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ENHANCING WALKABILITY IN JAKARTA'S TRANSIT ORIENTED DEVELOPMENT (TOD): A PATHWAY TO OPTIMIZING FIRST- AND LAST- MILE MOBILITY

MENINGKATKAN *WALKABILITY* DI TRANSIT ORIENTED DEVELOPMENT (TOD) JAKARTA: LANGKAH MENUJU OPTIMALISASI MOBILITAS *FIRST- AND LAST-MILE*

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ABSTRACT
For Jakarta's sustainable mobility transition, TOD (Transit-Oriented Development) success depends on seamless First-and-Last-Mile (FLM) connectivity. Specifically, high-quality walkability is essential to connect transit hubs to destinations and drive public transport adoption. This study investigates pedestrian behavior and infrastructure within Jakarta, Indonesia's Dukuh Atas TOD area, employing a quantitative descriptive approach. Data was collected through a survey of 400 respondents using accidental random sampling, observational studies, and the Pedestrian Environment Quality Index (PEQI). Analysis of commuter travel patterns reveals a predominance of work-related trips, reflecting its central business district function and high public transport usage. Health emerged as the dominant motivation for walking, outweighing cost factors, thereby underscoring the role of FLM connectivity in active commuting. Assessment of FLM connectivity highlights the importance of integrated transport solutions. Walkability near transit hubs is generally positive but require improvements in specific areas. Positive perceptions of pedestrian infrastructure—such as sidewalks, lighting, and vegetation—indicate opportunities for enhancement. These findings position Dukuh Atas as a model for effective TOD planning, highlighting the potential for infrastructure upgrades to promote walking and public transport use, contributing to more pedestrian-friendly and sustainable urban development.
Keywords: *Built Environment Attributes, First- and Last-Mile (FLM), Transit Oriented Development (TOD), Walkability*

ABSTRAK
Dalam transisi mobilitas berkelanjutan Jakarta, keberhasilan Transit-Oriented Development (TOD) bergantung pada konektivitas First-and-Last-Mile (FLM) yang terintegrasi. Secara khusus, kualitas walkability yang tinggi sangat esensial untuk menghubungkan simpul transit dengan tujuan akhir serta mendorong adopsi transportasi publik. Penelitian ini menginvestigasi perilaku pejalan kaki dan infrastruktur di area TOD Dukuh Atas, Jakarta, Indonesia, dengan menggunakan pendekatan deskriptif kuantitatif. Data dikumpulkan melalui survei terhadap 400 responden dengan metode accidental random sampling, studi observasi, serta penerapan Pedestrian Environment Quality Index (PEQI). Analisis pola perjalanan menunjukkan dominasi perjalanan kerja yang mencerminkan fungsi kawasan sebagai pusat bisnis serta tingginya penggunaan transportasi publik. Temuan menyoroti kesehatan sebagai motivasi utama berjalan kaki, melampaui faktor biaya, yang menekankan peran FLM dalam mendukung mobilitas aktif. Evaluasi FLM menekankan pentingnya integrasi transportasi, dengan tingkat walkability yang umumnya positif meski memerlukan perbaikan spesifik. Persepsi positif terhadap infrastruktur pejalan kaki—seperti trotoar, pencahayaan, dan vegetasi—mengindikasikan adanya peluang untuk peningkatan kualitas lingkungan jalan kaki. Temuan ini menempatkan Dukuh Atas sebagai model perencanaan TOD yang efektif, serta menyoroti potensi peningkatan infrastruktur dalam mendorong aktivitas berjalan kaki dan penggunaan transportasi publik, yang pada akhirnya berkontribusi terhadap pengembangan kota yang lebih ramah pejalan kaki dan berkelanjutan.
Kata Kunci: *Atribut Lingkungan Binaan, First- and Last-Mile, Kawasan Berorientasi Transit (KBT), Walkability*

1. INTRODUCTION

As one of East Asia's most densely populated metropolitan regions (World Bank, 2015), Greater Jakarta (comprising Jakarta, Bogor, Depok, Tangerang, and Bekasi) faces significant urban development challenges. Between 2000 and 2010, the region experienced a 3.2% annual population growth, coupled with a notable shift of residents from Jakarta's core to suburban areas, indicating significant suburbanization. This shift reflects rapid urbanization and marks a broader spatial change, exemplifying suburbanization along development corridors, which are often termed suburban sprawl (Goldblum & Wong, 2000). Between 2000 and 2010, Greater Jakarta experienced an annual population growth rate of 3.2% (Badan Pusat Statistik, 2010; Pratama et al., 2022). This urban sprawl exacerbates critical issues such as increased energy consumption, air pollution, greenhouse gas emissions, and traffic congestion, while also escalating infrastructure costs (Lamour et al., 2019; Litman et al., 2015; Rode et al., 2017). Mitigating these adverse effects necessitates the implementation of sustainable transport infrastructure (Pratama et al., 2022).

