DEVELOPMENT OF MICRO-MOBILITY MODES TO SUPPORT FIRST AND LAST MILE CONNECTIVITY IN THE PUBLIC TRANSPORTATION SYSTEM OF SURAKARTA CITY

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Abstract

Micro mobility has an important role in improving first–last mile (FLM) connectivity as a link between community activities and the public transportation system. In the city of Surakarta, the low use of public transportation is still driven by the low quality of accessibility to transportation nodes and variations in the performance of micromobility services. This study aims to analyze FLM's travel characteristics, user perceptions and preferences towards micromobility services, and identify priority service attributes that need to be optimized to support integration with public transportation. The research method used descriptive analysis, instrument validity and reliability tests, and Importance–Performance Analysis (IPA) applied to four micro mobility modes: pedicabs, walking, bicycles, and electric scooters. A total of 213 respondents who met the criteria participated in the survey. The results showed that all service attributes have a negative gap between importance and performance levels, so users judge that the current service quality does not meet FLM's travel needs. The analysis of IPA per mode shows that the main priority attributes include travel safety and security, the availability of protected lanes, supporting facilities, accessibility to public transportation nodes, and the availability of travel information. These findings confirm that the success of the integration of micro mobility and public transportation in Surakarta is highly dependent on improving the quality of basic facilities, protecting users' movement space, and strengthening access infrastructure support.

Keywords: Micro Mobility, First–Last Mile, Importance–Performance Analysis, Public Transportation, Accessibility

INTRODUCTION

The lack of public transportation in Indonesia is due to the lack of public interest and preferring to use private vehicles that are more flexible and practical. The low interest is influenced by the public's negative perception of public transportation. This is because people think that public transportation is not on time in its schedule, there is a risk of crime, the condition of facilities is not always adequate, and the distance of the nearest transit node from home/location of origin is too far (Hanny & Almassawa, 2021; Kriswardhana et al., 2022). Despite these challenges, transportation still has the potential to be one of the important instruments of sustainable urban development strategies (UITP, 2018). This can happen if there is a good transportation system, so that it can reduce the number of vehicles on the road and minimize congestion and carbon emissions (Romadhona *et al*., 2024). One of these good systems is the availability of good public transportation integration, so that it can provide mobility support to the community and have a good impact on the environment (Rohmah et al., 2024).

The transportation system is an important component of infrastructure that has a major impact on economic and social development, because of its role in facilitating the mobility of people or goods in various regions (Nur *et al*., 2021; Taylor, 2021). The system that encourages movement from one place to another requires an efficient mobility system that supports various modes of transportation. Active modes of transportation are usually known to be walking, cycling, buses, and trains in various cities. However, with rapid urbanization and urban growth, these modes or transportation networks need to be expanded in order to be connected to the entire city (Hussin *et al*., 2021). *The First and Last Mile* (FLM) of transit travel using public transport is one of those networks, and is the weakest network in the urban transport network (Kusuma & Handayeni, 2024; Venter, 2020). Nonetheless, FLM is becoming an important component of urban mobility planning, as the first and last mile will be the deciding factor for individuals to choose the next mode of transport (Kalašová et al., 2022). This is also because the improvement of public transportation infrastructure will depend on FLM connectivity (Chakraborty *et al*., 2025).

The weak FLM network makes this segment a major challenge in the use of public transportation. This refers to the lack of convenient FLM mode options to reach the public transportation node you want to use (Yin *et al*., 2024). FLM connectivity in most urban areas in Indonesia uses human-powered or electric micromobility, examples are scooters, bicycles, pedicabs, and walking (Yanocha & Allan, 2020). However, walking long distances will cause accessibility issues and make FLM's journey tiring (Oswar Mungkasa, 2021). Connectivity from pedestrian paths, safety on bicycle paths, and security from criminals are also other issues (Saputri & Tantyo, 2023). The weakness of this segment does not only require the addition of bicycle lanes or pedestrian paths, but also requires space to integrate existing urban infrastructure or that will be planned through smart connectivity or smart mobility (Bıyık *et al*., 2021).

