CONNECTIVITY AND ACCESSIBILITY APPROACHES TO NETWORK ROBUSTNESS:

THE ALLOCATION OF MOBILITY HUBS

Caterina Malandri, Roberto Patuelli, Michele Rabasco, Aura Reggiani, Rebecca Rossetti

Department of Economics, University of Bologna, Italy

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

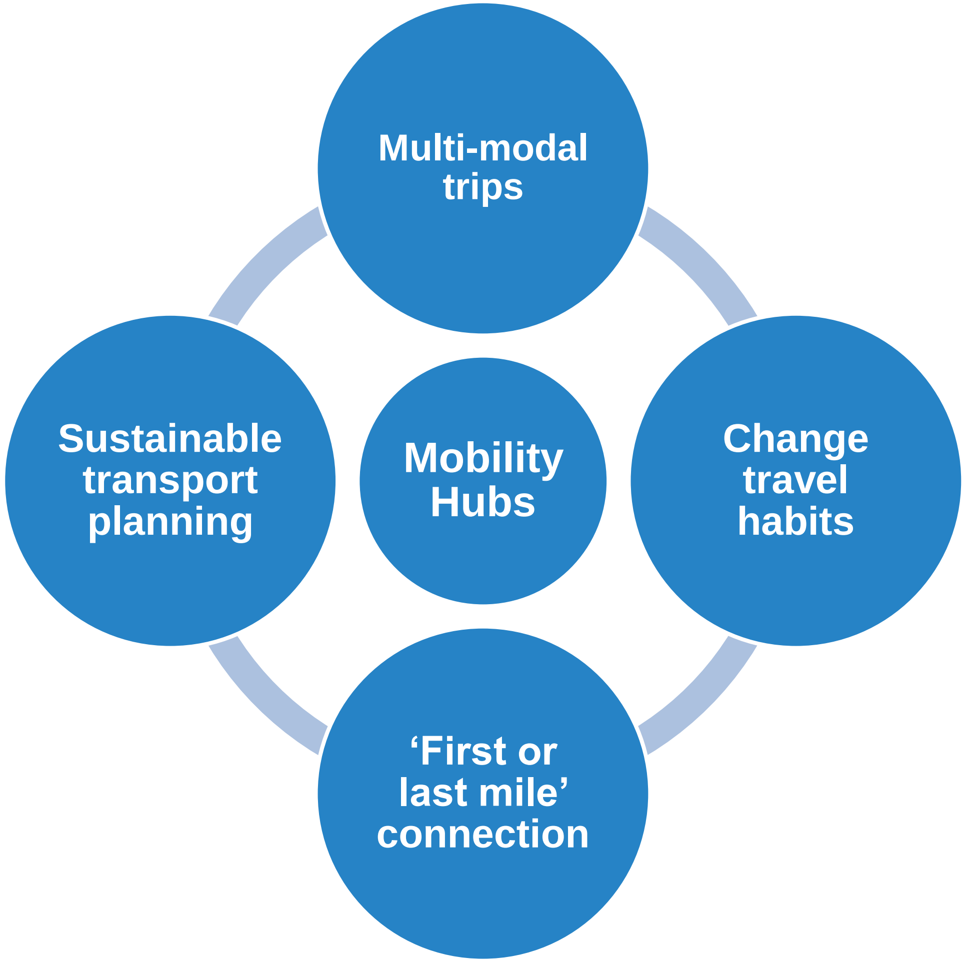
MOBILITY HUBS (MH)

Definition

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

2005 17 Cities

2019 2.900 Cities



RESEARCH QUESTIONS

Can network robustness and accessibility metrics help with MH location choice?

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

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

HOW TO ALLOCATE MOBILITY HUBS?

The location of bike sharing (BS) stations is mainly an optimization problem → Multi-Criteria Decision Methods (MCDM) → Including

- **Connectivity**
- **Robustness**
- **Accessibility**

We focus on:

Station-Based Bike-Sharing (SBBS) and Public Transport Network (PTN) integration

Reasons:

- SBBS is the most widespread and studied sharing mode and the one for which the most data are available
- Its role in **interchanging between public transport modes**

MCDM

Using "easily" accessible data

The most suitable PT stop for mobility hubs: multidimensional analysis					
Potential Location / **Criteria** / *Sub-criteria*	**Connectivity/ Robustness** *Node centrality measures* *PTN connectivity loss after the stop removal*	**Accessibility** *Area accessibility loss after the 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

Efficiency (to be added)

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

Unweighted

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

Weighted by the flow of “passengers”

Applied to:

1. Aggregated single-mode networks (**SMNs**): metro, tram, and bus network (**PTN**)
2. PTN including travel time (**PTNt**)
3. PTNt weighted by passenger flows (**WPTNt**)
4. Aggregated PTN stops and bike-sharing stations including travel time by bike (**PTNBt**)
5. PTNBt 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:

