University of Ljubljana
Faculty of Maritime Studies and Transport

An Adaptive Multi-Criteria Hybrid DEA approach to upgrade an existing Bike-Sharing System with electric bikes: The case of Ljubljana City Center

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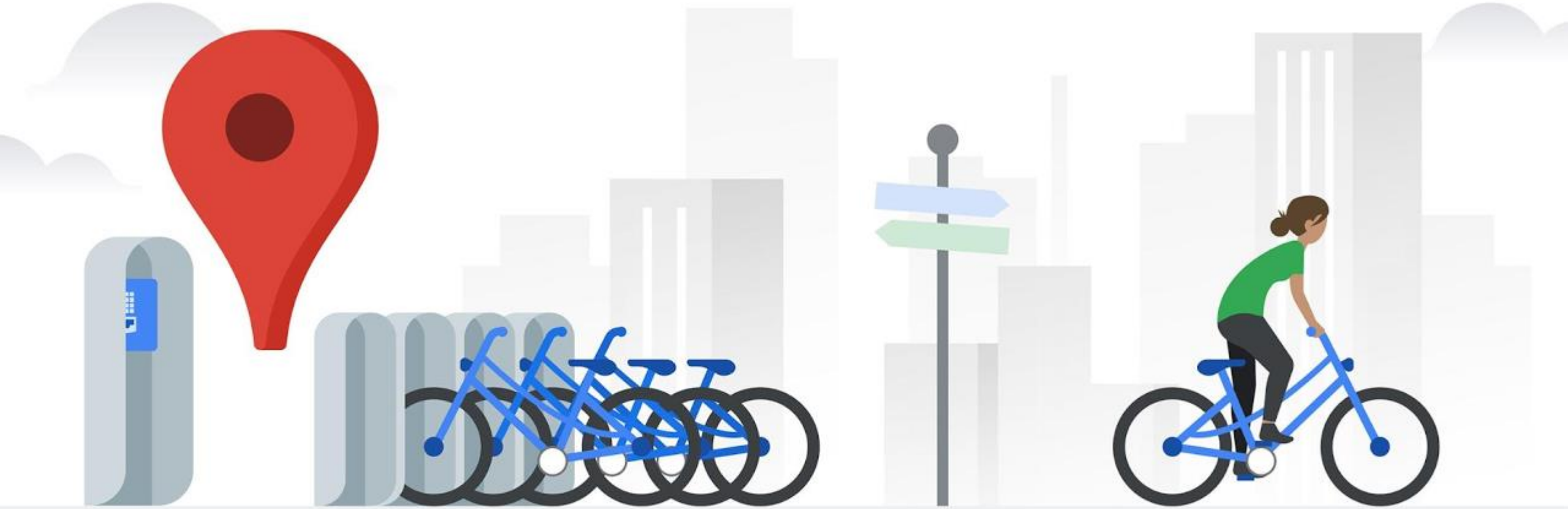


tps://blog.google/

BSS: Pro & Cons

+ bike-sharing systems (BSS) are used as an alternative to public passenger transport, first mile or/and a last mile with multi-modal trips and private cars;

+ more than 2900 BSS are operating in cities worldwide;

+ a favorable form of mobility for the younger population, employes in the urban area and tourists;

+ solves mobility problems over short distances between the suburb and the cities and medium-sized cities.

https://www.visitljubljana.com/en/visitors/travel-information/getting-around/bicikelj/

BSS: Pro & Cons

- does not solve mobiliy problems of travelling between cities or even through larger cities;

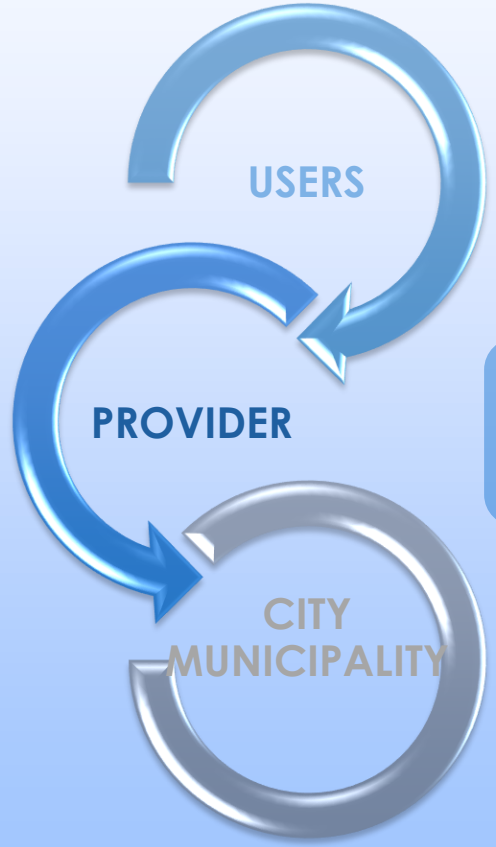
- not a favourable solution for overcoming distances on hilly terrain;

