The suitability level of bike-sharing station in Yogyakarta using SMCA technique

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Abstract. Yogyakarta is experiencing the increasing number of population (1,13%) from 2014 to 2017 that influences the rising number of motorized vehicles. Besides, it is also led by the easiness to access vehicles ownership in Yogyakarta. In 2017, Yogyakarta ranked fourth as the most congested city in Indonesia that indicates the importance of changing the transportation mode from private vehicles to public transportation. Through the mission of Yogyakarta to strengthen urban planning and environmental sustainability, it is necessary to implement green transportation along with transport demand management to reduce the disadvantage of road congestion in the city. Hence, bike-sharing system can be an option that provides new alternative mobility. However, the important thing to manage bike-sharing systems is the optimal location of bike-sharing station. In Yogyakarta, there is already a bike-sharing systems but only in 12 stations. This research aims to identify the best location for siting bike-sharing station based on spatial analysis using Analytical Hierarchy Process (AHP) and Spatial Multi-Criteria Analysis (SMCA). According to the analysis, the urban core of Yogyakarta and its surrounding are the most suitable location for bike-sharing station.

1. Introduction

Urban transportation is basically active or referred to active mobility. Active mobility, like walking and cycling, is important to cities as they give advantages not only to human, but also to the cities. Besides, it is one of the sustainable transportation modes that is necessary to cities in order to reduce traffic congestion and high level of air pollution [1]. Walking and cycling in the city are possible due to the high building density and centered activities in the core [2–4]. The implementation of active mobility can be done by establishing bike-sharing system that is showing an increasing trend in the world [2, 5–8].

Bike-sharing system is an alternative to overcome the first & last miles’ problem that enables people to rent a bike in a docking station. Its system influences the reduction of traffic congestion and related stressors. In addition, cities that own bike-sharing systems can improve their existing urban transportation network by adding advantages to health and the economy [9] and reducing nitrogen and carbon dioxide emission [10]. Moreover, besides contributing to sustainable transportation, the bike-sharing system is also in implementation of the smart city concept as its efficient and smart use of energy [11].
According to that, the application of bike-sharing system should be encouraged in many cities in Indonesia. The first mobile application based bike-sharing system in Indonesia is established in Bandung called BOSEH (Bike on Street Everybody Happy). Other cities in Indonesia are expected to follow the path of Bandung in applying bike-sharing system in their urban area to promote sustainable transportation. Before, cities should point the suitable location for bike-sharing station to meet the demand and to avoid the possibility of not being used in the future. Besides Bandung, Yogyakarta also has a bike-sharing system which was managed by private company called InaBike. InaBike was launched on October 2018 with 4 stations and is aimed to connect point-by-point tourist attractions in Yogyakarta. However, Yogyakarta which has 422,732 inhabitants is recommended to have bike-sharing station in the entire city [12].

Nevertheless, not all bike-sharing system has its successful story. Low security and safety level, poor infrastructure quality, and inappropriate tariffs are also factors of the failure of bike-sharing system. China is an example of a failure bike-sharing system according to the inappropriate distribution of bike-sharing station [13], whereas some researchers also mentioned that the selection of station location is a critical step before implementing bike-sharing system [7, 12, 14-17] in addition to system usage, tariffs, and the number of bicycle [18]. Therefore, the location of bike-sharing station is something that needs to be done by considering diverse demand, especially in Yogyakarta which is prominent as student and tourism city. This research aims to identify the suitable location for bike-sharing station in Yogyakarta using AHP and SMCA method.

2. Location of study
Yogyakarta is a capital city of Daerah Istimewa Yogyakarta Province which has 14 sub-districts (Figure 1). The population of Yogyakarta is 422,732 people in 2017 with a population density of 13,007 people/km². According to its population size, Yogyakarta is classified as medium city because it has population numbers between 100,000 and 500,000 people. Based on its RPJMD or medium-term regional development plan, the vision of Yogyakarta is to create a livable city by running a mission to actualize a green transportation system. Therefore, Yogyakarta is getting ready to serve cyclist by improving cycling infrastructure such as bicycle lanes.