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

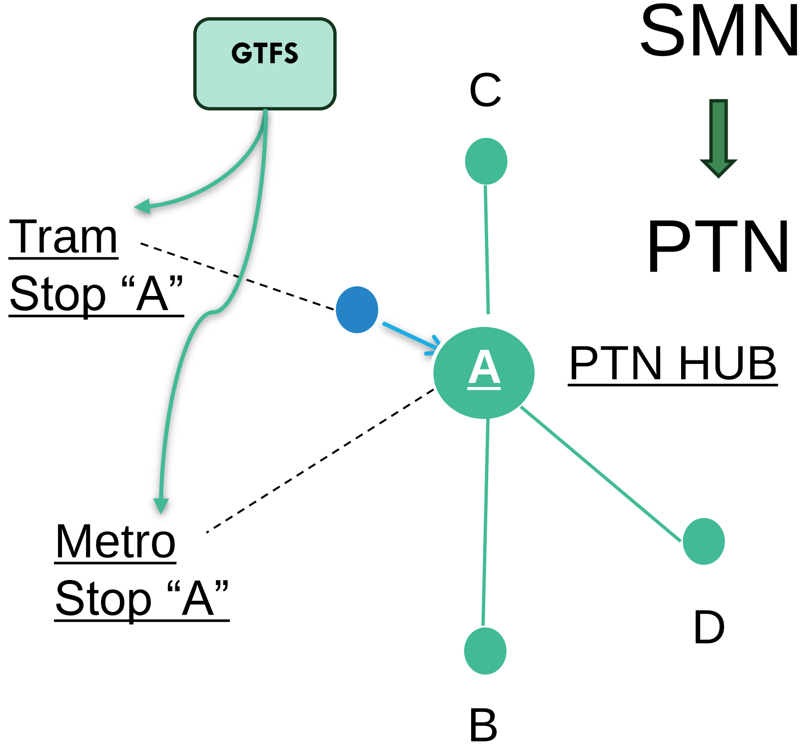
The parameter β (impedance parameter) may be calibrated (estimated) and used to calculate the indicator of Accessibility for each area