- not frequently used by elderly population.

https://www.visitljubljana.com/en/visitors/travel-information/getting-around/bicikelj/

E-BSS: weaknesses & challenges

- high investment costs in e-bikes and charging docks at the station;
- risky investment;
- inability to use e-bike during the charging;
- dock-less are not suitable for e-bikes.



- Distances from/to users;
- Enough e-bikes with full or suffciently full batery;
- Convenient e-bike characteristics;
- Enough replacement batteries;

- Saisfactory utilisation;
- Optimal investment in the infrastructure;

- Minimising the impact on the environment when setting up the infrastructure;
- Environmental friendly rebalancing of e-bikes;

https://www.themayor.eu/

„Recycling“ of BSS into mixed BSS/e-BSS

- designing e-BSS as an extension of already existing BSS→to promote a long-term implementation of e-BSS and win-win effects for crucial groups of stakeholders;
- Campbell, Cherry et al. (2016);
- a tool for a redesign of existing BSS network into mixed BSS and e-BSS network where mixed type of bikes is offered;

Model formulation

Landmark definition and subdivision of the urban area into sub-areas around landmarks.

Identification of existing BSS stations or adding new e-BSS stations in each sub-area.

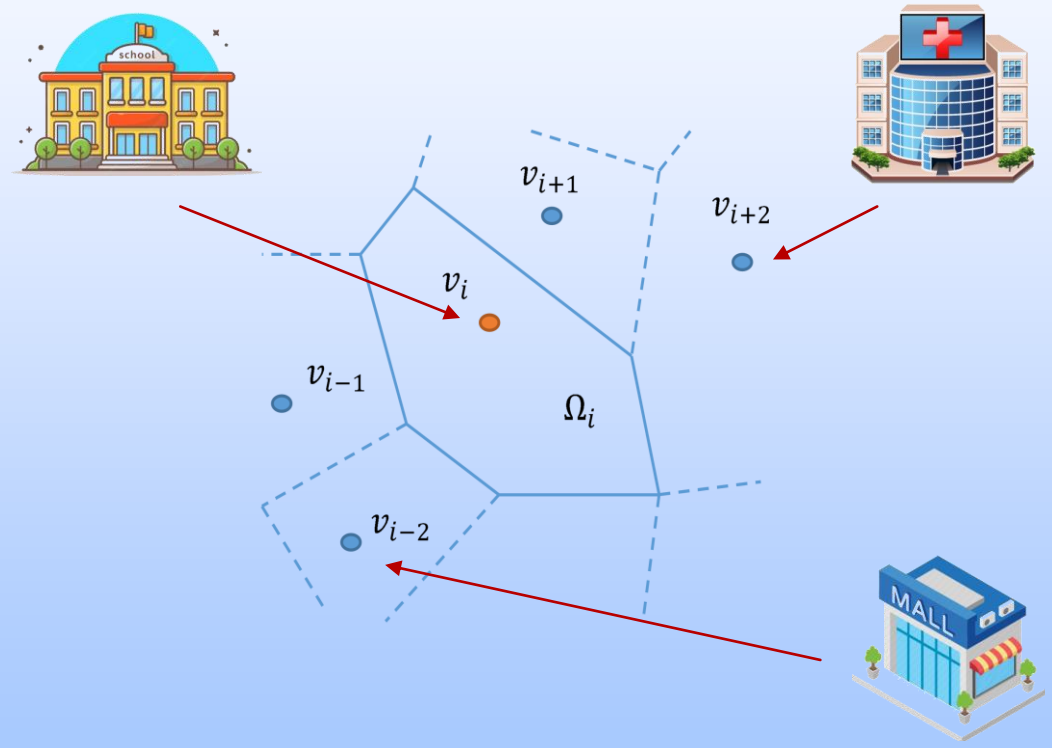
Criteria definition to evaluate the feasibility of upgrading a BSS station to an e-BSS station.

