New Bike-Sharing Stations in Urban Areas: A Multi-Criteria Approach

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mobil.TUM Conference 2024
10 April

Objective and introduction

Objective: Optimal location of new bike-sharing stations in urban areas.

Bike-sharing Systems (BSSs)

- Potential role in promoting sustainable urban mobility
- Integration with Public Transport

Multi-Criteria Analysis (MCA) for Decision-Making Process

The innovative contribution is the inclusion of *transport network robustness*.

Methodology

- Alternatives: public transport (PT) stops
- Criteria: Proximity to points of interest, Socio-demographic, Environmental, Network Robustness
- Weights with Analytical Hierarchy Process (AHP)
- Ranking of the best locations

Literature review

Location of bike sharing station with MCA

- Sayers (2003) weights criteria of MCA to construct a flexible, transparent and user-friendly method of ranking transport investment.
- Kanjanakorn (2013) aims to rank suitable locations for BSS in the city of Bangkok. They focus on 'accessibility' to points of interest, for example, bike routes and walkability to destinations.
- Ghandeh et al. (2013) select four main factors that influence the location of a bike station: closeness to the bicycle path, transportation and networks, demand, and user type.
- Kabak et al. (2018) use MCA and AHP to evaluate and compare current BSS and future stations. It combines the previous methods with the geographic information system (GIS) to address twelve conflicting criteria.
- Bahahori (2021) proposes an overview of studies dealing with the BSS location problem under planning and operational viewpoints.

What is missing?

The existing literature does not consider the possible contribution of BSS to the functionality of the *urban transport network*.

Research Questions

RQ1: What is the optimal public transport stop for installing a new bike-sharing station?

RQ2: How do optimal locations of bike-sharing stations change by considering transport network robustness?

RQ3: With our multi-criteria approach, can we replicate the current positioning of bike-sharing stations?

1st Methodological Step: Identification of the Criteria Weights through Analytical Hierarchy Process (AHP)

Saaty (2008) offers **AHP**, a method grounded in mathematical and psychological principles with a systematic approach to **handling intricate decision-making scenarios and determining the weights of the MCA criteria**. This process employs opinions from experts to assign their scores and to establish **hierarchies of importance between criteria**.

AHP proposes ratio scales from **paired comparisons** of criteria, both qualitative and quantitative.

Numerical Value	Explanation
1	Equal Importance
2	Slightly Importance
3	Moderate Importance
4	Moderate Plus Importance
5	Strong Importance
6	Strong Plus Importance
7	Very Strong Importance
8	Very, Very Strong Importance
9	Extremely Importance

Table 1: AHP scoring factors for pairwise comparison

The number of criteria should be between 5 and 9 to avoid inconsistent results.

Analytical Hierarchy Process (AHP) (continuation)

A reciprocal matrix is computed, with actual judgment values on the left side of the diagonal, and the reciprocal values on the right side, all positive valued.

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & a_{23} & \cdots & a_{2n} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \frac{1}{a_{3n}} & \cdots & 1 \end{bmatrix} \tag{1}$$

Then, the normalized Eigenvector $\lambda_{\max}$ of the matrix is computed from the average across rows of the normalized relative weights of the reciprocal matrix.

To verify the consistency of the stakeholders' answers, in other words, if they respect the transitive property, the AHP method provides a formula to measure it, the **consistency ratio CR**:

$$CR = \frac{CI}{RI} \tag{2}$$

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{3}$$

where CI is the Consistency Index and RI is the Random Index for a given matrix size n. The ratio gives the meaning of an acceptable **level of inconsistency** which must be **smaller or equal to 10%**, otherwise, we need to revise the subjective judgement (Elboshy 2022; Saaty 2008; Goepel 2018).

2nd Methodological Step: Multi-Criteria Analysis (MCA)

The weights are assigned to each criterion's value. The output of this process is **the performance/impact matrix** allows to capture how each alternative performs across criteria. Values for each criterion are normalized to have a comparable scale in a range [1-100] with the following formula

$$\text{min\_max\_norm}(x) = \left(\frac{x - \min(x)}{\max(x) - \min(x)}\right) \times 100 \tag{4}$$

where x is original data vector.

