# IMPLEMENTING NEW BIKE-SHARING STATIONS IN URBAN AREAS:

# A MULTI-CRITERIA APPROACH

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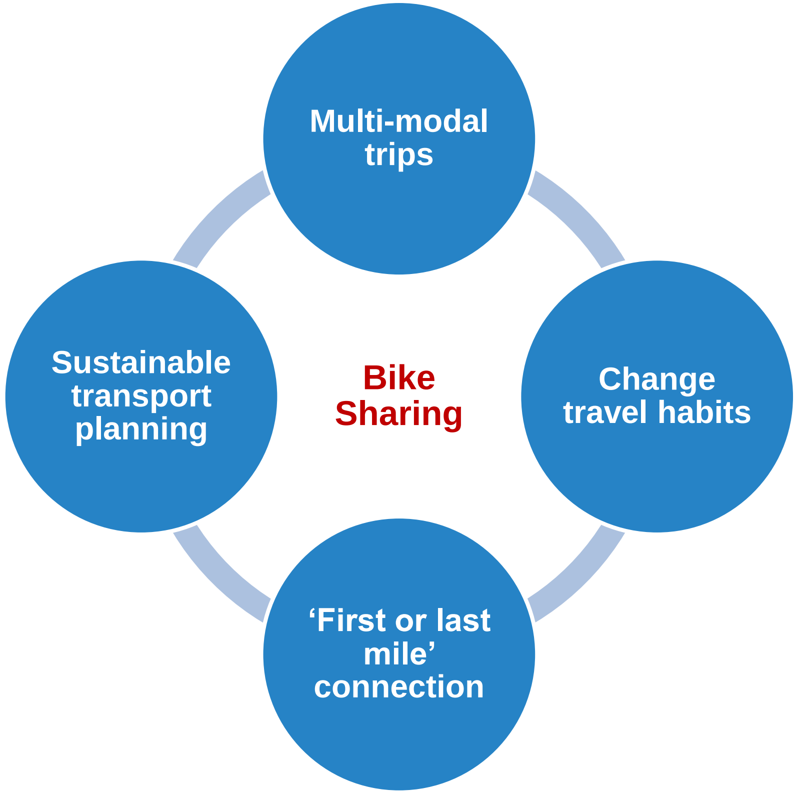
# BIKE-SHARING (BS)

## Definitions

**Bike Sharing:** a shared transport service where bicycles are available for shared use by individuals at low cost

17 Cities 2.900 Cities

2005 → 2019




**Station-Based Bike-Sharing:** bicycles can be borrowed or rented from a station or "dock" and can be returned at another station belonging to the same system

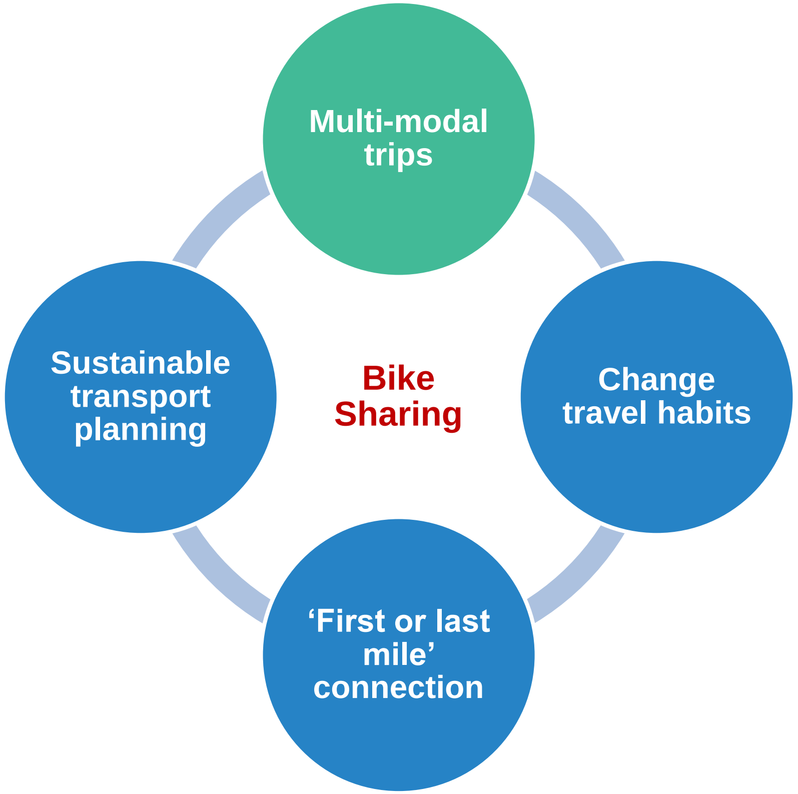
# BIKE-SHARING (BS) STATIONS - ALLOCATION