Hybrid AHP – DEA multi-criteria evaluation/ranking of e-BSS candidates to enhance future use.

Subdivision of the urban area region in sub-areas around landmarks points

Landmark points:

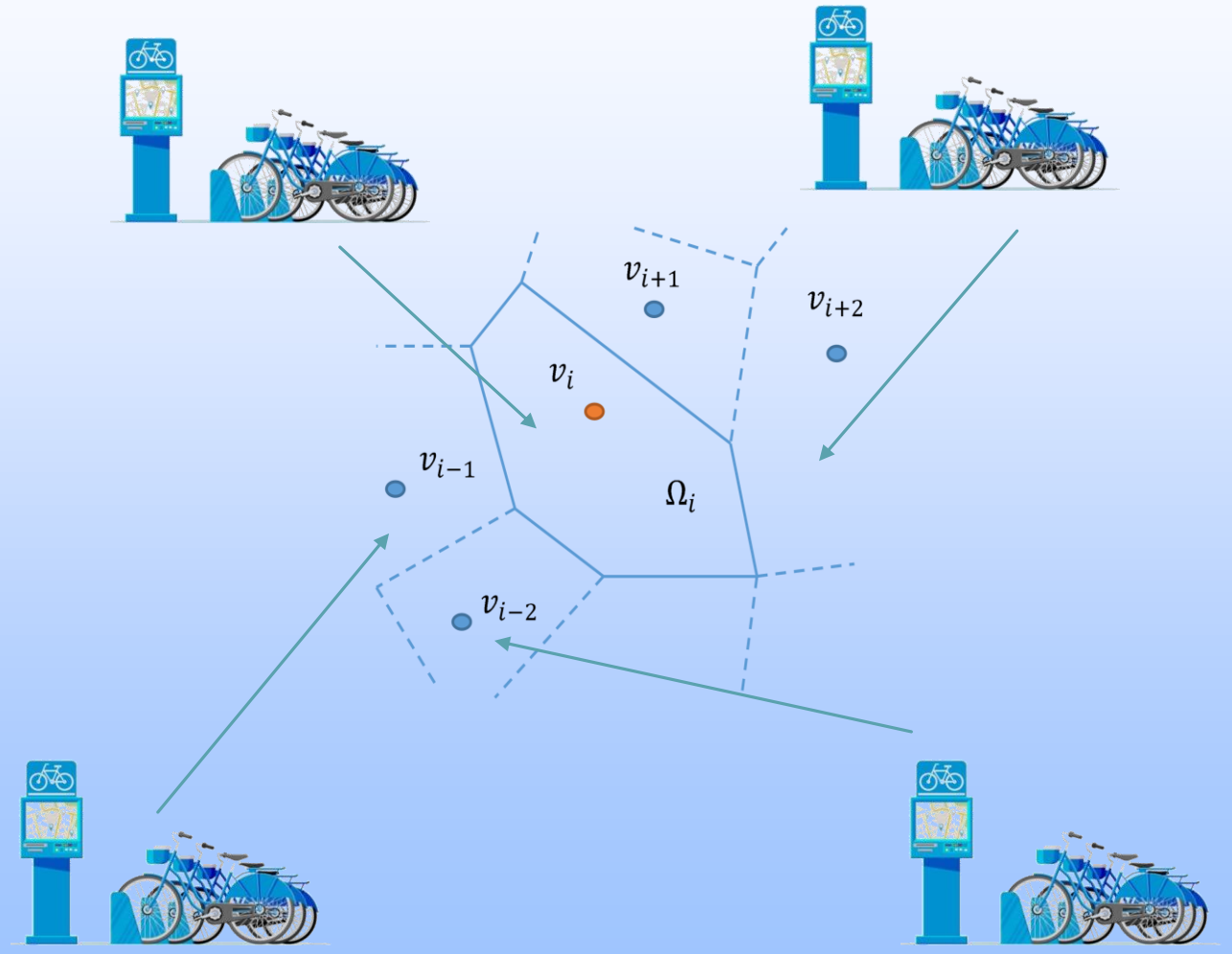
- shopping malls,
- primary/secondary schools,
- commercial buildings,
- recreational areas,
- campuses,
- cultural elements/tourism/social life,
- industrial areas,
- public administration buildings,
- hospitals or health centers,
- hub parking areas, and
- public transportation intersections.