Figure 1. The location of Yogyakarta
Based on the identification of bikeability, Yogyakarta has high level of bikeability which is determined by the bicycle lanes density, point of interest density, and topography (Figure 2). Bikeability is the ability of using a bicycle as a transport mode based on city’s spatial structure and streets [19]. Most of the slope in Yogyakarta is flat with a slope of about 1 degree which accommodate comfort and attractiveness in using bicycles [20]. Besides, the point of interest density in Yogyakarta is high enough to encourage people to use bicycles. Moreover, bicycle lanes in Yogyakarta consist of 2 types which are straight lines and intermittent lines. The government also concern about the alternative bicycle lanes and the bicycle crossing in the city (Figure 3).

![Figure 2. Bikeability level of Yogyakarta](image1.png)

![Figure 1. Cycling infrastructure in Yogyakarta](image2.png)
3. **Data and methodology**

The data used in this research consist of secondary data. Meanwhile, the method used in this research is the combination of AHP and SMCA.

3.1. **Data and materials**

Spatial analysis which was conducted in this research uses shape file (.shp) data from Spatial Plan Agency of Yogyakarta, Transportation Agency of Yogyakarta along with open source data from Open Street Map. Data from both sources were being corrected and fixed in order to delete the unnecessary data outside Yogyakarta area. Table 1 shows the list of data and sources.

| Type of Data  | Sources                          |
|---------------|----------------------------------|
| Transport network |                                  |
| Bus stop       | Spatial Plan Agency of Yogyakarta, |
| Bus terminal   | Transportation Agency of Yogyakarta, |
| Train station  | Open Street Map                   |
| Bicycle lanes  |                                  |
| Land use       |                                  |
| Culinary attractions | Spatial Plan Agency of Yogyakarta, |
| Cultural attractions | Open Street Map                   |
| Shopping malls |                                  |
| Office complex |                                  |
| Public park    |                                  |
| Demand         |                                  |
| Population density | Statistical Agency of Yogyakarta, |
| University     | Spatial Plan Agency of Yogyakarta, |
| Schools        | Open Street Map                   |
| Hotels         |                                  |

3.2. **Methodology**

3.2.1. **Analytical Hierarchy Process (AHP).** The first method used in this research is AHP. AHP is used to produce decision based on the desired goals [21]. AHP is carried out in six stages that are:

1. build a model consisting of goals, criteria and alternatives,
2. determine the priority scale of the variable used,
3. derive preference by comparing the weights between variables and performing consistency tests,

| Explanation       | Weight |
|-------------------|--------|
| Extremely important| 9      |
| Very more important| 8      |
| More important     | 7      |
| A little more important| 6      |
| Equally important  | 5      |
|                    | 4      |
|                    | 3      |
|                    | 2      |
|                    | 1      |
Lambda Max

\[ \lambda_{max} = \text{Priority vector} \times \text{weighted sum} \div n \]  

Consistency Index (CI)

\[ CI = (\lambda_{max} - n) \div (n-1) \]  

Consistency Ratio (CR)

\[ CR = \frac{CI}{RI} \]  

If the CR value is \( \leq 0.1 \), the assessment carried out using AHP is reliable and can be used for further analysis.

4. derive the weight of total to get priority,
5. do sensitivity analysis, and
6. determine the final decision that answers the purpose of the model.

Therefore, this research only used three stages as the analysis of each variable was carried out using the next method called SMCA. If the value of the consistency ratio is \( \leq 0.1 \), then the weight obtained are able to be used to do the SMCA.