- ✓ **Station location** is an essential factor for designing/extending a **bike-sharing system**
- ✓ The main goal of most of the selected studies was finding the **optimal station location**
- ✓ Techniques: mathematical algorithms, **multi-criteria decision making**, and "GIS-based modeling
- ✓ Criteria: proximity to PTN stops, proximity to point of interest, demographic data, maximum distances between bike stations, the extent of the cycling infrastructure, etc.

- ○ Scarce literature on the multi-modal role of bike-sharing
- ○ Interest for equity is usually missing
- ○ **Network robustness and area accessibility are usually not included in the optimization process**

**OUR OBJECTIVE: ROLE OF NETWORK ROBUSTNESS AND AREA ACCESSIBILITY FOR THE OPTIMAL BS ALLOCATION**

# RESEARCH QUESTION (RQ)




Network robustness is the ability of networks to resist failures or attacks (Rose, 2009)

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

RQ: Given our objective of the bike-sharing stations' allocation choice, what is the role of network robustness metrics and area accessibility metrics – jointly with urban metrics?

**Focus on:**

**Bike-Sharing Stations (BSS) - Public Transport Network (PTN) integration**

# APPROACH

Using “easily” accessible data

Combined approach:
Multi Criteria Analysis (MCA) + Geo Information System (GIS) methods + Network Analysis (NA) + Spatial Interaction Models (SIM)

**The most suitable public transport stops for bike-sharing implementation: multidimensional analysis**

| *Alternatives* | Criterion1 | Criterion2 | … | CriterionN | *Score* |
|---|---|---|---|---|---|
| **Stop 1** | | | | | |
| **Stop 2** | | | | | |
| … | | | | | |
| **Stop N** | | | | | |

OUR NOVELTY (1)

# MCA: ALTERNATIVES' SELECTION

**Alternatives: Public Transport Stops (Selection Process)**

The Lowest Accessibility Areas: Urban Districts

↓

Urban Sub-Districts with the Lowest Public Transport Density (within the selected districts)

↓

**Alternatives:**

**All the Public Transport Stops within the selected sub-districts**

## Area Accessibility ($ACC_i$)

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

The accessibility ($ACC_i$) of each origin $i$ is a function of the **attractiveness** ($D_j$) of each destination, and the **cost** ($d_{ij}$) of overcoming the separation between them

$\beta$ = **cost/time parameter** in the impedance function calibrated by doubly constrained Spatial Interaction Model (SIM)

## Public Transport Density

Number of PTN stops/sub-district extension

# MCA: 8 CRITERIA

FROM LITERATURE

**C1. Urban Life Dimension**

C1.1. Proximity to green areas (+)

C1.2. Proximity to sport centers (+)

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

C1.4. Proximity to schools (+)

**C2. Demographics**

C2.1. Population Density (+)