The subdivision of the area is done with the help of the Voronoi diagram.

Identification of existing BSS stations in each sub-area

- In the case where there are no pre-existing BSS stations in a selected region Ω_i, a candidate e-BSS station is placed as the centroid of a polytope Ω_i.

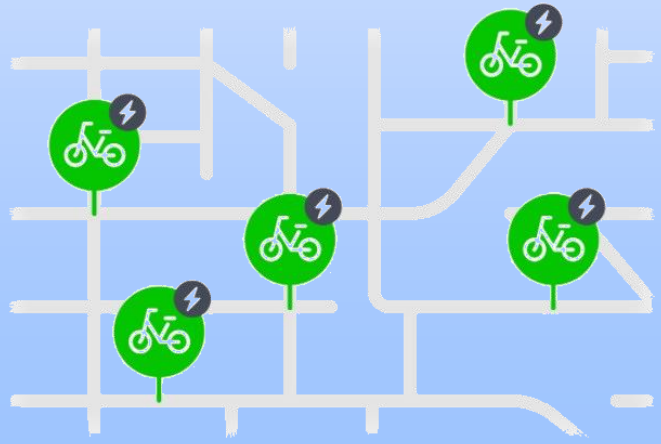


Definition of the criteria set

User Count Related Criteria	•Population density (aged 15 - 25 years) (per cent) •Population density (aged 25 - 65 years) (per cent) •Population density (aged 66 or more years) (per cent)
Transportation Network Criteria	•Proximity to a bike lane (meter) •Proximity to the subway network (meter) •Proximity to the bus transport network (meter) •Proximity to transit hubs and intersections (meter) •Proximity to road networks (meter) •Proximity to high traffic density roads (meter) •Proximity to the parking area (meter)
Terrain Related Criteria	•The slope of the terrain (maximum slope of a hill in per cent) •Possibility of expansion in the future (per cent)
Environment Related Criteria	•Emission reduction due to e-BSS (kg CO_2eq) •Proximity to repositioning trucks depot location (meter)
Battery related criteria	•Number of batteries at the station (number of batteries) •Number of charging piles at the station (piles) •E-bike battery autonomy under regular use (minutes)
E-bike related criteria	•Number of e-bikes at the station (number of e-bikes) •Number of e-bikes slots (number of e-bikes)
Economic criteria	•Infrastructure and updating costs (€) •Annual/ operation and maintenance costs (€ / bike station) •Investment payback period (years) •Land occupation/acquisition costs (€ / m^2)
Electricity related criteria	•The power supply capacity of transmission and distribution network (Volts) •Availability of existing electric network of the city (meter) •Sustainable energy potential (per cent) •Proximity to an electric substation (meter)

Hybrid multi-criteria evaluation method

- The AHP weighting method is used to evaluate the importance of the criteria.
- The slack based output oriented DEA method is used to evaluate the technical efficiency of the electric bike-sharing station candidates.
- The super-efficiency DEA is performed among technical efficient BSS to create a ranking.
- In this way, the decision-makers can select those with the best characteristics to enhance future use.



Case study – Ljubljana city center

- Ljubljana - cultural, educational, economic, political, and administrative center of Slovenia.
- The area of the capital is 163.8 sqkm (metro area is 2334 sqkm).
- The height above sea level is 295 m.
- The population in the capital is 295,504 inhabitants (the metro area has 537,893 inhabitants).
- Density is 1712/sqkm.