Transportation networks with smart connectivity and mobility allow people or users to travel and return from their destinations efficiently, easily, conveniently, affordably, and sustainably (Ismagilova *et al*., 2019). Smart mobility is the foundation of a smart city that is very closely related to decisions and policies across administrations. This concept prioritizes the development of tools, data innovation, and communication with the aim of minimizing economic, environmental, and time costs (Aletà *et al*., 2017). Based on these goals, smart mobility encourages the use of environmentally friendly transportation, such as public transportation and active transportation such as walking and cycling. The more efficient the mobility system, the more the region can increase their economic strength (Lukijanto, 2023).

Based on its function and geographical location, the city of Surakarta is the center of regional activities and ideal as a transit area, making the city an economic, activity, and transportation node (Nurdiani *et al*., 2019; Rosyidi & Krisnawaty, 2024). Based on this potential, the facts on the ground are known that the city of Surakarta faces the challenge of integrating the development of the center and sub-center and transportation system with the surrounding area, which has not been comprehensively planned. In addition, the implementation of public transportation integration also faces challenges in the lack of synchronization between modes of transportation and has only focused on the availability of public transportation modes. Transportation policies between the central and regional governments are also not fully well coordinated, and hinder the implementation of transportation integration (Rohmah et al., 2024). The lack of public transportation system in the city of Surakarta certainly plays a role in decreasing public interest in using public transportation and active transportation.

The Surakarta City Government, in overcoming the challenges of the existing transportation system, has taken an approach with the main goal of encouraging the shift from private mode to public mode. This is outlined in the Regional Spatial Plan (RTRW) for 2021 - 2041, which is a development that focuses on the integration of public transportation networks with non-motorized transportation (Non-Motorized Transport) networks. This integration is defined as the process of combining advantages between micromobility (flexibility and accessibility) and public transportation (range and speed). The integration of NMT with public transportation is also carried out by developing the concept of transit-oriented areas or Transit Oriented Development (TOD). The city of Surakarta plans to develop 4 TOD areas to serve the surrounding area, namely the TOD Purwosari, TOD Joglo, TOD Jebres, and TOD Gading areas. The concept, in addition to focusing on integration with NMT, is also expected to reduce the use of motor vehicles and the development of mixed areas with space intensity from medium to high.

The integration of NMT or micromobility with public transport has various benefits in urban transport systems and their impact on the environment. Based on this potential and supported by the City Government's plan to develop a transportation system, especially in public transportation connectivity and micro mobility, this study aims to find out the attributes of services that can be intervened in planning the integration of micro mobility and public transportation in the city of Surakarta. These priority attributes will then be developed to encourage the use of micromobility as FLM. This research also aims to support Sustainable Development Goal number 11 to provide sustainable transportation and ensure safe, economical, and accessible transportation for every community.

RESEARCH METHOD

This research was conducted in Surakarta City with a study scope focused on the road network connecting service centers, sub-centers, and various public transport nodes such as BST shelters, feeder routes, and other transit points. The research objects include public transport users who utilize micro-mobility modes such as walking, bicycles, pedicabs, and electric scooters to reach transport nodes. Data collection consisted of primary and secondary

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data obtained through field observations, questionnaires, and document reviews of planning documents such as the RTRW, RDTR, and RPJMD. The questionnaire used a Likert scale of 1–5 covering service attributes including comfort, safety, accessibility, information, cleanliness, and supporting facilities. The sampling technique applied was non-probability purposive sampling, and the sample size was determined using the Lemeshow formula. The calculation resulted in 213 respondents who met the research criteria. Questionnaire distribution was carried out using Google Forms and monitored regularly to ensure sufficient data collection. The analysis phase began with descriptive statistical analysis to describe respondents' socio-demographic profiles and mobility patterns. The results of this descriptive analysis served as the basis for understanding user preferences and needs within the context of first–last mile travel.

The analysis of user perceptions and preferences was conducted to assess which micro-mobility service factors influence mode choice, utilizing questionnaire data that reflected respondents' travel experiences. Assessment was carried out by assigning scores for the importance and performance levels of each attribute, supported by open-ended questions to explore users' preferred modes. Field observation was also conducted to evaluate the actual condition of micro-mobility infrastructure so that the analysis accurately represented real-world conditions. Validity testing using the product-moment correlation and reliability testing using Cronbach's Alpha were performed to ensure the instrument's feasibility. The instrument was considered valid when the calculated r-value exceeded the table value and reliable when the alpha value was greater than 0.70, with all calculations assisted by SPSS version 30. The subsequent analysis employed the Importance–Performance Analysis (IPA) method to determine service improvement priorities based on the average importance and performance scores. The mean values of both aspects were then mapped into a four-quadrant Cartesian diagram to classify attributes that require improvement, maintenance, or minimal attention. The first quadrant indicated attributes with high importance but low performance, thus requiring priority enhancement. Meanwhile, the other quadrants provided direction regarding maintenance, efficiency, and resource allocation in the development of micro-mobility services.