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

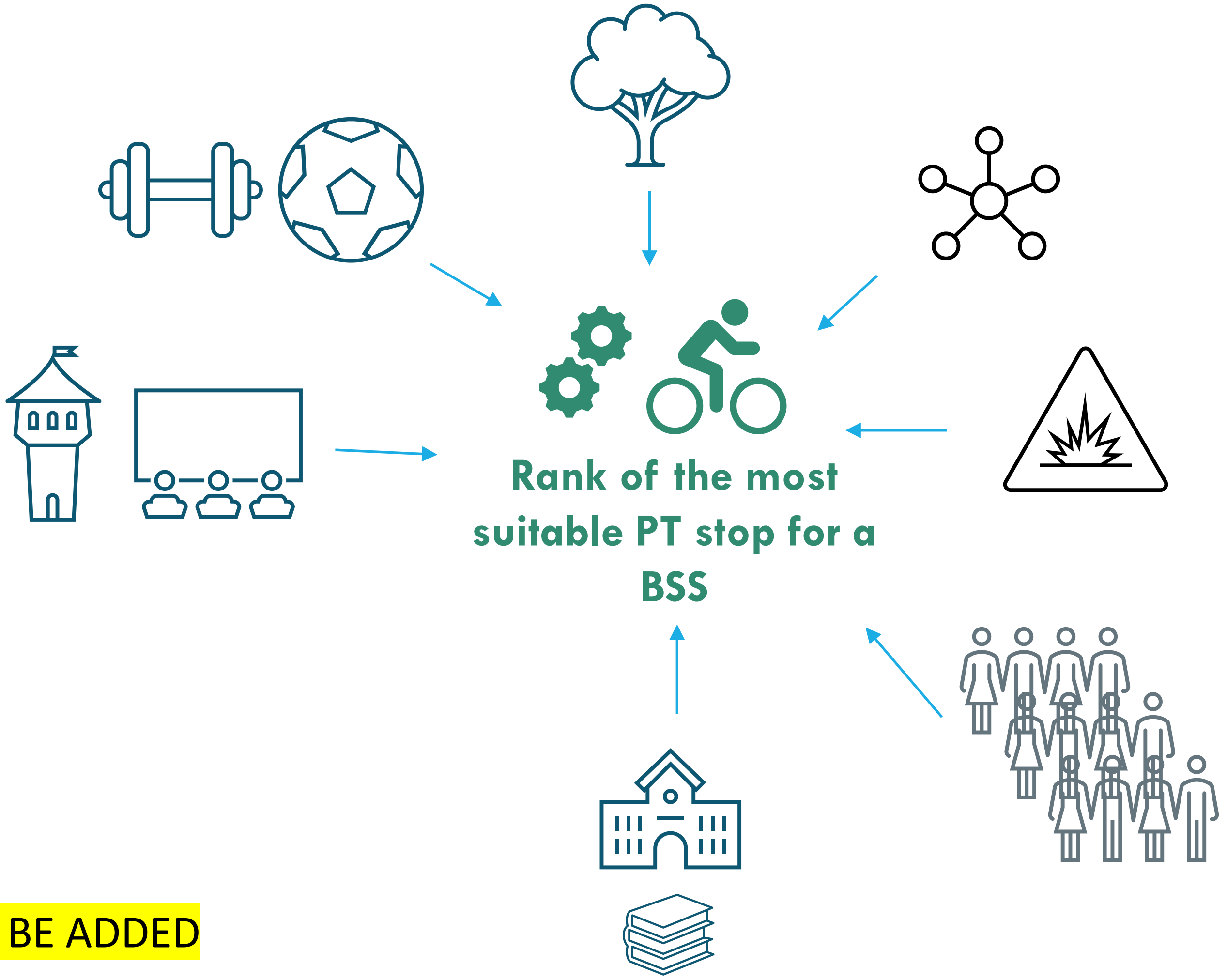
OUR NOVELTY

**C3. Network Robustness**

C3.1. Degree centrality (+)

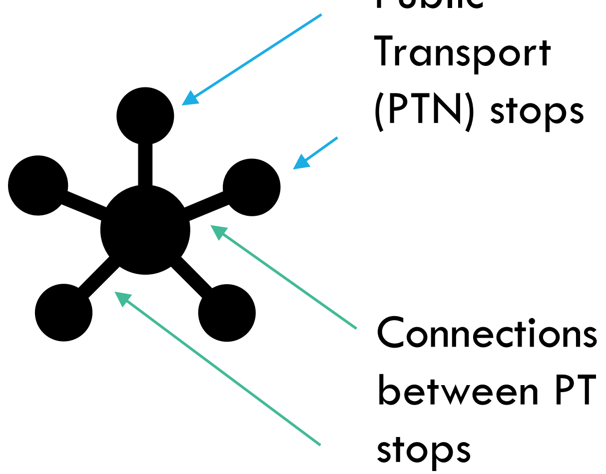
C3.2. Betweenness centrality (+)