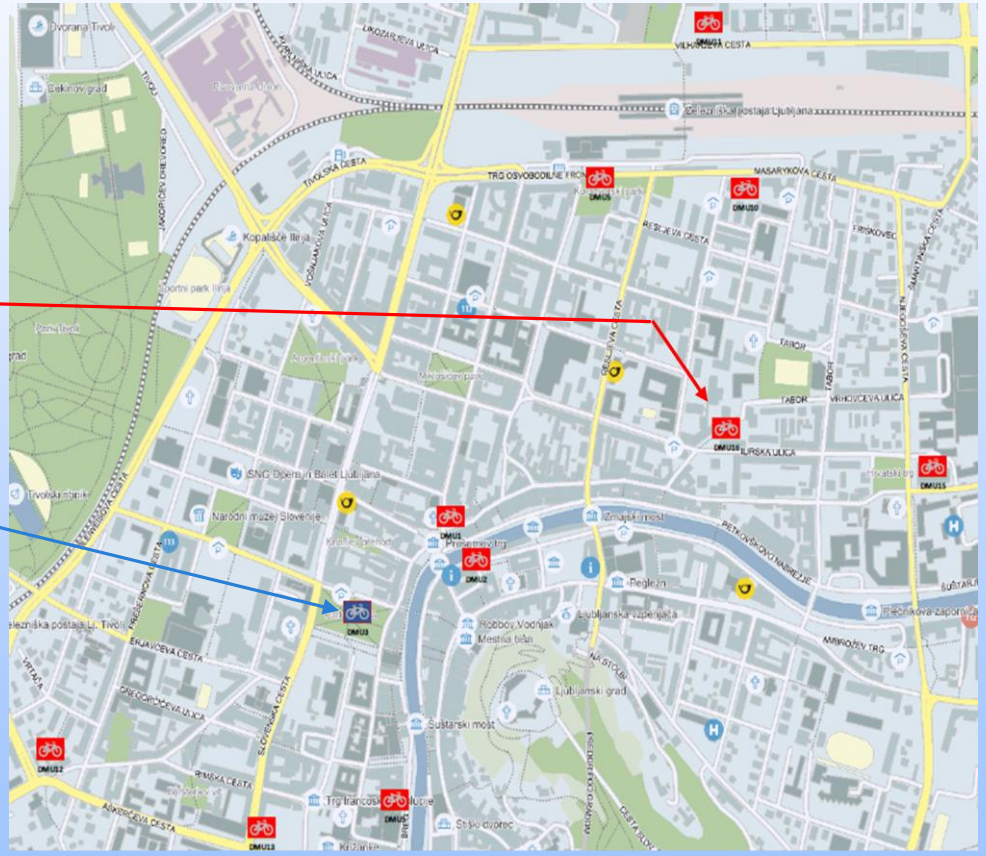
Identification of existing BSS stations

- The existing BSS is composed of **86 stations**, and **860 bikes** are available for the users.

https://www.bicikelj.si/

Results

Landmark v_1 ="campus"		Landmark v_2 = "public administration buildings"	
	Super - Efficiency score		Super - Efficiency score
DMU_{16}	0.9987	**DMU_{16}**	0.9999
DMU_{13}	**0.9986**	**DMU_9**	0.9999
DMU_9	0.9985	**DMU_{10}**	0.9987
DMU_3	0.9979	**DMU_3**	0.9979
DMU_{10}	0.9975	**DMU_1**	0.9958
DMU_{15}	0.9948	**DMU_{15}**	0.9902
DMU_1	0.9941	**DMU_{11}**	0.9599
DMU_{11}	0.9719	**DMU_{12}**	0.9223
DMU_5	0.9335	**DMU_5**	0.9061
DMU_{12}	0.8239	**DMU_2**	0.6206
DMU_2	0.5759		



Results

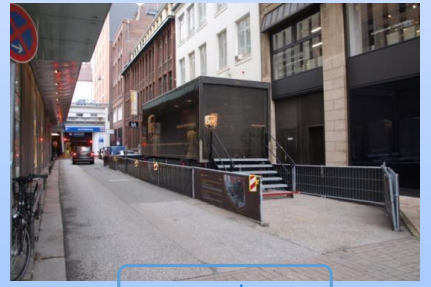
- A bike in a blue square represents DMU_{13}, positioned near the National and University Library of Ljubljana, which is the most important Slovenian library and a very popular study space among students in Ljubljana. All other BSS stations are located near buildings that are close to both landmarks.

- DMU_{16} has the highest score in both evaluations, since is located in an intermediate point between landmarks near administrative buildings, health facilities and university campuses. This clearly makes it optimal for both considered landmarks.