The transportation sector, particularly in developing countries, is a major contributor to carbon emissions and air pollution, underscoring the urgent need for sustainable solutions (Ahmed & Monem, 2020). Rapid urbanization has intensified the demand for efficient and high-quality transportation services, often leading to a growing reliance on private vehicles (Sperling & Salon, 2002). Jakarta exemplifies this trend, with over 12 million registered private vehicles in 2024 (Badan Pusat Statistik Provinsi DKI Jakarta, 2025). Social factors such as prestige and status, as well as individual pride in car ownership, further hinder the shift towards public transportation and other sustainable alternatives (Belgiawan et al., 2016; Kharizsa et al., 2015).

The First- and Last-Mile (FLM) concept in transportation refers to providing connectivity from the starting point to mass transit stations (first mile) and from those stations to the destination (last mile) (Raghunathan et al., 2018). This often involves walking, which can consume a significant portion of travel time and may be perceived as burdensome by commuters (Ha et al., 2023), only 1.4% of Jabodetabek commuters walk or cycle (Badan Pusat Statistik, 2024). While the built environment influences FLM behavior (Mo et al., 2018), travel behavior and sociocultural factors may exert greater effects (Hasibuan & Mulyani, 2022).

Encouraging public transportation use is a complex issue, shaped by various factors including user experience, comfort, safety, cleanliness, frequency, reliability, and speed of the system (Carreira et al., 2014; Cheng & Chen, 2015; Ha et al., 2020; Mouwen, 2015). Safety and transfer experiences significantly impact user satisfaction and loyalty (Park et al., 2021). Commuter characteristics, such as gender and income, affect mode choice. For example, Bastarianto et al. (2019) found that female commuters in Bekasi prefer public transportation, while high-income individuals are more likely to use cars, and low-income individuals tend to use motorcycles. Additionally, travel time and cost are deterrents to choosing public transportation.

To mitigate the effects of urban sprawl, integrating mass transportation with land use policies via TOD is essential (Rode et al., 2017). TOD aims to align urban development with mass transit infrastructure, reducing reliance on cars (Kamruzzaman et al., 2015; Lamour et al., 2019). These policies promote pedestrian-friendly environments, emphasizing walkability, which includes pedestrian comfort, safety, and amenities (Mateo-Babiano, 2016). Dukuh Atas TOD in Jakarta, the city's first and most integrated TOD, serves five public transport modes and is a key urban activity hub access (MRT Jakarta, 2021). Implementing TOD in Jakarta is seen as an effective strategy for addressing land use, transportation, and environmental challenges, thereby enhancing urban sustainability (Hasibuan et al., 2014; Taki et al., 2017).

Despite the recognized importance of walkability, research evaluating the built environment and its relationship to pedestrian comfort, safety, and security remains limited (Fonseca et al., 2022). While established studies have demonstrated the significant role of built environment accessibility in shaping mobility choices (Saghapour et al., 2019), much of this evidence is derived from Global North contexts. This creates a critical gap when applied to developing regions, where sustainable transport frameworks must account for distinct rapid urbanization challenges and informal transport dynamics (Pojani & Stead, 2015).

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In the specific context of Jakarta, Napitupulu & Rudiarto (2025) recently evaluated the physical walkability index of Dukuh Atas TOD, providing essential baseline data on infrastructure performance. This aligns with findings from the nearby Sudirman-Thamrin corridor, where improvements increased the walkability index by 38.98% and user satisfaction to 82%–94% (Mulyadi et al., 2022). However, these studies do not analyze how physical attributes influence First-Last Mile (FLM) mode choices. This study addresses this critical gap by integrating a detailed walkability assessment with FLM dynamics within the Dukuh Atas TOD, linking physical attributes directly to behavioral shifts.

This research therefore aims to: (1) identify and analyze the physical built environment attributes influencing walkability in the Dukuh Atas TOD area; (2) examine the relationship between walkability and the choice of walking as an FLM mode; and (3) provide evidence-based recommendations for urban planners and policymakers to enhance walkability and support TOD implementation in Jakarta and other developing cities.

2. DATA AND METHODS

2.1. Area of study

This study was conducted in the Dukuh Atas TOD area in Jakarta, Indonesia. This area was selected due to its strategic importance as Jakarta's first integrated TOD, serving five major mass transit modes: Jakarta MRT, TransJakarta BRT, Railink airport train, Commuter Line, and LRT. The study area encompassed a 350–700 meter radius from the nearest transit stations, representing a typical walkability catchment area within a TOD (see Figure 1 for a map of the study area.). Dukuh Atas's integration of residential, commercial, and business functions, coupled with its high public transport accessibility, makes it an ideal environment for analyzing pedestrian behavior and urban movement patterns.

