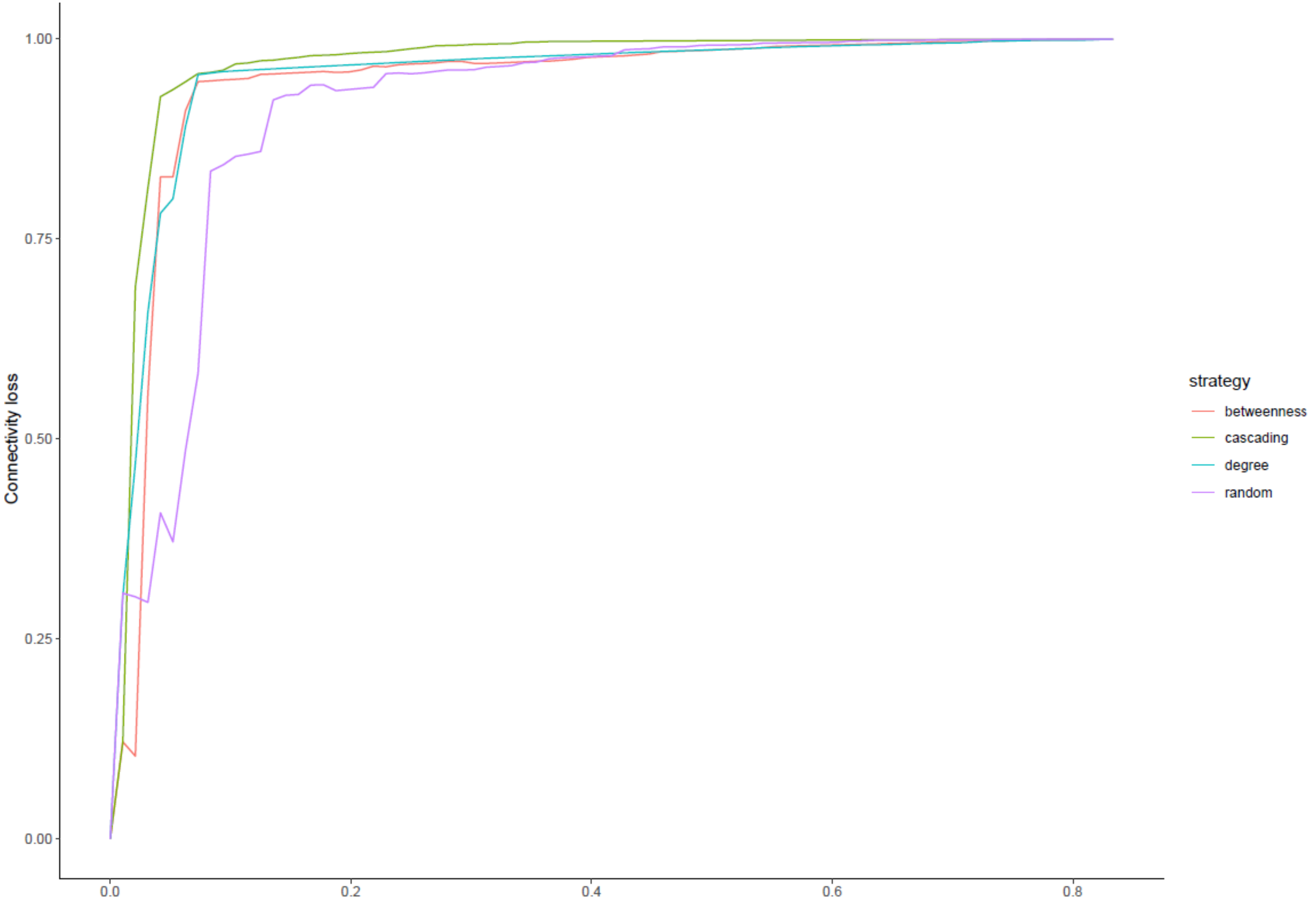
Loss Network Efficiency $= -0.83\%$



Remove 5 nodes
randomly
with
flows re-distribution

Loss Network Efficiency $= -0.63\%$

PRELIMINARY SIMULATIONS: METRO

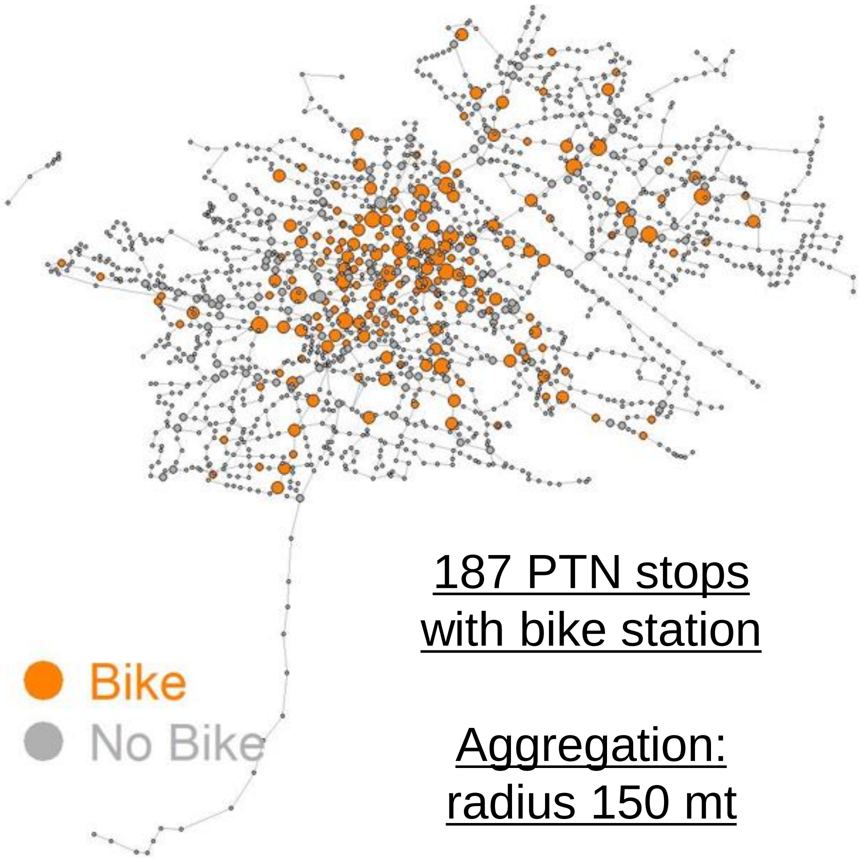


Very sensitive to strategic disruptive event

We will see how the plot changes when **multi-modality** is considered!

ADDING THE SHARE-BIKE SERVICE

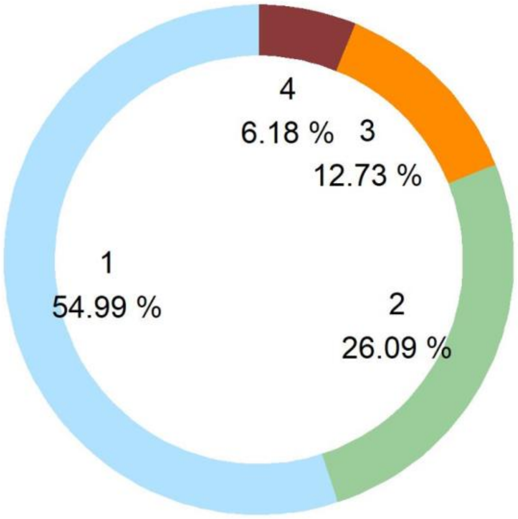
From PTN to PTNB



187 PTN stops with bike station

Aggregation: radius 150 mt

Percentage of PTN by number of modes



NEXT STEPS

- Full demand per O/D **areas** → PTN demand per per O/D **areas**
- Computing areas accessibility
- Linking PTNB stations and computing travel time between any of them
- Setting parameters and improving node assignment
- Complete robustness and accessibility analysis after disruptions
- Select criteria for MCDM and provide a rank of the most suitable PT stops for mobility hubs

LIMITATIONS

- We do not include capacity and congestion
- We do not include the probability of a disruptive events
- Computational time is an issue

Thank you

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