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



OUR NOVELTY (2)

# MCA: NETWORK ROBUSTNESS METRICS




## C3.1. Degree centrality (+)

The total number of connections linked to a node (stop)

## C3.2. Betweenness centrality (+)

The number of the shortest paths that pass through the node (stop)

## C3.3. Loss of efficiency after node removal (+)

Efficiency «$E$» is the mean of the inverse of the travel time (in vehicle + waiting + penalty for transfer) between each pair of nodes

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

where $d_{ij}$ is the distance from *i* to *j* (Latora & Marchiori, 2001)

When passenger flows ($w_{ij}$) for starting stop and final stop or origin and destination data are available, we can use passenger-based efficiency «$E_p$»

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

# MCA: SCENARIOS

The scenarios/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

# MCA: ADOPTED 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

# MCA: CASE STUDY - VIENNA

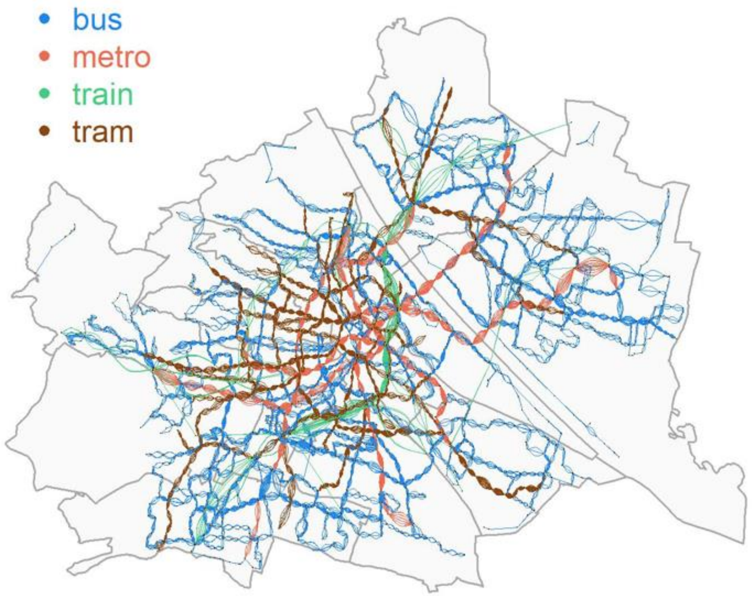
Vienna is divided in 23 districts and 250 subdistricts


# VIANNA: PUBLIC TRANSPORT NETWORK (PTN) AND BIKE SHARING STATIONS (BSS)

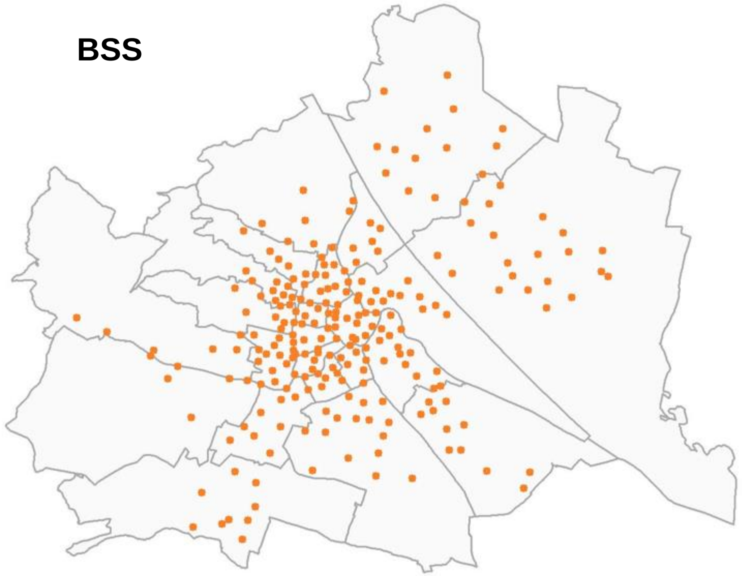
Vienna benefits from the services of a unique PT provider, namely Wiener Linien GmbH (WL)
Vienna's PTN consists of **5 metro, 29 tram, and 127 bus routes**

WienMobil Rad is the public bicycle rental service with **233** fixed bike-stations 3,000 bicycles

PTN




BSS



Working day
Time: 7- 8 a.m.