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

From 2. PTN including travel time

FROM SMNS TO PTN

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

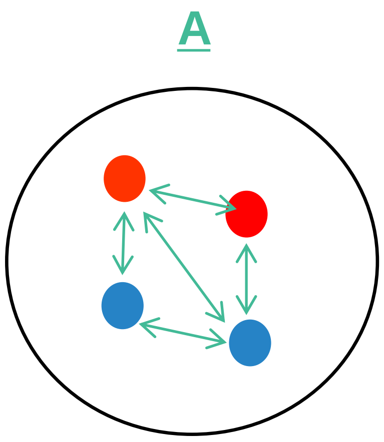


SMNs

PTN

2 **Adding Travel Time Graph Expansion**

PTNt

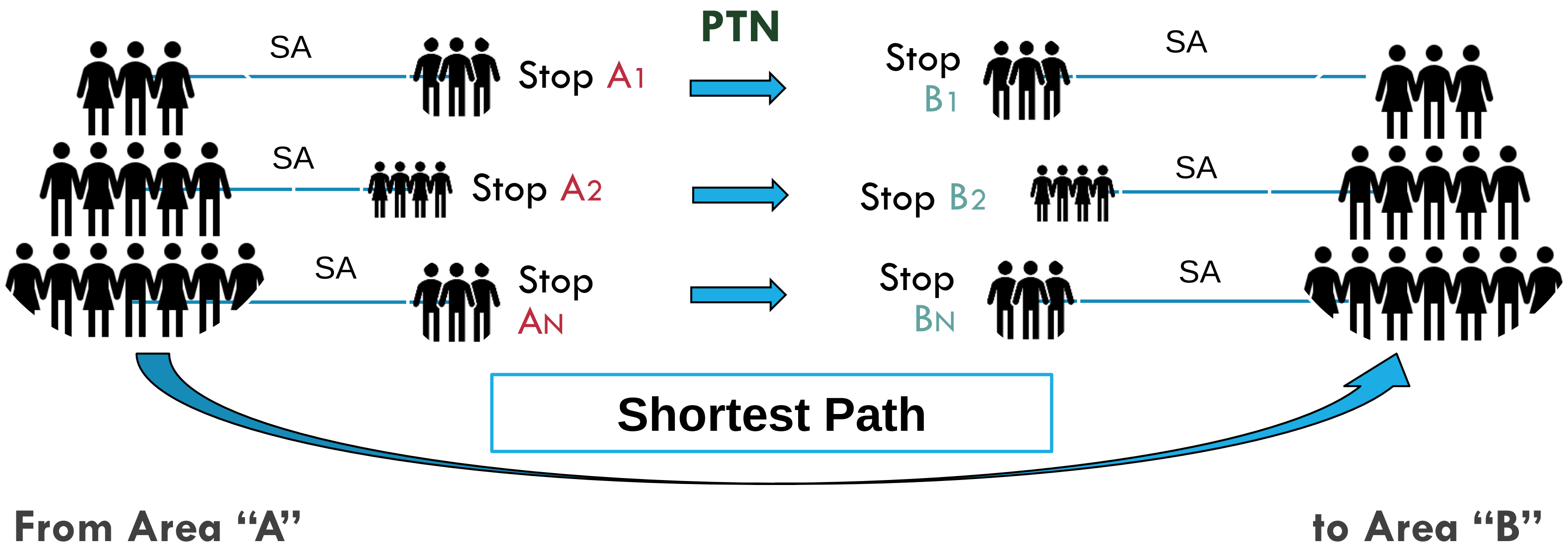


Intra-Inter links

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

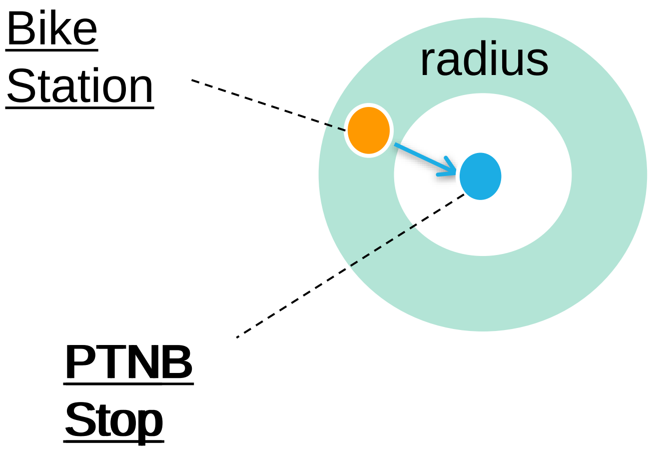
ADDING PASSENGERS FLOWS 3

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



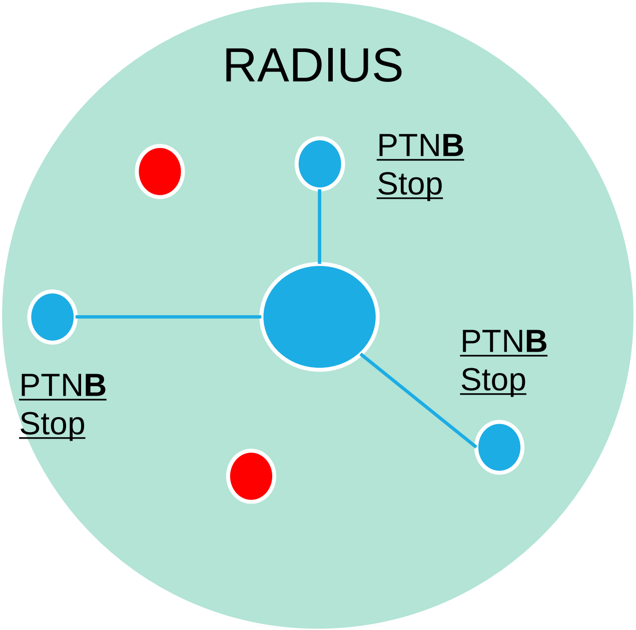
ADDING THE BIKE-SHARING MODE 4

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

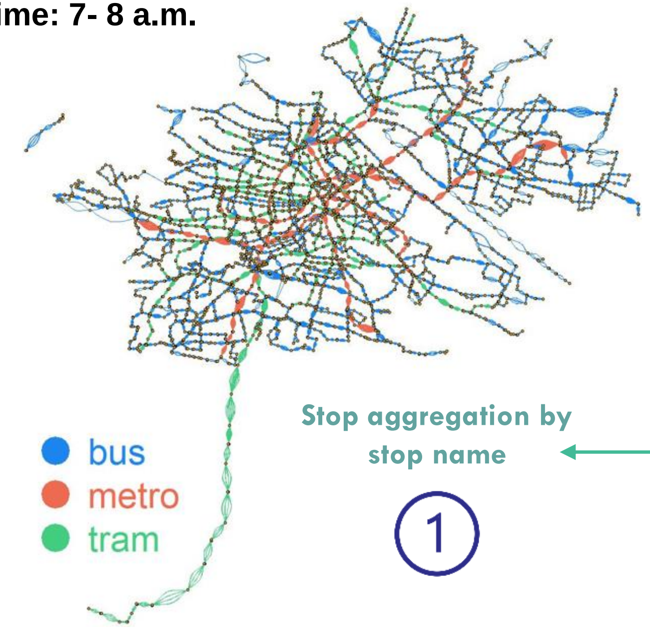
CASE STUDY: VIENNA

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

Working day
April
Time: 7- 8 a.m.