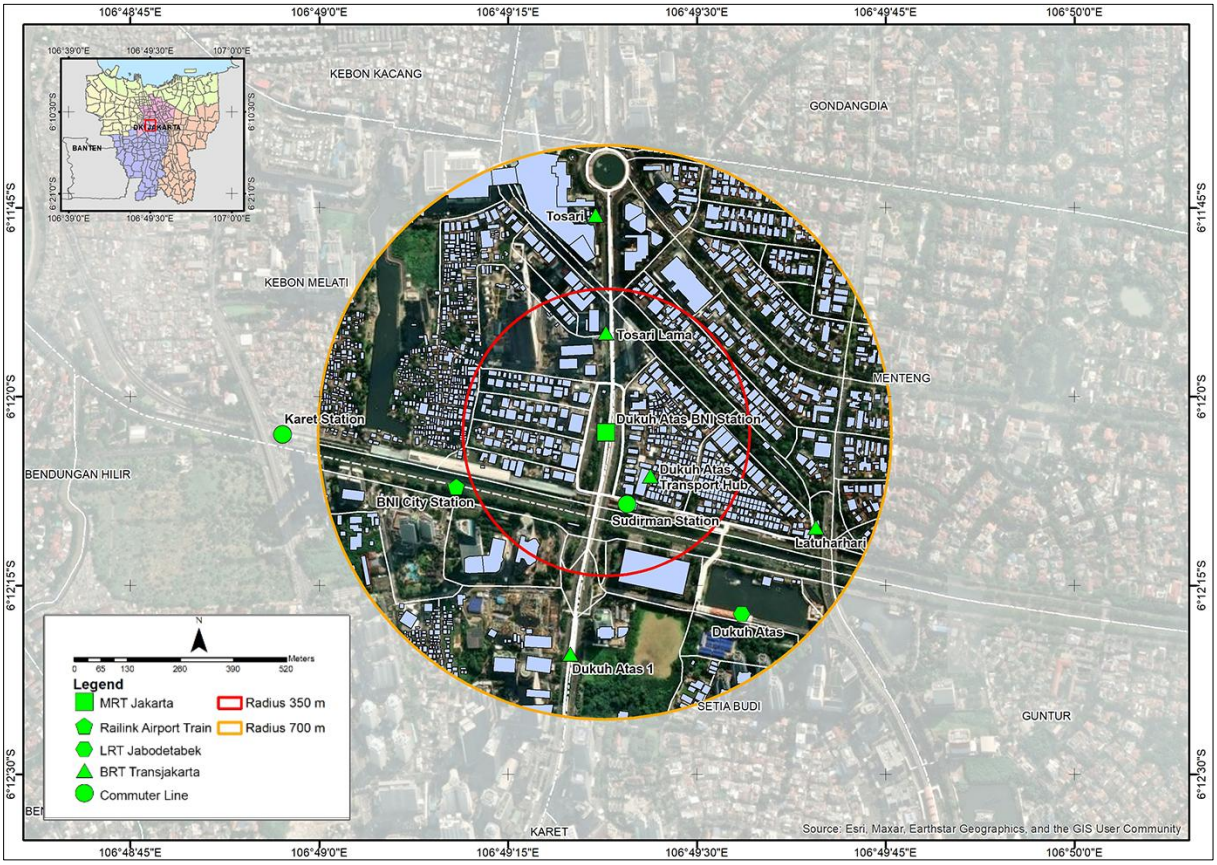