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

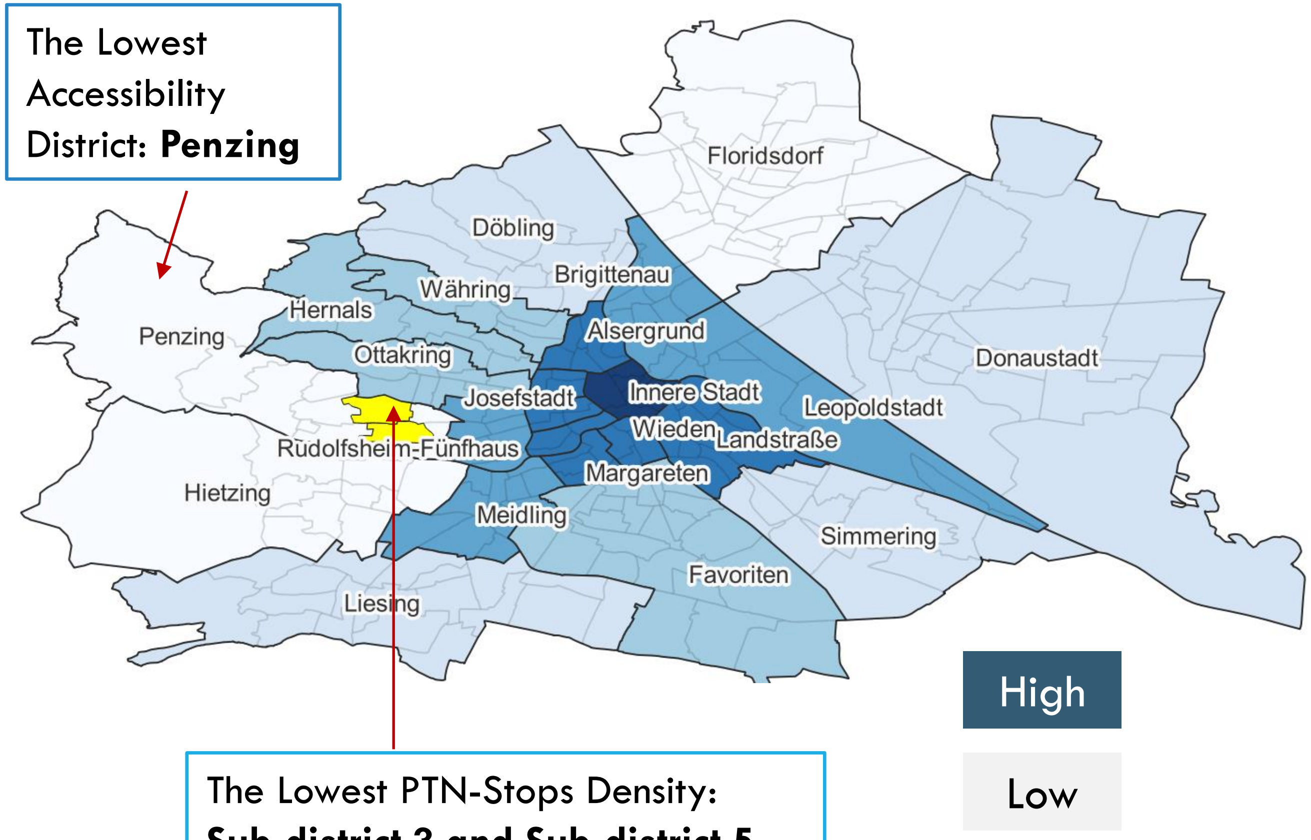
# ALTERNATIVES SELECTION: PUBLIC TRANSPORT STOPS

**Accessibility**

Source: statistik.at

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

The Lowest Accessibility District: **Penzing**




The Lowest PTN-Stops Density: **Sub-district 3 and Sub-district 5**

The Lowest Accessibility Area: **Penzing**

The Lowest PTN Stops Density: **Subdistricts 3 and 5**

Alternatives: **12 Public Transport Stops**

| | | |
|---|---|---|
| Hietzing | Penzinger Straße | Burgersteingasse |
| Braillegasse | Schloss Schönbrunn | Ameisbachzeile |
| Raimannstraße | Hanusch-Krankenhaus | Reichmanngasse |
| Lebingergasse | Cumberlandstraße | Schrekergasse |