Recycling of BSS into mixed BSS/e-BSS, including e-cargo bikes

- not all BSS stations that proved to be suitable for upgrading in our previous case are not adapted to the needs of last mile delivery;
- e-cargo bikes charging stations are located at the same location of micro-hub or in the immediate vicinity (depending on the type of micro-hub location)

Mobile hubs



nearby

Fixed hubs

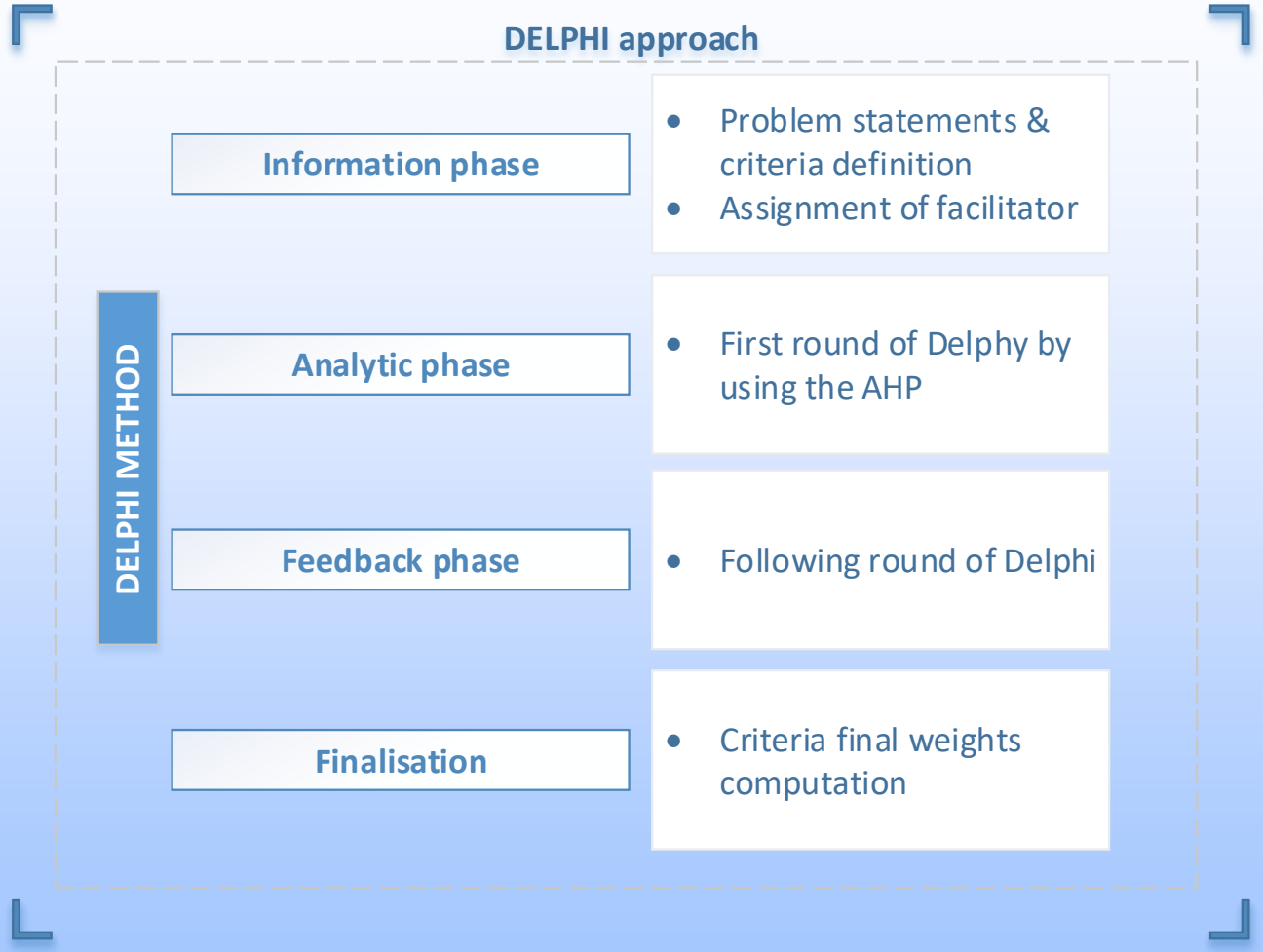
same location

https:///tntexpressturkiye.wordpress.com

https://eclf.bike/

COSTS RELATED CRITERIA (Anderluh et al., 2020, Fritzsche and Assmann, 2017, Assman et al., 2020, Rudolph et al., 2022, Rao et al., 2015, Shahparvari et al., 2020, Huang et al., 2020)	• Initial investment costs (existing infrastructure) • Existing infrastructure • Operating costs • Transport and distribution costs
TRANSPORTATION NETWORK CRITERIA (Anderluh et al., 2020, Fritzsche and Assmann, 2017, Assman et al., 2020, Rudolph et al., 2022, Rao et al., 2015, Shahparvari et al.)	• Proximity to a bike lane • Proximity to the subway network • Proximity to the bus transport network • Proximity to transit hubs and intersections • Proximity to road networks • Proximity to e-bike station • Existing/Available infrastructure
ENVIRONMENTAL CRITERIA (Anderluh et al., 2020, Fritzsche and Assmann, 2017, Rao et al., 2015, Shahparvari et al.)	• GHG emission reduction • Reduction of NOX and noise • Impact on landscape
USER COUNT RELATED CRITERIA (Anderluh et al., 2020, Fritzsche and Assmann, 2017, Assman et al., 2020, Rudolph et al., 2022, Rao et al., 2015, Shahparvari et al., 2020, Huang et al., 2020)	• Demand/Population density • Proximity to end customers