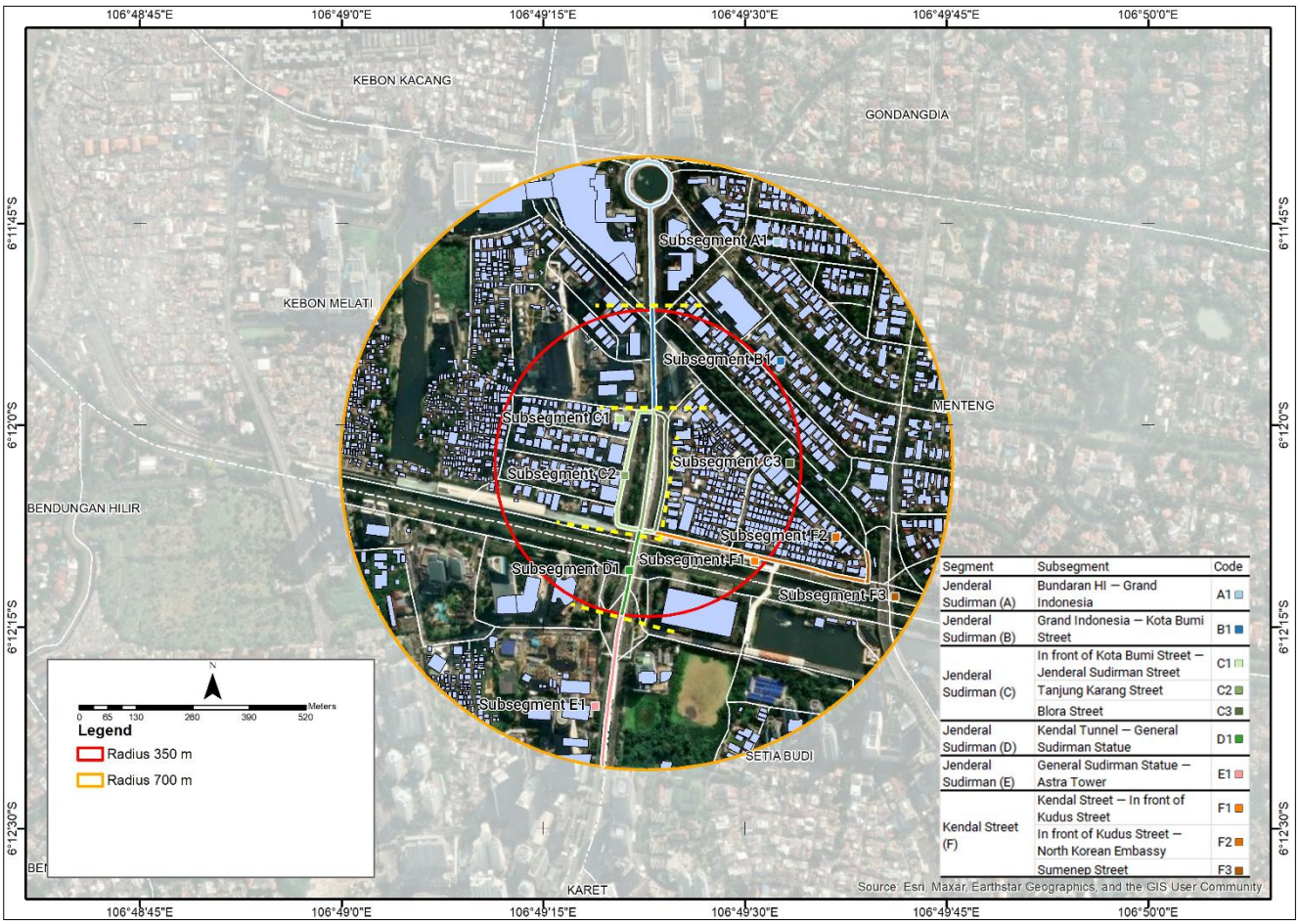