PTN

GTFS



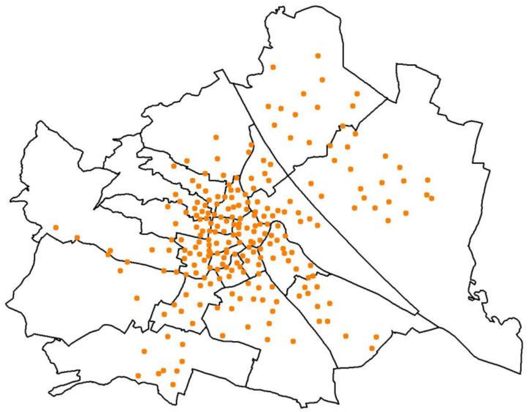
Stop aggregation by stop name

1

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



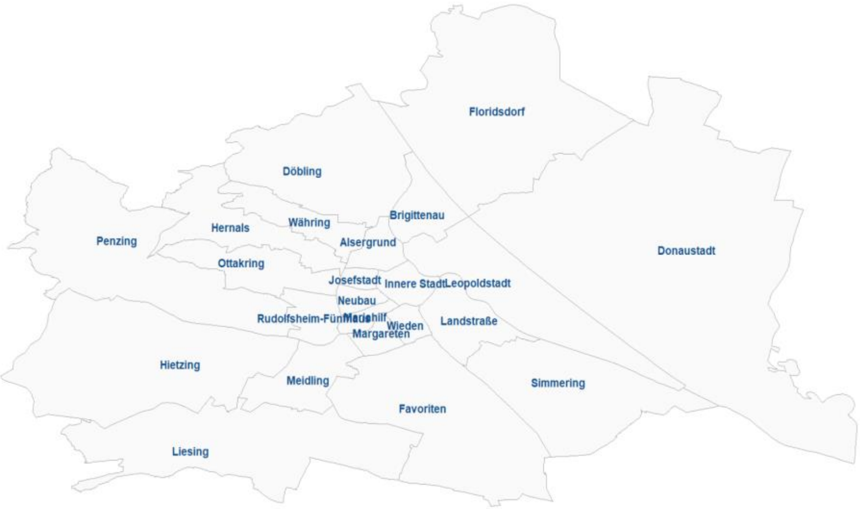
Bike-sharing stations

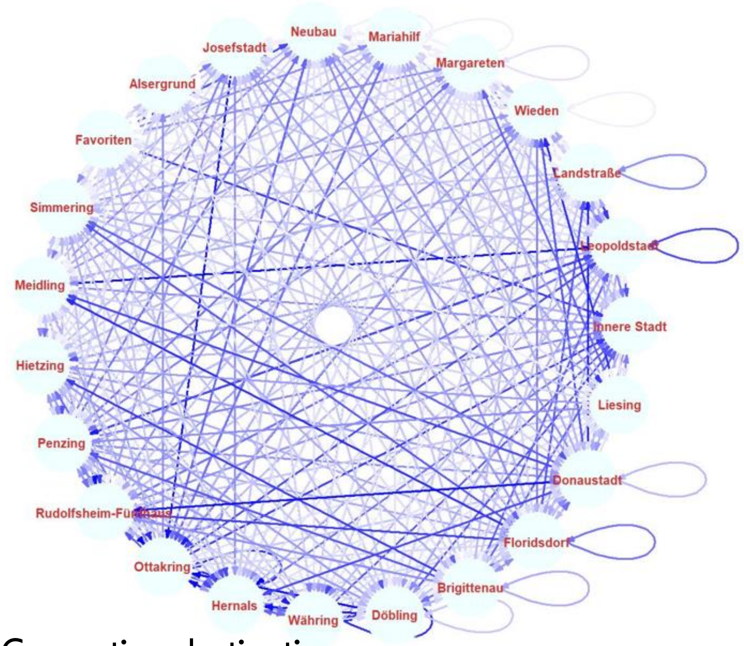
GIS

Data source: City of Vienna - https://data.wien.gv.at

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**





OD