3.2.2. Spatial Multi-Criteria Analysis (SMCA). SMCA method is a multidisciplinary analysis that combines spatial data and assessment from the AHP [22]. As mentioned by Boggia et al, the SMCA method is useful in regional and city planning, sustainable forest management and planning, catchment area planning, and ecological planning. Therefore, the SMCA method is important in determining decision and to minimize risk. The shape file from each variable were processed by using Euclidean Distance in ArcGis. The pixel values for each raster data were normalized to 0-1 so that the pixel values have the same range of values. It aimed to get a balance and reliable result of raster analysis. After normalizing the pixel values, it was multiplied by the weight obtained from AHP by using raster calculator. The integration between AHP weight and SMCA is illustrated in Figure 4.

4. Results and discussion
4.1. Weight of variables

In determining the priority for locating bike-sharing station, 12 variables were used which are the proximity of bus stop, bus terminal, train station, bicycle lanes, cultural attraction, culinary attraction, shopping malls, office complex, public park, university, schools, hotels, and the population density of each sub-district. For example, the proximity of bus stop is compared with the proximity of university using the question which is considered more important. If the proximity of bus stop is a little more important than the proximity of university, it weight 3 while the weight of university is the opposite or 0.3.

In this case, the highest weight is transport network criteria while the lowest weight is land use criteria. Transport network outweighs other criteria with 0.411 with the most important factor in the transport network criteria is the proximity of bicycle lanes (0.445) (Table 3). Other factors in transport network criteria, ranked by weight are as follows: proximity to bus stop (0.363), proximity to train station (0.120), and proximity to bus terminal (0.072). The consideration of this high weight is that bike-sharing station will link other urban transport network and its proximity to transport network will encourages people to use it more often [5, 23-27].

In addition, variables in demand criteria, ranked by weight are as follows: population density (0.392), proximity to university (0.310), proximity to hotels (0.207), and proximity to schools (0.091). Population density has the highest weight as it depicts the number of population in an area which determines the proximity to bike-sharing demand. University weights more than hotels and schools because the university students are the potential users of bike-sharing. Besides, locating bike-sharing stations near university has a positive influence on the usage of bike-sharing [28, 29] while the proximity to schools have a negative influence [30].

Furthermore, variables in land use criteria, ranked by weight are as follows: proximity to cultural attraction (0.316), proximity to shopping malls (0.283), proximity to culinary attraction (0.195), proximity to office complex (0.115), and proximity to public park (0.092). Proximity to cultural attraction more important than other variables because it is where tourists usually located. Tourists tend to try various public transportation in other cities to gain more experiences.

| Variables                     | Priority Vector | Wi   | Lambda | CR  |
|-------------------------------|-----------------|------|--------|-----|
| Proximity to bicycle lanes    | 0.445           |      |        |     |
| Proximity to bus terminal     | 0.072           |      |        |     |
| Proximity to train station    | 0.120           | 0.411| 4.157  | 0.053|
| Proximity to bus stop         | 0.363           |      |        |     |
| Proximity to culinary attraction | 0.195         |      |        |     |
| Proximity to shopping malls   | 0.283           |      |        |     |
| Proximity to cultural attraction | 0.316          | 0.261| 5.329  | 0.069|
| Proximity to office complex   | 0.115           |      |        |     |
| Proximity to public park      | 0.092           |      |        |     |
| Population density            | 0.392           |      |        |     |
| Proximity to university       | 0.310           |      |        |     |
| Proximity to schools          | 0.091           | 0.328| 4.211  | 0.071|
| Proximity to hotels           | 0.207           |      |        |     |

4.2. Spatial analysis
Having derived weight for each variable, a spatial analysis using Euclidean Distance was carried out to know the distance of 400 meters from each variable. Euclidean Distance was used to produce the results on a raster output. It has a more realistic output than buffer tools. The chosen distance is 400 meter as it is the ideal distance of someone to walk. The results are shown in Figure 5 and are being used to run the SMCA. The pixel values from each variable are multiplied by the weight of AHP (priority vector) according to its group criteria. For example, the variable from demand criteria were processed together also with other variables in demand criteria. After getting 3 map layers that consist of each group criteria, the pixel values were calculated by multiplying it with Wi and resulted a site suitability map.