Figure 1. Study Area Map

Previous studies indicate that the area is predominantly used by commuters for work-related travel (52%), followed by other activities such as recreation (12%) and education (10%) (Rakhmatulloh & Dewi, 2020). The demographic profile of the area, as reported by Chotib et al. (2019), indicates that most residents are employees (60%), followed by entrepreneurs (21.3%), and a combination of homemakers and students (14.6%). More detailed occupational distribution includes 39.3% homemakers and students, 32% employees, and 12.7% entrepreneurs. This demographic and functional context significantly influences pedestrian travel patterns and transportation choices within the TOD.

2.2. Population and sampling technique

The study population comprises two groups: (1) pedestrian pathways and (2) mass transit users in the Dukuh Atas area. The pedestrian pathways were selected based on their function as connectors between mass transit stations or stops and their high levels of pedestrian traffic. The second group consists of mass transit users in the study area who also utilize these pedestrian pathways as part of their daily travel activities. Pedestrian pathways directly categorized across ten street subsegments, each 350 meters long, as presented in Figure 2, which provides a mapped delineation of street subsegments. Mass transit user respondents were selected using accidental random sampling, with inclusion criteria of (a) transit users in the area, (b) recorded activity, gender, and age, and (c) willingness to participate.



Segment	Subsegment	Code
Jenderal Sudirman (A)	Bundaran HI – Grand Indonesia	A1
Jenderal Sudirman (B)	Grand Indonesia – Kota Bumi Street	B1
Jenderal Sudirman (C)	In front of Kota Bumi Street – Jenderal Sudirman Street	C1
	Tanjung Karang Street	C2
	Blora Street	C3
Jenderal Sudirman (D)	Kendal Tunnel – General Sudirman Statue	D1
Jenderal Sudirman (E)	General Sudirman Statue – Astra Tower	E1
Kendal Street (F)	Kendal Street – In front of Kudus Street	F1
	In front of Kudus Street – North Korean Embassy	F2
	Sumenep Street	F3

Figure 2. Pedestrian Pathways Segmentation

Data was collected through questionnaires administered to 400 respondents using transit around the Dukuh Atas TOD area. The questionnaire included questions about age, gender, activities undertaken, economic status, and preferences regarding pedestrian paths. Respondents' preferences about pedestrian paths were assessed based on their first- and last-mile experiences, including start and end points of their journeys to identify the routes taken. Data collection was conducted from February to March 2024 using a mixed-mode approach. Approximately 20% of the data was gathered through face-to-face interviews, while the remaining 80% was collected via a web-based survey platform. To ensure the sample represented peak mass transit usage, the survey distribution took place on weekdays (Monday–Friday) during three specific high-traffic sessions: morning (07:00–09:00), afternoon (16:00–18:00), and evening (19:00–21:00). Pedestrian perceptions were quantified using a 5-point Likert scale (1 = Very Poor to 5 = Excellent) embedded in the questionnaire. This section specifically evaluated respondents' views on the comfort and safety of the routes taken.

2.3. Walkability measurement method

The growing focus on sustainable urban development underscores the significance of pedestrian-friendly environments in cities globally. The Pedestrian Environment Quality Index (PEQI) serves as an essential tool for assessing the quality of urban pedestrian environments. Developed by the San Francisco Department of Public Health in 2008, it evaluates the safety and quality of pedestrian environments (Batteate, 2013).

In this research, the PEQI methodology is applied to analyze walkability within TOD areas. To gather the necessary data for the analysis, a systematic field audit was conducted via direct observation. Surveyors physically walked along each street segment and intersection within the defined study area to assess the existing pedestrian infrastructure. During the survey, physical attributes—such as sidewalk width, surface quality, presence of obstructions, and crossing facilities—were measured and recorded using a standardized checklist based on the adapted PEQI indicators (Table 1). Quantitative measurements, such as path width, were taken using measuring tapes, while qualitative aspects were documented through photographic evidence to validate the scoring process. This field assessment was conducted concurrently with the pedestrian perception survey to ensure that the recorded physical conditions corresponded with the respondents' experiences. Following data collection, the data was processed to calculate the PEQI score for each street segment using the predefined formula.

The formula used for this calculation considers various environmental aspects that can affect pedestrian safety and comfort. These categories delineate the suitability of the walking conditions, ranging from unsuitable for walking (0-20) to ideal (81-100). The intermediate levels are categorized as poor (21-40), basic (41-60), and reasonable (61-80). The formula is as follows:

$$PEQI\ score = (unadjusted\ score - minimum\ score)\ \times (\frac{100}{max\ score - min\ score})$$

In this equation, where the unadjusted score is the sum of indicator scores for each segment, the minimum and maximum scores define the possible scoring range, and the result is scaled to 0–100 for standardized comparison. In this study, the PEQI indicators as shown in Table 1, were adapted to better reflect local conditions in the Dukuh Atas TOD area, while maintaining the core structure of the original index (Batteate, 2013).

Table 1. PEQI Indicators Used in this Study

Category	Element
Traffic	1. Number of lanes 2. Two-way traffic 3. Vehicle speed limit
Sidewalk	1. Sidewalk width 2. Sidewalk surface condition 3. Major sidewalk obstructions 4. Presence of curbs 5. Driveway cuts 6. Trees 7. Plants/gardens 8. Public seating 9. Public trash bins 10. Presence of buffers
Safety and Aesthetics	1. Illegal graffiti 2. Litter 3. Pedestrian street lighting
Perception of Walkability	1. Visual appeal 2. Sense of safety 3. Odor 4. Noise 5. Overall walkability

Source: Modified from Batteate (2013)

3. RESULT AND DISCUSSION

3.1. Commuter behaviors

Understanding urban mobility patterns and commuter behavior is crucial for developing effective and sustainable urban planning strategies. Our analysis of transportation modes and destinations in the Dukuh Atas TOD, summarized in Table 2, reveals significant insights into commuter choices in 2024.

Table 2. Modes of Transportation Used by Commuters and Their Destinations

Transportation Mode	Destination								Total	%
	Recreation		Office		Transit-related		Other			
	Person	%	Person	%	Person	%	Person	%		
Other than walking	22	5,50	102	25,5	85	21,25	42	10,5	251	62,75
Walking										
< 500 m	10	2,50	52	13	36	9	7	1,75	105	26,25
500 - 1.000 m	1	0,25	18	4,50	13	3,25	1	0,25	33	8,25
1.001 - 2.000 m	0	0	2	0,50	3	0,75	0	0	5	1,25
> 2.000 m	0	0	0	0	6	1,5	0	0	6	1,5
Total									400	100

As shown in Table 2, mechanized transportation accounts for the majority of trips (62.75%), highlighting a continued reliance on non-walking modes within this TOD area. A significant portion (25.5%) of these mechanized trips are to offices, suggesting that workplaces are often located beyond comfortable walking distances, thus necessitating efficient public transport connectivity.