Commuting destination
Data from statistik.at

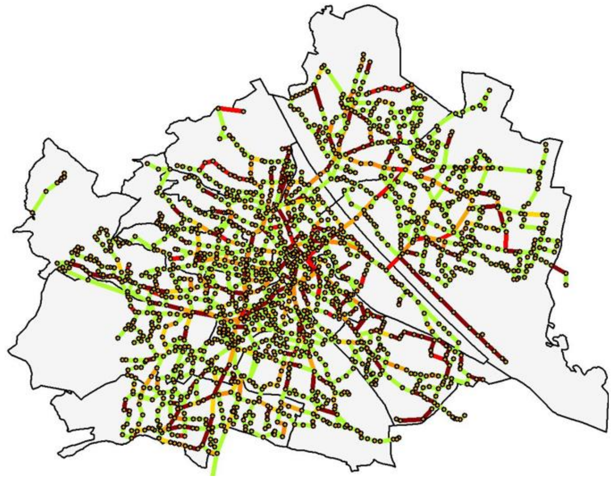
FLOWS ASSIGNMENT

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

M

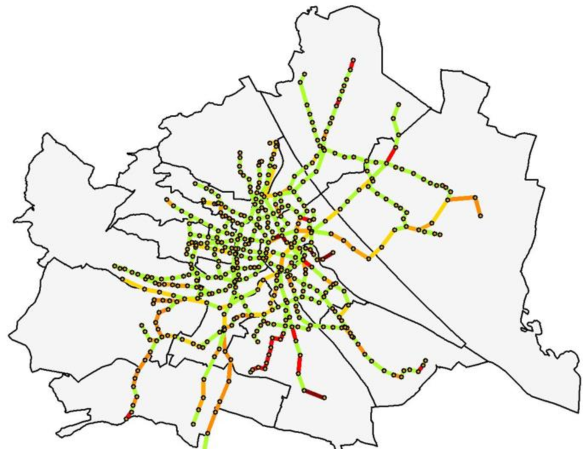
Baseline - Scenario

PTN



High

Low

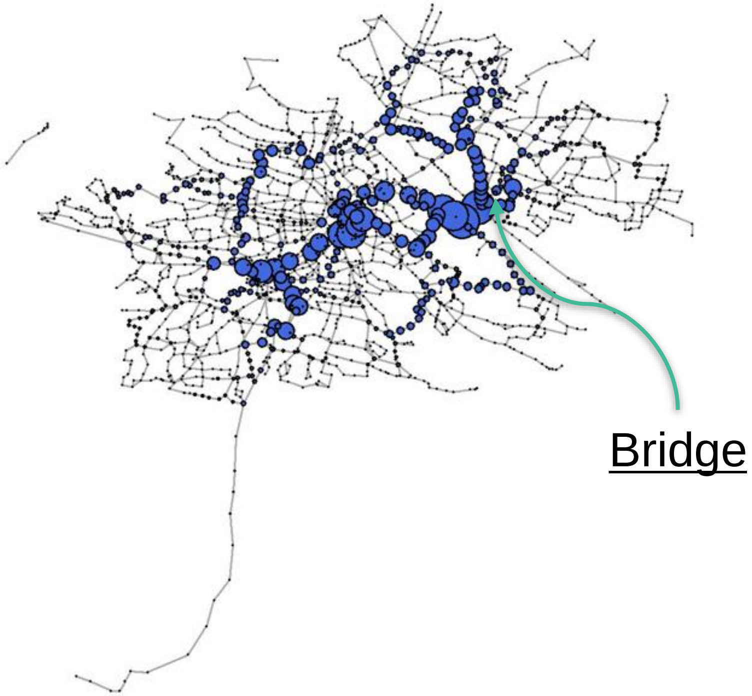


M + T

ANALYSES: NODE CENTRALITY

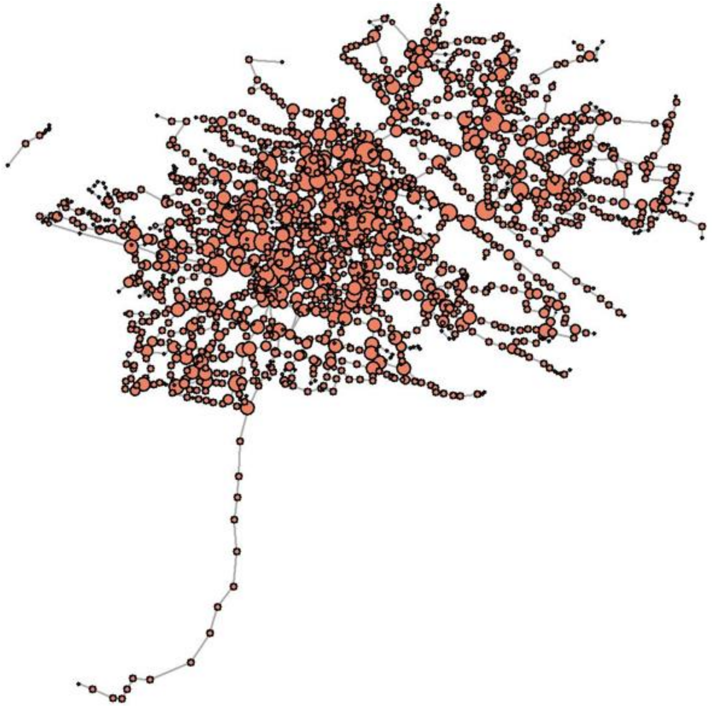
Betweenness

(Aggregated Stops)