# CRITERIA: DATA

**C1. Urban Life Dimension**

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/

**C2. Demographics**

C2.1. Population Density (+)

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

Census 2008 data census

From https: www.data.gv.at

**C3. Robustness**

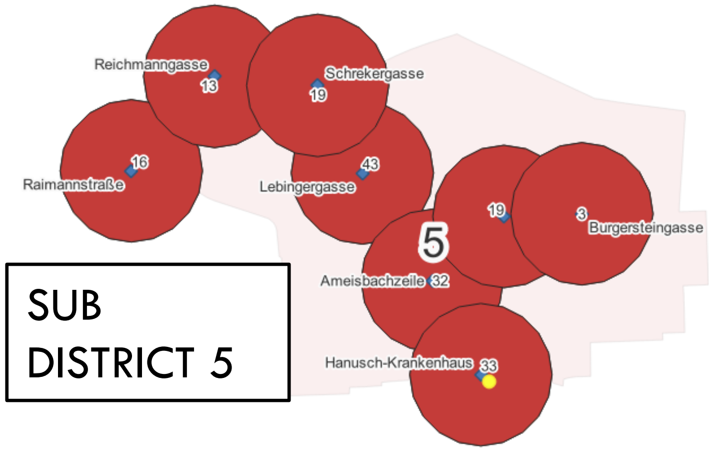
C3.1. Degree centrality (+)

C3.2. Betweenness centrality (+)

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

GTFS data

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



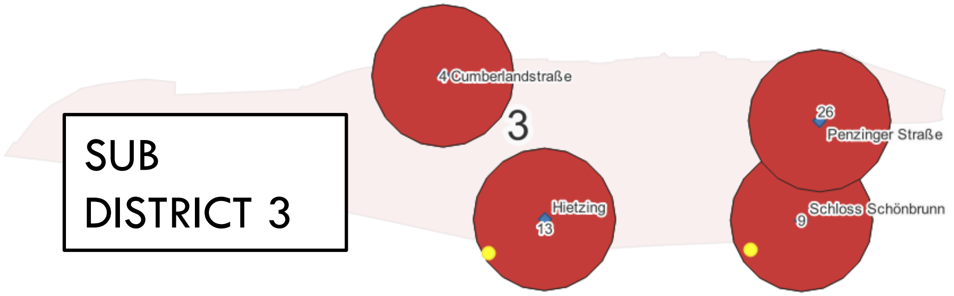

**Legend**

Blue dots = Public Transport stops

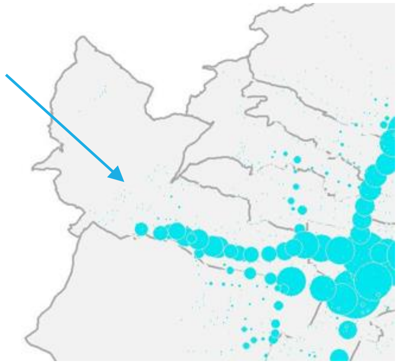
Yellow dots = bike sharing stations

Red circles = buffer of 200 mt radius

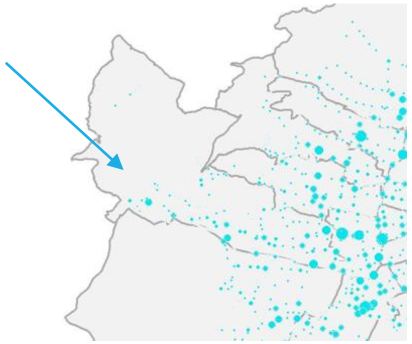
Numbers = sum of the points of interest (urban life dimension C.1 ) within each buffer