Conversely, walking constitutes 37.25% of all trips, with the vast majority (26.25%) being for distances under 500 meters. This strongly emphasizes the critical role of accessible and high-quality pedestrian infrastructure for short-distance travel. The sharp decline in walking for distances over 500 meters, suggests

a significant drop-off in pedestrian appeal or feasibility beyond this range. This pattern indicates a need for urban planning strategies that extend pedestrian-friendly zones and enhance connectivity for longer walking trips, as improved walkability around workplaces can significantly increase commute walking rates (Osmënaj et al., 2024).

Transportation needs vary by destination. Trips to offices and transit-related collectively dominate both mechanized and walking modes, underscoring the demand for integrated transport solutions focused on daily commuting. In contrast, recreational activities show lower utilization of both walking and mechanized transport, potentially indicating a localized or infrequent nature of such activities within the study area.

Table 3. Walking Behaviour in the Dukuh Atas in 2024: Motivation and Cost

Monthly Transportation Cost	Motivation										Total	%
	Cost		Proximity		Health		Accesibility		Not define			
	Person	%	Person	%	Person	%	Person	%	Person	%		
Rp250.000 - Rp500.000	19	12,75	17	11,41	58	38,93	11	7,38	1	0,67	106	71,14
Rp500.001 - Rp750.000	14	9,4	5	3,36	14	9,4	1	0,67	1	0,67	35	23,49
> Rp750.001	1	0,67	0	0	7	4,7	0	0	0	0	8	5,37
Total											149	100

Table 3 further explores walking behavior by examining the relationship between monthly transportation costs and primary motivations for walking. Health emerges as the primary motivation for walking, accounting for 38.93% of respondents who spend between Rp250,000 and Rp500,000 on transportation, indicating a conscious choice for well-being. This finding is critical as it validates the concept of "active commuting," where the FLM trip serves as a key mechanism for meeting daily physical activity recommendations (Lachapelle et al., 2011). It suggests that the pedestrian infrastructure at Dukuh Atas successfully shifts user perception of walking from a utilitarian necessity to a value-added health benefit, aligning with global evidence that integrated planning can effectively reduce sedentary behavior (Giles-Corti et al., 2016).

Proximity also plays a significant role (11.41%), reinforcing the demand for mixed-use developments that reduce travel distances. While health remains a strong motivator even for those with higher transportation costs (e.g., 4.7% for > Rp750,001), cost considerations also influence a notable portion of walkers (12.75% in the mid-range), indicating the economic benefits of walking.

While mechanized transport dominates overall trips in Dukuh Atas, the significant proportion of walking trips, especially for short distances, emphasizes the critical need for robust pedestrian infrastructure. Enhancing walkability, expanding pedestrian-friendly zones, and improving connectivity are essential to encourage longer walking distances and foster sustainable urban mobility (Movahed & Habibian, 2024; Wali et al., 2024; Yang et al., 2022). This integration of physical activity facilities and green spaces within workplaces can further promote healthier commuting cultures (Yang et al., 2022).

3.2. First- and last-mile

Figure 3 illustrates the origin-destination patterns and associated transportation modes within the Dukuh Atas TOD, providing crucial insights into first- and last-mile (FLM) connectivity. Sudirman KRL Station emerges as the dominant starting point, accounting for 151 recorded trips. This highlights its pivotal role as a primary gateway for commuters accessing central Jakarta via rapid urban transit. Similarly, the Dukuh Atas MRT Station (Gate A) is increasingly popular, with 69 uses, reflecting the MRT's growing appeal as a swift alternative to road congestion. Collectively, Transjakarta bus stops (Dukuh Atas, Tosari, Latuharhari) report 158 uses, underscoring the network's significant role in providing affordable and reliable commuter options. The notable usage of the Sudirman KRL Station drop-off point by 20 individuals further emphasizes the integration and reliance on app-based transport services for flexible FLM solutions.