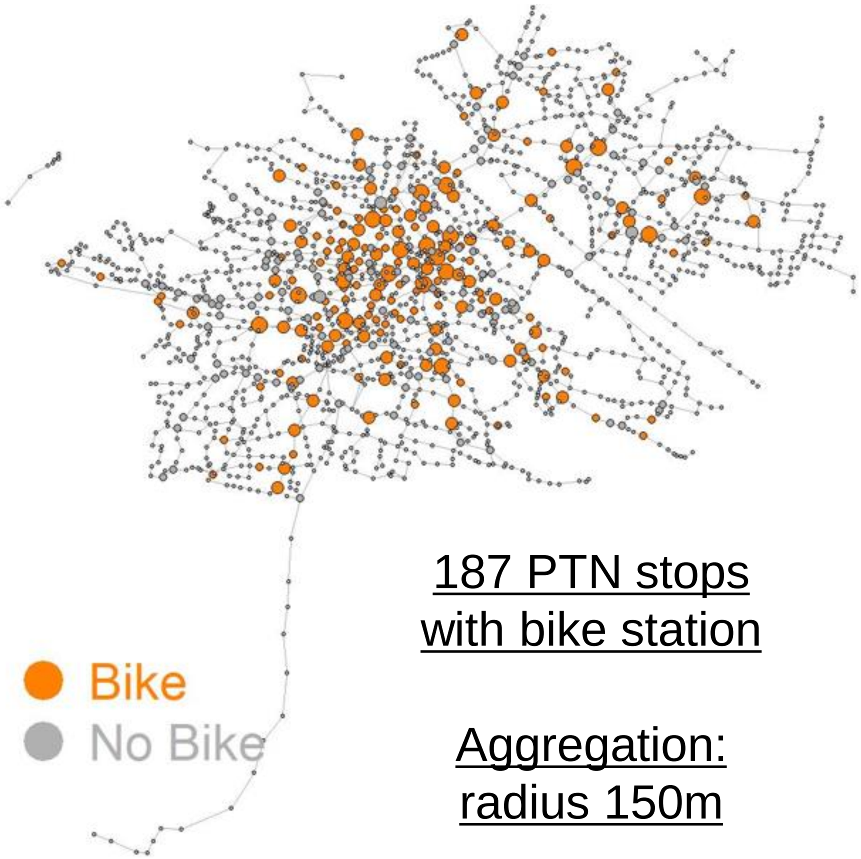
Degree

(Aggregated Stops)