Table 2: Performance Matrix

Altern.	**Criteria & Weights**					
	C1	**W1**	**C2**	**W2**	**C3**	**W3**
A1	x_{11}	w_{11}	x_{12}	w_{12}	x_{13}	w_{13}
A2	x_{21}	w_{21}	w_{22}	x_{22}	x_{23}	w_{23}
A3	x_{31}	w_{31}	x_{32}	w_{32}	x_{33}	w_{33}

AHP application

Problem definition: how to select a suitable location for a new bike-sharing station, based on criteria from the literature and network robustness metrics

Selection of criteria:

C1. Points of Interest
- C1.1. Proximity to green areas (PGA)
- C1.2. Proximity to sport/recreation centres (PSC)
- C1.3. Proximity to tourism areas (PTA)
- C1.4. Proximity to schools (PS)

C2. Socio-demographics
- C2.1. High-density areas (HDA)
- C2.2. High-employment areas (HEA)
- C2.3. Low-income areas (LIA)

C3. Environment
- C3.1. High polluted areas (HPA)

C4. Network Robustness
- C4.1. Proximity to critical public transport stop (CPT)

AHP results

Assignment of weights:

- A panel of 17 experts in the transport field was consulted;
- Their judgements were reported into the **Geopel Excel Tool**, coded to calculate AHP parameters, including consistency values for both individual judgements and aggregated arrays, and suggesting improvement where necessary.
- The tool presents also the **Aggregated Matrix with Normalized Principal Eigenvector**, which represents the weights assigned to each criterion.

The results:

Table 3: Criterion Weights and +/- Values

Criterion	Weights	+/-
CPT	0.188	±0.028
HDA	0.169	±0.018
HEA	0.124	±0.019
LIA	0.095	±0.009
PGA	0.093	±0.018
PTA	0.092	±0.012
PS	0.087	±0.014
HPA	0.087	±0.012
PSR	0.065	±0.013

CR = 0,8 %

Measurements for criteria:

Criteria are district-specific, except for C1 and **C4** which are by PT stops.

- C1. Points of interest are considered within of 5-minutes radius of a buffer where the alternative is the centre. They are individuated from openstreetmap.
- C2. Socio-demographics criteria are extracted by Landeshauptstadt München - Indikatorenatlas 2022, for population density, and Münchner Armutsbericht 2022, for unemployed rates. GDP per capita used for Low-income areas criterion is drawn from Driven EnviLab
- C3. Environment criteria are drawn by Driven EnvirLab as average exposure to PM2.5
- **C4. Network robustness** uses data from MGV (2022) for BSS and GTFS for PT, and it is measured as **'Betweenness centrality' (Boccaletti et al., 2006)**:

  $$BC(i) = \frac{1}{n(n-1)} \sum_{j \neq i \neq k} \frac{\sigma_{jk}(i)}{\sigma_{jk}} \quad (1)$$

The alternatives for the MCA:

The 3 districts where the number of PT stops for residents is the lowest: Untergiesing-Harlaching (18), Laim (25), Schwabing-West (4).

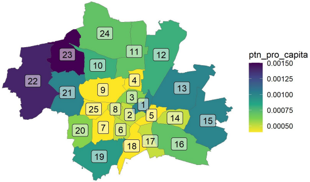


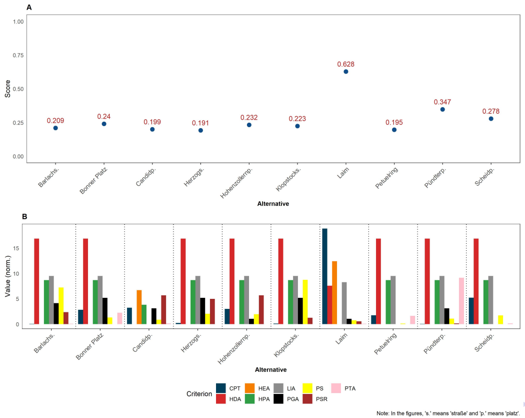
Figure 1: Number of PT stops for residents