RESULTS AND DISCUSSION

Priority Attributes in Micro Mobility Mode Integration for First-Last Mile Travel

Validity Test

This test uses the help of the SPSS program with the product moment correlation technique, where the correlation value of each question item (r calculated) is compared to the r value of the table. The determination of the r-value of the table was carried out based on the number of respondents (n) and the degrees of freedom (df = n – 2). In this study, the number of respondents was 213 people, so the degree of freedom was 211. Based on the critical r distribution table at a significance level of 5% (0.05) for df = 211, the table r value of 0.1345 was obtained as the minimum limit of instrument validity. The results of the validity test of the questions from the questionnaire are shown in Table 1.

Table 1. Service Attribute Validity Test

No	Code	Service Attributes	Interests		Validation	Performance		Validation
			r count	R table		r count	R table	

1	P1	Convenience of FLM travel facilities	0,476	0,1345	Valid	0,786	0,1345	Valid
2	P2	Availability of information in FLM travel	0,504	0,1345	Valid	0,754	0,1345	Valid
3	P3	Risk of crime in travel using micromobility	0,575	0,1345	Valid	0,715	0,1345	Valid
4	P4	Safety of FLM travel using micromobility	0,488	0,1345	Valid	0,723	0,1345	Valid
5	P5	The level of ease of access to urban public service facilities with micro mobility	0,566	0,1345	Valid	0,754	0,1345	Valid
6	P6	The level of ease of access to public transportation using micromobility	0,591	0,1345	Valid	0,813	0,1345	Valid
7	P7	The existence of a policy of providing micro mobility facilities	0,600	0,1345	Valid	0,791	0,1345	Valid
8	P8	Availability of pedestrian and bicycle lanes separate from motorized vehicle lanes	0,613	0,1345	Valid	0,817	0,1345	Valid
9	P9	Availability and completeness of supporting facilities *(street furniture)*	0,583	0,1345	Valid	0,801	0,1345	Valid
10	P10	Availability of crossing facilities	0,636	0,1345	Valid	0,829	0,1345	Valid
11	P11	Availability of parking facilities at transit points	0,518	0,1345	Valid	0,744	0,1345	Valid
12	P12	Cleanliness of micro-mobility paths (pedestrian, bicycle, etc.)	0,620	0,1345	Valid	0,793	0,1345	Valid

The results of the validity test showed that all variables had a calculated r-value greater than the r-table (0.1345), so that all instruments used were declared valid. For example, the comfort variable of travel facilities has a calculated r value of 0.476, a travel information variable of 0.504, and a crime risk variable of 0.575, all of which far exceed the r-value of the table. This indicates that each question indicator is able to represent the research variables accurately and consistently. Thus, the questionnaire used is suitable as a measuring tool in further analysis, both for reliability tests and subsequent analysis methods.

Reliability Test

Reliability tests are carried out to determine the extent to which the research instrument can produce consistent data if used repeatedly under the same conditions. In this study, the reliability test was carried out using the Cronbach's Alpha method through the SPSS program. An instrument is said to be reliable if it has a Cronbach's Alpha value greater than 0.70. Thus, the higher the value obtained, the higher the level of reliability of the instrument in measuring the research variables.

Table 2. Questionnaire Reliability Test

No	Data Groups	Nilai Cronbach Alpha	Status
1	Interests	0,835	Reliable
2	Performance	0,940	Reliable

Based on the test results shown in Table 2, a Cronbach's Alpha value of 0.835 was obtained for the interest data group and 0.940 for the performance data group. Both values are greater than the minimum limit of 0.70, so the questionnaire instrument is declared reliable. This means that this research instrument is consistent and reliable to measure interest and performance factors in the context of micro mobility and first-last mile (FLM) travel. These results strengthen the validity of the previous instrument, so the questionnaire used is worthy of being used as a basis for further analysis.