ADDING THE BIKE-SHARE SERVICE

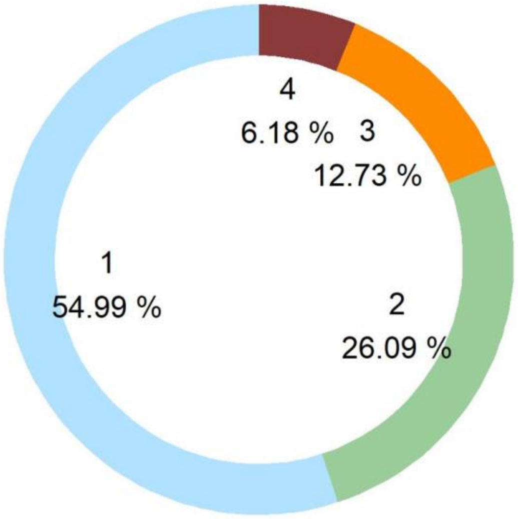
From PTN to PTNB



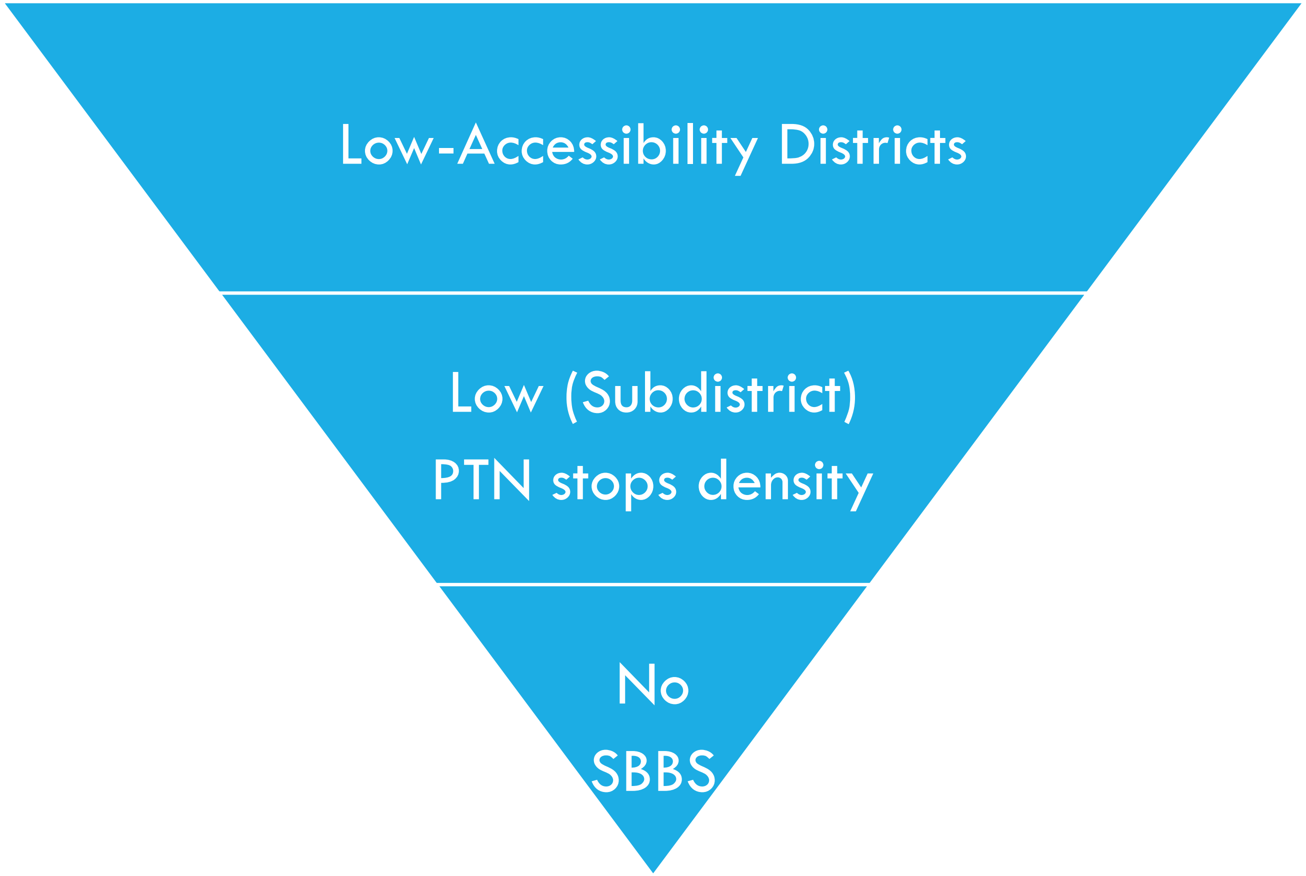
187 PTN stops with bike station

Aggregation: radius 150m

Percentage of PTN by number of modes



MCDM – HOW TO CHOOSE ALTERNATIVES



ALTERNATIVES AND CRITERIA

C1. Urban Life Dimension (Red dots)

C1.1. Proximity to green areas (+)

C1.2. Proximity sport centers (+)

C1.3. Proximity to tourism/recreation areas (+)

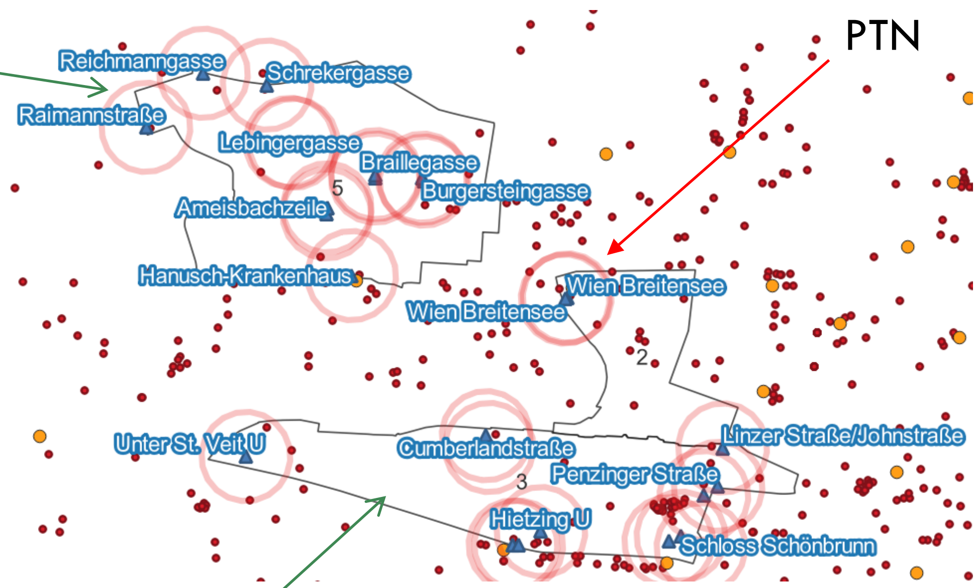
C1.4. Proximity to schools (+)

GIS data

From https://www.openstreetmap.org/

Low PTN density (subdistrict)

BSSB and PTN



Low PTN density (subdistrict)

C2. Demographics

C2.1. Population Density (+)

C2.2. 15-64 years ratio (+)

Census 2008 data census

From https: www.data.gv.at

C3. Robustness

C3.1. Degree centrality (+)

C3.2. Betweenness centrality (+)

C3.3. Loss of efficiency (+) (TO BE ADDED)

GTFS data

From City of Vienna - https://data.wien.gv.at

MCDM – WEIGHTS

The weights are **derived** from the answers of an international panel of experts, academics and professional working in the domain of transportation and shared mobility services

(SmartHubs project)

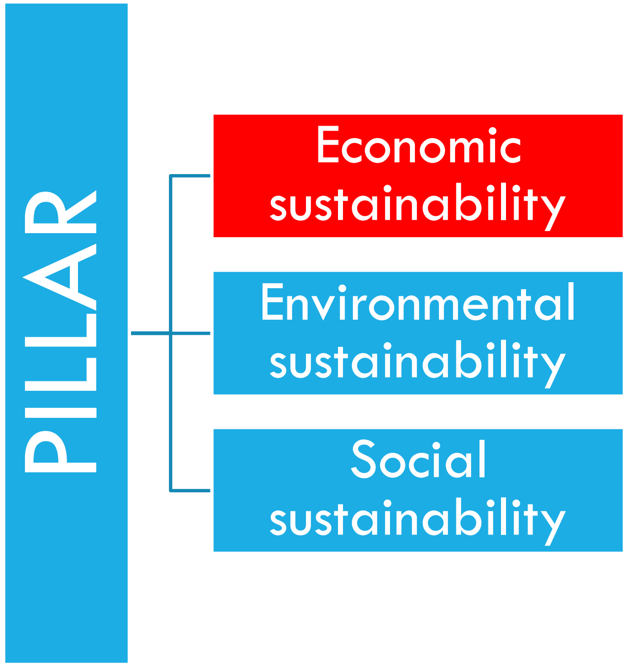
Since the original analysis was about the sustainability impacts of mobility hubs, the weights are **adapted** to match the purposes of our work