SOCIAL CRITERIA (Anderluh et al., 2020, Fritzsche and Assmann, 2017, Rao et al., 2015)	• Increase in safe and security
ELECTRICITY RELATED CRITERIA	• The power supply capacity of transmission and distribution network • Availability of existing electric network of the city • Sustainable energy potential • Proximity to an electric substation

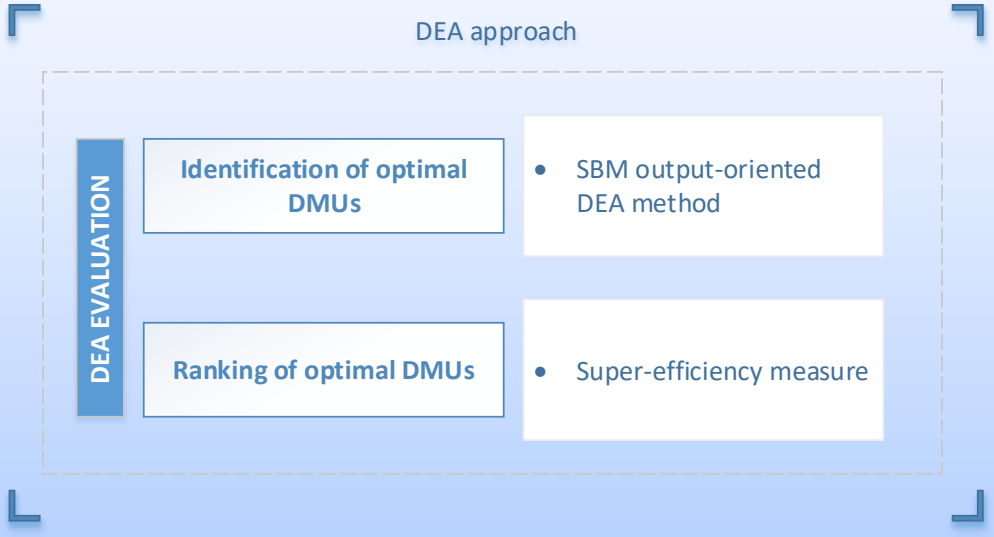
- Proposed methodology can be used to locate micro-hub but a **criteria system** has to be adapted to micro-hub site location;



Three groups of stakeholders:

- 8 members of the municipality of Ljubljana,
- 16 participants from logistics service providers and
- 22 Ljubljana citizens.

Sub-criteria	Before pandemic			After pandemic		
	City administration	Logistics companies	Citizens	City administration	Logistics companies	Citizens
Initial investment cost	0.078	0.086	0.021	**0,320**	0,017	0,020
Operating cost	0.094	0.108	0.046	0,049	0,149	0,031
Transport and distribution cost	0.150	**0.173**	0.058	0,027	**0,302**	0,041
Reduction of climate-relevant greenhouse gases	**0.182**	0.064	0.101	0,202	0,038	0,134
Reduction of health-relevant emissions (particulate matters, NO_x) and noise	**0.188**	0.097	**0.180**	**0,166**	0,026	0,119
Increase in safety and security	0.094	0.042	0.140	0,099	0,051	**0,179**
Inbound logistics to the hub	0.070	0.163	0.141	0,079	0,124	0,085
Outbound logistics from the hub	0.120	**0.190**	**0.176**	0,049	**0,218**	**0,325**
Existing/available infrastructure at the hub	0.024	0.076	0.138	0,017	0,074	0,066



Thank you for the attention.