RQ1 results and final rank

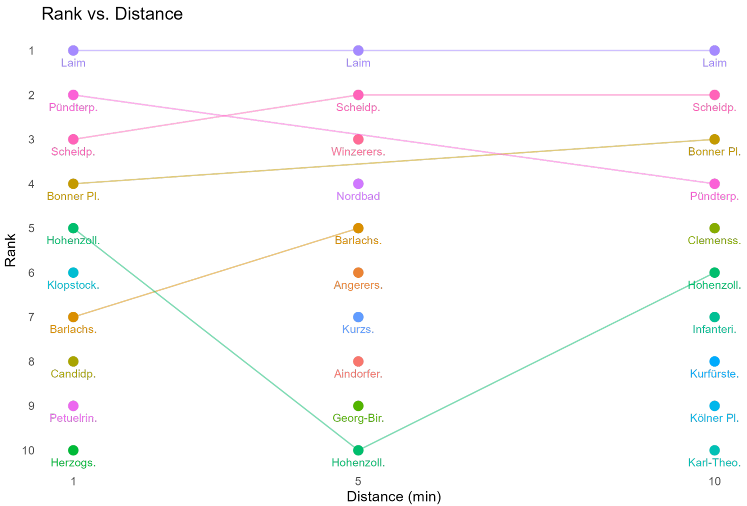
72 alternatives (PT stops with NO BIKES) evaluated by TOPSIS method within MCA.

Applying the criteria and relative weights defined with AHP, we obtain a ranking of alternatives. Here the top ten best suitable locations for a bike-sharing station:

Figure 2: Final rank (top ten)



Concerning C1, a sensitivity analysis for 1, 5 and 10 minutes radius has been performed. Note: we refer to 5*min* as a reference scenario.



Note. Alternative names are truncated to the ninth character.

Counterfactual 1 for RQ2: exclusion of network robustness criterion

Re-calibration of weights and new computation of the ranking of alternatives.

Table 4: Criterion weights when CPT is excluded

Criterion	Weights	+/-
HPA	0.310	±0.062
PGA	0.252	±0.094
PTA	0.120	±0.053
PSR	0.098	±0.037
HDA	0.068	±0.023
HEA	0.068	±0.023
PS	0.045	±0.017
LIA	0.041	±0.015

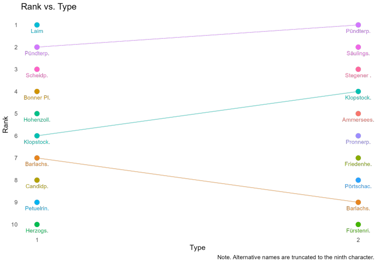


Figure 3: Top 10 with (Type 1) and without (Type 2) CPT

Counterfactual 2 for RQ3: analysis repeated for all the PT stops (with and without bike sharing - 75 alternatives). The already 3 existing bike stations result in positions 8, 30, and 40 of the rank.

Discussion and conclusion

RQ1: The most suitable location to implement bike-sharing station is Laim, which is the most important stop because of the large weight given to the criterion "Proximity to critical PT stop".

RQ2: AHP allows to exclude a criterion without affecting the correctness of the evaluation. Excluding PT network robustness, "Proximity to green areas" is the new most important criterion and the ranking changes.

RQ3: Different criteria have been used to implement the actual bike-sharing stops.

Figure 4: PT network's map of Munich.

To conclude, the MCA approach allows to rank the PT stops according to a multidimensional perspective: socio-economic, environmental and, mostly, transport network characteristics.

We stress that the supply of PT and the **evaluation of PT network robustness** are relevant pillars around building a **new urban mobility policy** aiming at increasing the bike sharing system and its integration with the PT network.

Thank you for your attention

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Q & A