Weighted Betweenness



Degree



# SCENARIOS: FIRST EXPERIMENTS WITH EQUAL WEIGHTS

Derived from a preliminary survey (SmartHubs) project

**Our adaptation**

| Macro-criteria | Weights | Sub-criteria | Macro-criteria | Sub-criteria | Adjusted Weights |
|---|---|---|---|---|---|
| Social sustainability | 0.33 | Access to opportunities | C1. Urban Life Dimension | Proximity to point of interest (Urban Life Dimension) | 0.33 |
| Economic* sustainability | 0.33 | | C2. Demographics | Population Density | 0.165 |
| | | | | Age 14-16 Ratio | 0.165 |
| Environmental sustainability | 0.33 | Resilience | C3. Network Robustness | Betweenness | 0.165 |
| | | | | Degree | 0.165 |

Note: weights emerging from Smarthubs Project (SP)
https://www.smartmobilityhubs.eu/_files/ugd/c54b12_8c0d1dd1b7ea4ef2b27db027a1f5ff74.pdf

* Since criteria about economic sustainability are not available, following the literature we substituted that pillar with C2. Demographics, and keeping the same weights partition

# PRELIMINARY RESULTS

Legend: In red are stops near a bike-sharing station (buffer radius: 200 mt)

| | FROM LITERATURE | | | OUR NOVELTY | | |
|---|---|---|---|---|---|---|
| | C1. Urban Life Dimension | C2. Demographics | | C3. Netw. Robustness | | |
| Stop Name | Sum C1.1-C1.4 | Pop_dens | Ratio_14_65 | Betweenness | Degree | Rank |
| Hietzing | 13 | 0.14 | 0.68 | 427180 | 12 | 1 |
| Lebingergasse | 43 | 0.06 | 0.66 | 6493 | 2 | 2 |
| Ameisbachzeile | 32 | 0.06 | 0.66 | 10559 | 4 | 3 |
| Hanusch-Krankenhaus | 33 | 0.06 | 0.66 | 4784 | 2 | 4 |
| Penzinger Straße | 26 | 0.14 | 0.68 | 4154 | 5 | 5 |
| Schloss Schönbrunn | 9 | 0.14 | 0.68 | 17797 | 9 | 6 |
| Braillegasse | 19 | 0.06 | 0.66 | 14946 | 4 | 7 |
| Schrekergasse | 19 | 0.06 | 0.66 | 13147 | 4 | 8 |
| Raimannstraße | 13 | 0.06 | 0.66 | 3722 | 2 | 9 |
| Cumberlandstraße | 4 | 0.14 | 0.68 | 27646 | 4 | 10 |
| Burgersteingasse | 3 | 0.06 | 0.66 | 18035 | 4 | 11 |
| Reichmanngasse | 2 | 0.06 | 0.66 | 10994 | 4 | 12 |

The emerging Rank (from the normalized impact matrix)

1) suggests a real hub (Hietzing) as a first option;
2) suggests that Lebingergasse and Ameisbachzeile are «good» options for implementing new Bike-sharing stops

# NEXT STEPS

- Expanding criteria for MCA (C3.3. Loss of efficiency after node removal, spatial economic data)
- Ask the experts for a more specific evaluation of weights
- Explore different methods and scenarios for testing the stability of the results
- Extension of the set of alternatives (additional subdistricts, additional districts)