Importance-Performance Analysis

The analysis process was carried out by comparing the average score of interest and performance obtained from the results of user surveys and dividing by the number of respondents. Based on Table 8, which shows the average value of each service attribute from the level of importance and performance level, a gap analysis or GAP was also carried out. The analysis was carried out by subtracting the average value of the performance level by the average value of the importance level of each micromobility service attribute. This analysis aims to find out if there is a positive gap or a negative gap. Positive gaps are shown by positive values and negative gaps are shown by negative values. Based on the results of the calculation, the result is obtained in the form of a minus or negative gap in each service attribute where the value of. This shows that the performance level of each service attribute of the micro mobility mode is perceived by users to be lacking.$\bar{Y} > \bar{X}$

Table 3. Calculation of the average value of the level of importance and performance

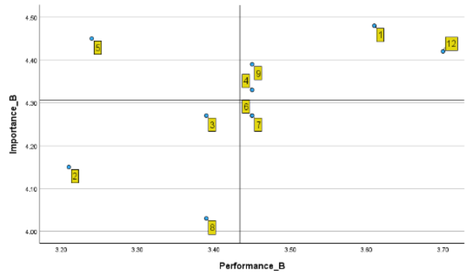
No	Code	Variable	Interests		Performance		GAP
			$\bar{X}$	$\sum x$	$\bar{Y}$	$\sum y$	$\bar{Y} - \bar{x}$
1	P1	Convenience of FLM travel facilities	4,46	950	3,70	789	-0,760
2	P2	Availability of information in FLM travel	4,28	912	3,55	756	-0,730

No	Code	Variable	Interests		Performance		GAP
			$\overline{X}$	$\sum x$	$\overline{Y}$	$\sum y$	$\overline{Y} - \overline{x}$
3	P3	Risk of crime in travel using micromobility	4,38	934	3,62	772	-0,760
4	P4	Safety of FLM travel using micromobility	4,40	938	3,54	755	-0,860
5	P5	The level of ease of access to urban public service facilities with micro mobility	4,39	936	3,68	783	-0,710
6	P6	The level of ease of access to public transportation using micromobility	4,31	918	3,55	757	-0,760
7	P7	The existence of a policy of providing micro mobility facilities	4,36	928	3,67	781	-0,690
8	P8	Availability of pedestrian and bicycle lanes separate from motorized vehicle lanes	4,34	925	3,54	753	-0,800
9	P9	Availability and completeness of supporting facilities (street furniture)	4,44	946	3,48	742	-0,960
10	P10	Availability of crossing facilities	4,40	937	3,67	782	-0,730
11	P11	Availability of parking facilities at transit points	4,25	905	3,53	751	-0,720
12	P12	Cleanliness of micro-mobility paths (pedestrian, bicycle, etc.)	4,38	932	3,71	790	-0,670

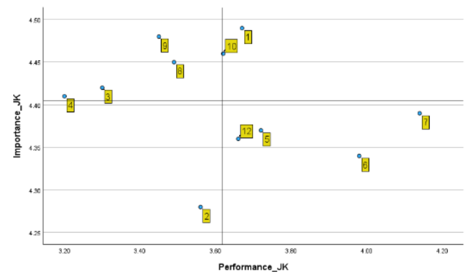
In the next stage, Importance–Performance Analysis is applied separately to each micromobility mode so that the results match the characteristics of the mode. This separation is done because not all service attributes are relevant to all modes. Walking modes, the attributes analyzed include P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, and P12; while the P11 attribute (parking facility) was removed because it was irrelevant to pedestrians. The pedicab mode, the attributes used are P1, P2, P3, P4, P5, P6, P7, and P12, attributes related to protected lanes, special crossing facilities, street furniture, and parking facilities are not used because they are not in accordance with the operational character of pedicabs as a driver-based service.

Bicycle mode, all attributes (P1–P12) are relevant because cyclists need separate lanes, supporting facilities, information, safe crossings, and parking. Likewise, electric scooters, which are also analyzed using all attributes (P1–P12) given that these modes share characteristics with bicycles in terms of infrastructure, safety, and technological support needs. With this more precise classification of attributes, IPA analysis can more accurately describe service improvement priorities in each mode. The visual results of this analysis are applied to the Cartesian diagram in Figure 1.