Figure 6 shows the suitability level for bike-sharing station in Yogyakarta. It explains that Yogyakarta has level of suitability from low to high. The urban core which lies on Gedongtengen, Danurejan, and Gondomanan have medium to high suitability for bike-sharing station. In addition, Jetis, Gondokusuman, Ngampilan, Pakualaman, Mergangsan, Kraton, Wirobrajan, and Mantrijeron also have medium to high level of suitability. Meanwhile, other sub-districts have low level of suitability as there are lack of transport network and urban activities although Kotagede is one of the tourist area in Yogyakarta. In contrast, Kraton, which also the tourist area in Yogyakarta has a medium level of suitability.
According to the suitability level of bike-sharing in Yogyakarta, the future expansion of bike-sharing system in Yogyakarta should accommodate urban core and tourist area. The existing bike-sharing station are only located in Danurejan and Gondokusuman sub-districts which are the urban core. It means that the existing station has occupied the appropriate location although the distance of each station only 250 meters and the station in Gondokusuman (Suroto Street), they are not linked to the bus stops. Therefore, the existing station in Danurejan (Malioboro Street) have already linked to the bus stops since they are placed near the bus stops. In addition, Kraton and Kotagede sub-districts should be the next priority area of bike-sharing system as those sub-districts are tourist area according to the Spatial Plan of Yogyakarta. Moreover, in locating bike-sharing station, the government needs to pay attention to the walking distance from every residential area in Yogyakarta, at least one within a 5-minute walk.

Despite the high level of bikeability, the government of Yogyakarta are expected to strengthen its public transportation network that will influence the usage of bike-sharing. By improving public transportation network, the suitability level of bike-sharing station in Yogyakarta will be evenly distributed. It may have a positive effect on the willingness of residents to use bike-sharing as a daily transportation mode.

5. Conclusion

In conclusion, Yogyakarta has a high level of bikeability that is suitable for the implementation of bike-sharing system. According to the site suitability map, the potential area for locating bike-sharing station are located in the urban core area and its surrounding which are Gedongtengen, Danurejan, Ngampilan, Jetis, and Pakualaman. In addition, several locations that are the center of tourism activities, Kraton and Kotagede, are also suitable for bike-sharing station but in a smaller scale to serve the tourists. Besides, the colors difference in the results may depict the implementation step of bike-sharing station in Yogyakarta. In order to strengthen the results, the next research should elaborate more detail parameters.
Based on its bikeability and site suitability, the government of Yogyakarta along with private company which manage InaBike should promote active mobility to strengthen its bike-sharing system.

Acknowledgment
This research is a part of master thesis in Master of Urban and Regional Planning, Universitas Gadjah Mada entitled “The Level of Suitability of Bike-sharing Station Location Based on User Preferences in The City of Yogyakarta”. This research is done under the financial support from Ministry of Education and Culture of Republik Indonesia through Beasiswa Unggulan scholarship.