Thank you

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

# ADDITIONAL MATERIAL

# 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:

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

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

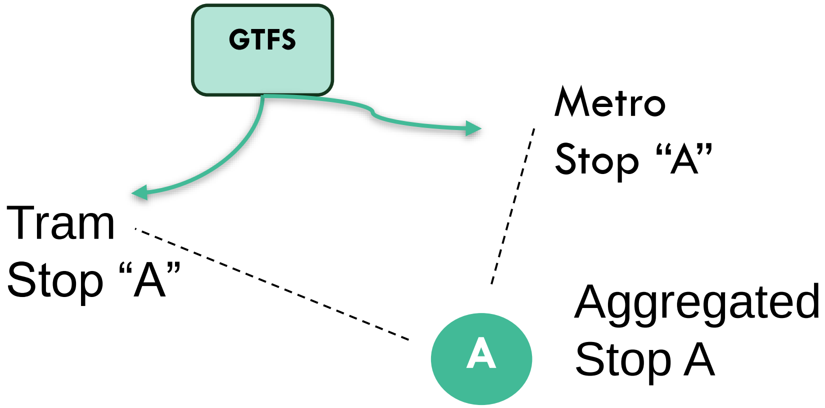
$$B_j = \left(\sum_i A_i O_i exp(\beta d_{ij})\right)^{-1}$$

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

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

# STOP AGGREGATION AND TRAVEL TIME

1 **Stop Aggregation**




2 **Adding Travel Time**

**Links are weighted by Travel Time**

**Travel Time**

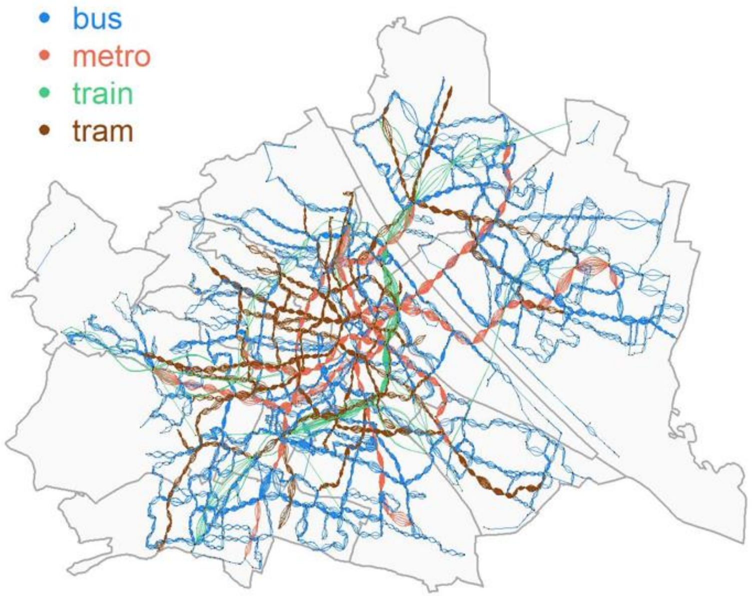
**In-vehicle Time (Arr. time – Dep time)**

**Waiting Time (Hour Frequency)**

**Transfer Penalty (5min)**

# AGGREGATED NETWORK

Single Modes Networks



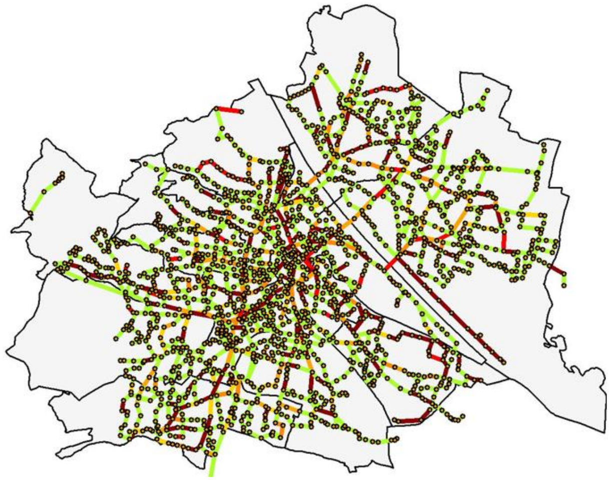

Aggregated (by name) Network

# FLOWS ASSIGNMENT

**Non-adaptive assignment:** Metro (M), metro+tram (M+T), metro+tram+bus (PTN) considering waiting time (1/frequency) and a 5-min penalty for line changes (also in route choice)

Baseline - Scenario

**PTN**



High

Low

# NODE REMOVAL

*Remove nodes*

*flows re-distribution*

- 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