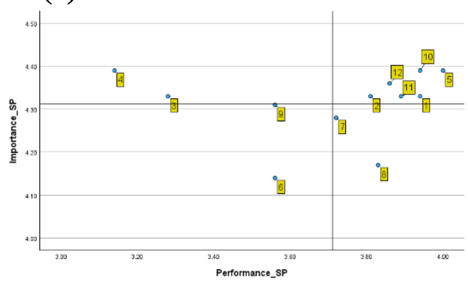
Figure 1. Importance-Performance Matrix Based on Micro Mobility Mode



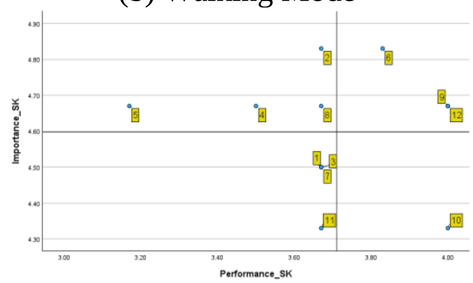
(a) Fashion Vienna



(b) Walking Mode



(c) Bike Fashion



(d) Fashion Scooter

Source: Analysis Results, 2025

Based on the cartesian diagram, it can be known that the assessment of the service attributes of the micro mobility mode as FLM connectivity in the public transportation system in the city of Surakarta can be seen. The results of the analysis of each quadrant are as follows:

a. Quadrant I "Top Priority". This quadrant shows that the level of importance of a service attribute is considered very important but has a low/poor performance value. There are 2 service attributes included in this quadrant, which are as follows:
   1. Motorcycle Mode : Service Attributes 5
   2. Walking Mode : Service attributes 3, 4, 8, and 9
   3. Bicycle Mode : Service attributes 3 and 4
   4. Scooter Mode : Service attributes 2, 4, 5, and 8
b. Quadrant II "Keep". In this quadrant, the level of importance of a service attribute is considered very important and the level of performance that is considered to be very good, so there is a need for efforts to maintain this performance. There are 5 attributes that fall into this quadrant, which are as follows:
   1. Pedicab Mode : Service attributes number 1, 4, 9, & 12
   2. Walking Mode : Service attributes number 1 & 10
   3. Bicycle Mode : Service attributes number 1, 2, 5, 10, 11, & 12
   4. Scooter Mode : Service attributes number 6, 9, 12
c. Quadrant III "Low Priority". This quadrant shows that the level of importance of a service attribute is considered less important and has a low/poor performance value. There are 4 attributes of service included in this quadrant, which are as follows:
   1. Pedicab Mode : Service attributes number 2, 3, and 8
   2. Walking Mode : Service Attribute number 2
   3. Bicycle Mode : Service attributes numbers 6 and 9
   4. Scooter Mode : Service attributes numbers 1, 3, 7, and 11

d. Quadrant IV "Excessive". This quadrant shows that the level of importance of a service attribute is considered insufficient but has a performance value that is considered good so that it is considered excessive. There are 1 service attributes included in this quadrant, which are as follows:
   1. Pedicab Mode : Service attributes number 6 and 7
   2. Walking Mode : Service attributes number 1 and 10
   3. Bicycle modes : Service attributes number 7 and 8
   4. Scooter Mode : Service attribute number 10

The large gap between importance and performance shows that Surakarta has an FLM infrastructure that is not consistent or has not met user comfort and security standards. Users prioritize security, safety, protection, and accessibility aspects rather than the physical availability of the path.

CONCLUSION

Based on the results and discussion, it can be concluded that the majority of micro-mobility users are within the productive age group, have high daily mobility, and own private vehicles; therefore, the quality of first–last mile (FLM) access becomes a key determinant in their decision to use public transportation. Micro-mobility is most frequently utilized for short-distance trips such as walking and cycling, with travel motivations dominated by work-related and recreational activities. FLM travel durations generally fall under 30 minutes, and the associated costs are relatively low, making fast, affordable, and easily accessible modes the primary choices for users.

The importance–performance assessment shows that all service attributes are considered important, yet their performance remains at a ‘fairly good’ level, leading to negative gaps indicating that the services have not fully met user expectations. Improvement priorities differ across modes; however, safety, security, protected lanes, accessibility to public service nodes, and supporting facilities consistently emerge as essential needs across all micro-mobility options. Overall, the quality of micro-mobility services in Surakarta is functional but not yet optimal, indicating that improvements to basic infrastructure and user protection should be prioritized to strengthen FLM integration within the urban public transportation system.

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