References
[1] Ernst 2011 Environmental challenges of urban transport: the impacts of motorization Urban Transportation in the Developing World (United Kingdom: Edward Elgar Publishing Limited)
[2] DeMaio 2009 Bike-sharing: history, impacts, models of provision, and future Journal of Public Transportation. 12 41-56
[3] Guo 2015 Active Mobility in Cities: Ten Design Principle Urban Solution
[4] Haufe, Millonig A and Markvica K 2016 Developing encouragement strategies for active mobility Transportation Research Procedia 19 49-57
[5] Cetinkaya 2017 Bike sharing station site selection for Gaziantep Sigma Journal of Engineering and Natural Science 35 535-543
[6] Fishman 2016 Cycling as transport Transport Reviews 36 1-8
[7] Frade and Ribeiro A 2015 Bike-sharing stations: A maximal covering location approach Transportation Research Part A 82 216-227
[8] Shaheen, Guzman S and Zhang H 2010 Bikesharing in Europe, the Americas, and Asia Transportation Research Record 2143 159-167
[9] Otero, Nieuwhuizen M J and Rojas-Rueda D 2018 Health impacts of bike sharing systems in Europe Environment International 115 387-394
[10] Zhang and Mi Z 2018 Environmental benefits of bike sharing: A big data-based analysis Applied Energy 220 296-301
[11] Rani and Vyaz O P 2017 Advances in Computer and Computational Sciences. Advances in Intelligent Systems and Computing (Singapore: Springer)
[12] Garcia-Palomares, Gutierrez J and Latorre M 2012 Optimizing the location of stations in bike-sharing programs: A GIS approach Applied Geography 35 235-246
[13] Sun 2018 Sharing and riding: how the dockless bike sharing scheme in China shapes the city Urban Science 2 1-19
[14] Chen, Zhang D, Pan G, Ma X, Yang D and Kushlev K 2015 Bike sharing station placement leveraging heterogeneous urban open data ACM International Joint Conference on Pervasive and Ubiquitous Computing 571-575
[15] Conrow, Murray A T and Fischer H A 2018 An optimization approach for equitable bicycle share station siting Journal of Transport Geography. 69 163-170
[16] Mete, Cil Z A and Ozceylan E 2018 Location and coverage analysis of bike-sharing stations in University Campus Business Systems Research 9 80-95
[17] Straub, Rudloff C, Graser A, Kloimullner C, Raidl G R and Pajones M 2018 Semi Automated location planning for urban bike-sharing systems 7th Transport Research Arena TRA 2018
[18] Wang, Tsai C H and Lin P C 2016 Applying spatial-temporal analysis and retail location theory to public bikes site selection in Taipei Transportation Research Part A 94 45-61
[19] Munoz B, Monzon A and Lopez E 2016 Transition to a cyclable city: Latent variables affecting bicycle commuting Transportation Research Part A 84 4-17
[20] Hartanto 2017 Developing a bikeability index to enable the assessment of Transit-Oriented Development (TOD) nodes (Enschede: University of Twente)
[21] Mu and Pereya-Rojas M 2017 Understanding the Analytic Hierarchy Process (America: Springer International Publishing)

[22] Massei, Rocchi L, Paoletti L, Greco S and Boggia A 2014 Decision Support System for environmental management: A case study on wastewater from agriculture Journal of Environmental Management 146 491-504

[23] Ghandehari, Pouyandeh V H and Javadi M H M 2013 Locating of bicycle stations in the City of Isfahan using mathematical programming and multi-criteria decision making techniques International Journal of Academic Research in Accounting, Finance, and Management Sciences 3 18-26

[24] Jahanshahi, Minaei M, Kharazmiv O A and Minaei F 2019 Evaluation and relocating bicycle sharing stations in Mashhad City using multi-criteria analysis International Journal of Transportation Engineering 6 265-283

[25] Kabak, Erbas M, Cetinkaya C and Ozceylan E 2018 A GIS-based MCDM approach for the evaluation of bike-sharing stations Journal of Cleaner Production 201 49-60

[26] Kanjanakorn and Piantanakulchai M 2013 Prioritizing suitable locations of bike sharing station by using the Analytical Hierarchy Process (AHP) Proceedings of the International Symposium on the Analytical Hierarchy Process 2013 1-10

[27] Midgley 2009 The role of smart bike-sharing systems in urban mobility Journeys 23-31

[28] DeMaio and Gifford J 2004 Will smart bikes succeed as public transportation in the United States? Journal of Public Transportation 7 1-15

[29] Imani, Eluru N, Geneidy A M E, Rabbat M and Haq U 2014 How land-use and urban form impact bicycle flows: evidence from the bicycle-sharing system (BIXI) in Montreal Journal of Transport Geography 41 306-314

[30] Kim, Shin H, Im H and Park J 2012 Factors influencing travel behaviors in bike-sharing, Transportation Research Board 91st Annual Meeting