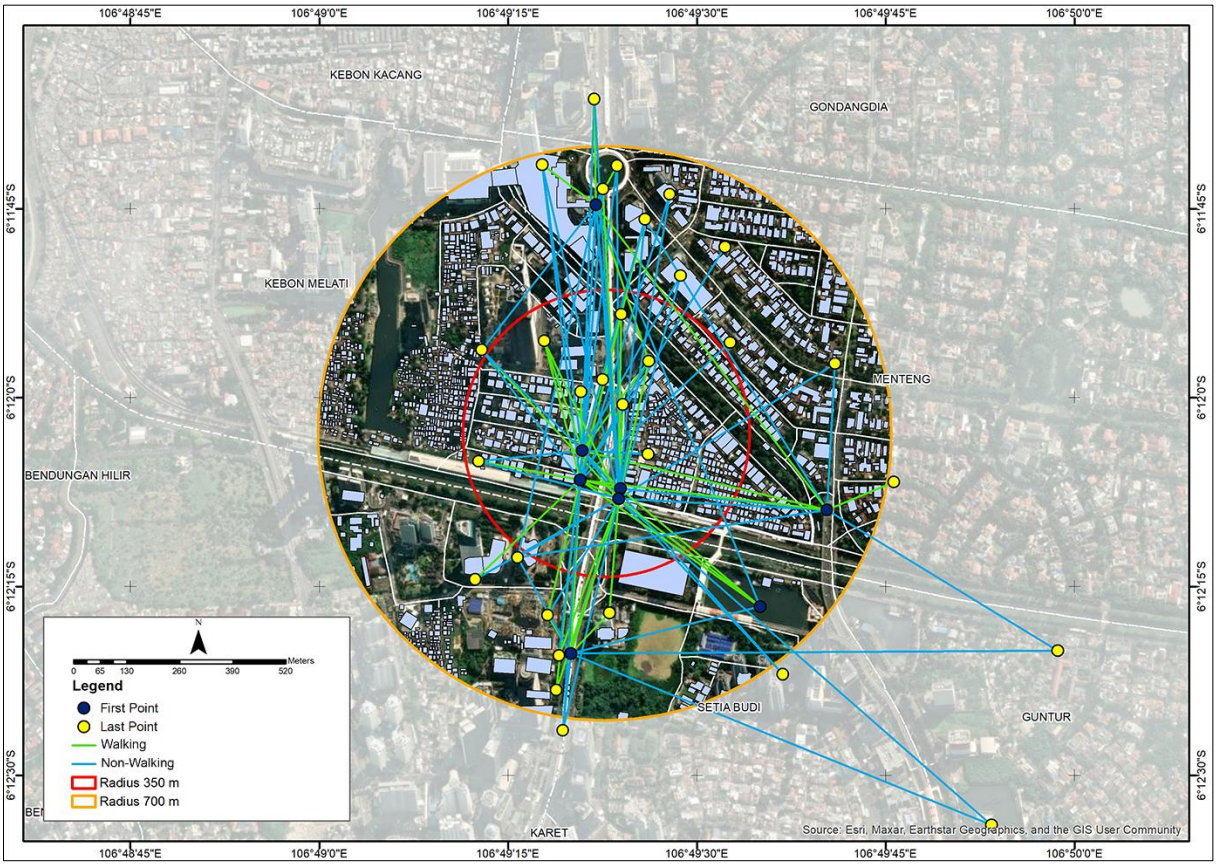


Figure 3. Origin-Destination Map Commuter in Dukuh Atas with Their Transportation Mode

Regarding endpoints, Thamrin Nine Tower (37 uses) and Grand Indonesia Shopping Mall (32 uses) are frequent destinations, underscoring their function as key business and retail hubs driving economic activity in Dukuh Atas. Transjakarta stops like Latuharhari, Bundaran HI, and Dukuh Atas collectively account for approximately 60 endpoint uses, reinforcing the network's effectiveness in dispersing commuters across Jakarta. The substantial 58 endpoints at Sudirman KRL Station illustrate a common round-trip commuting pattern, especially for residents outside the city center. Other commercial buildings and hotels, while showing lower frequencies, confirm the area's diverse professional and tourist activities.

The findings confirm Dukuh Atas TOD's function as a pivotal transportation integration center, with the Sudirman KRL Station being the most utilized hub. The prominence of commercial and office destinations highlights the critical need for continued investment in infrastructure and transport services that effectively support these dynamic FLM demands. This analysis suggests that while major transit hubs are well-connected, further improvements in seamless transitions between modes and enhanced pedestrian pathways could significantly optimize the FLM experience, reducing reliance on informal or private last-mile solutions.

3.3. Walkability conditions

This study systematically investigated the physical walking conditions across ten strategically selected segments within the Dukuh Atas TOD, each measuring 350 meters and representing primary pedestrian routes leading to mass transit stops. Figure 4 illustrates the PEQI scores for these segments.