A FIRST IMPACT MATRIX

Red alternatives are “real”, in order to test the adequacy of actual bike hubs

stop_id	stop_name	Amenities	Betweenness	Degree	Pop_dens	Ratio_14_65
at:49:166:0:3	Wien Breitensee	4	77	2	0,332356706	0,737878718
at:49:166:0:7	Wien Breitensee	4	77	2	0,332356706	0,737878718
at:49:1176:0:3	Schloss Schönbrunn	4	496451	2	0,142943812	0,682509308
at:49:1158:0:5	Linzer Straße/Johnstraße	3	446991	2	0,142943812	0,682509308
at:49:1561:0:2	Cumberlandstraße	4	130	2	0,142943812	0,682509308
at:49:520:0:19	Hietzing U	9	132	2	0,142943812	0,682509308
at:49:1561:0:1	Cumberlandstraße	4	132	2	0,142943812	0,682509308
at:49:1005:0:1	Penzinger Straße	8	7684	3	0,142943812	0,682509308
at:49:520:0:2	Hietzing U	11	38193	2	0,142943812	0,682509308
at:49:1176:0:2	Schloss Schönbrunn	24	35083	3	0,142943812	0,682509308
at:49:520:0:1	Hietzing U	11	36581	3	0,142943812	0,682509308
at:49:1176:0:5	Schloss Schönbrunn	25	36631	2	0,142943812	0,682509308
at:49:1005:0:3	Penzinger Straße	17	36681	3	0,142943812	0,682509308
at:49:1404:0:3	Unter St. Veit U	2	6785	2	0,142943812	0,682509308
at:49:764:0:2	Lebingergasse	1	60	2	0,057196309	0,66214208
at:49:54:0:2	Ameisbachzeile	1	76	2	0,057196309	0,66214208
at:49:156:0:2	Braillegasse	0	90	2	0,057196309	0,66214208
at:49:187:0:2	Burgersteingasse	3	102	2	0,057196309	0,66214208
at:49:187:0:1	Burgersteingasse	2	112	2	0,057196309	0,66214208
at:49:156:0:1	Braillegasse	0	102	2	0,057196309	0,66214208
at:49:1853:0:1	Hanusch-Krankenhaus	6	90	2	0,057196309	0,66214208
at:49:54:0:1	Ameisbachzeile	0	76	2	0,057196309	0,66214208
at:49:764:0:1	Lebingergasse	1	60	2	0,057196309	0,66214208
at:49:1065:0:1	Raimannstraße	2	1267	2	0,057196309	0,66214208
at:49:1082:0:2	Reichmanngasse	2	6438	2	0,057196309	0,66214208
at:49:1188:0:2	Schrekergasse	2	6450	2	0,057196309	0,66214208

WEIGHTS



Source: https://www.smartmobilityhubs.eu/_files/ugd/c54b12_8c0d1dd1b7ea4ef2b27db027a1f5ff74.pdf

Pillar			Weight
Demographics		Population Density	0.165
		Ratio Age 14-16	0.165
Environmental sustainability	Resilience	Betweenness	0.165
		Degree	0.165
Social sustainability	Amenities		0.33

PRELIMINARY RESULTS

stop_id	stop_name	rank
at:49:166:0:3	Wien Breitensee	6
at:49:166:0:7	Wien Breitensee	7
at:49:1176:0:3	Schloss Schönbrunn	5
at:49:1158:0:5	Linzer Straße/Johnstraße	8
at:49:1561:0:2	Cumberlandstraße	13
at:49:520:0:19	Hietzing U	11
at:49:1561:0:1	Cumberlandstraße	12
at:49:1005:0:1	Penzinger Straße	9
at:49:520:0:2	Hietzing U	10
at:49:1176:0:2	**Schloss Schönbrunn**	**1**
at:49:520:0:1	Hietzing U	4
at:49:1176:0:5	Schloss Schönbrunn	2
at:49:1005:0:3	Penzinger Straße	3
at:49:1404:0:3	Unter St. Veit U	15
at:49:764:0:2	Lebingergasse	22
at:49:54:0:2	Ameisbachzeile	21
at:49:156:0:2	Braillegasse	25
at:49:187:0:2	Burgersteingasse	16
at:49:187:0:1	Burgersteingasse	20
at:49:156:0:1	Braillegasse	24
at:49:1853:0:1	Hanusch-Krankenhaus	14
at:49:54:0:1	Ameisbachzeile	26
at:49:764:0:1	Lebingergasse	23
at:49:1065:0:1	Raimannstraße	19
at:49:1082:0:2	Reichmanngasse	18
at:49:1188:0:2	Schrekergasse	17

MCA method:

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

It is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS)

Normalization: min-max

Schloss Schönbrunn results to be the most desirable location

Real hubs actually perform rather well

NEXT STEPS

- Improving full demand per O/D **areas** → PTN demand per O/D **areas**
- Linking PTNB stations and computing travel time between any of them
- Adding bike network and repeating analysis on complete network
- Completing robustness and accessibility analysis after disruptions
- Testing parameters → sensitivity analysis
- Expanding criteria for MCDM

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

Roberto Patuelli
roberto.patuelli@unibo.it

SmartHubs project:
https://www.smartmobilityhubs.eu/