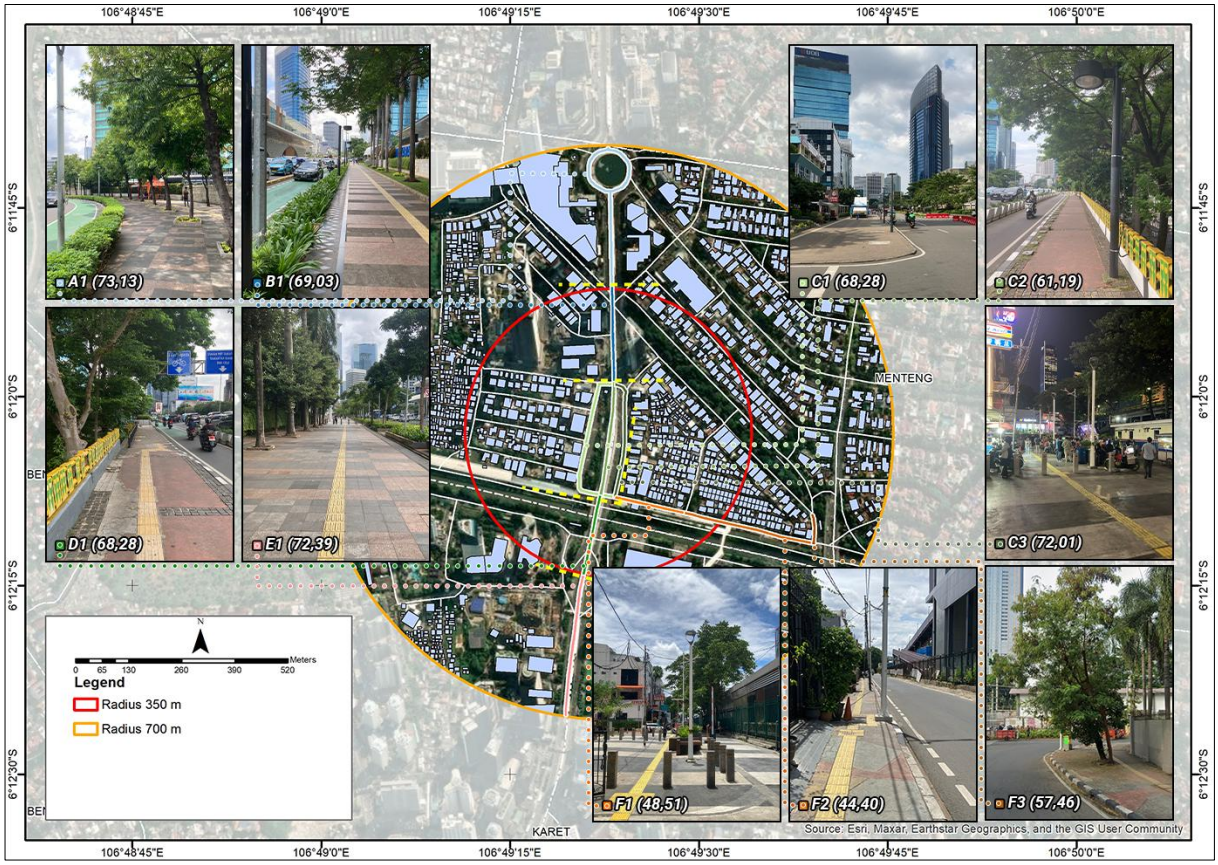


Figure 4. PEQI Score Map in Dukuh Atas Area

Segment A1 extends from Bundaran HI to Grand Indonesia Shopping Mall, serving as a pivotal commercial hub due to its proximity to luxury hotels and major retail centers, thus facilitating significant pedestrian traffic. Adjacent to this, Segment B1 continues from Grand Indonesia Shopping Mall to Kota Bumi Street, transitioning the landscape from high-end retail to more localized commercial zones.

Further along, Segment C1 stretches from the front of Kota Bumi Street to Jenderal Sudirman Street, augmented by subsegments C2 and C3, which include Tanjung Karang Street and Blora Street. These roads are essential for enhancing access to residential and smaller business areas, supporting a diverse urban fabric. Meanwhile, Segment D1, spanning from Kendal Tunnel to Jenderal Sudirman Statue.

The extension of Jenderal Sudirman into Segment E1, from Jenderal Sudirman Statue to Astra Tower, delineates the boundary of the central business district. This segment is characterized by high-rise corporate offices that facilitate professional commuting and economic activities, marking it as a vital area for the business community. Complementing these segments, Kendal Street, divided into F1, F2, and F3, serves as a crucial connector. Segment F1 supports local traffic from Kendal Street to the front of Kudus Street, while F2 extends to the North Korean Embassy. Segment F3 along Jalan Sumenep further enhances neighborhood access.

Segment A1, encompassing the area from Bundaran HI to the Tosari Lama Bus Stop, achieves a PEQI score of 73.13, reflecting a highly favorable pedestrian environment. The sidewalks are notably wide, reaching up to 9 meters, and are free from obstructions, ensuring comfort in various weather conditions. Safety is further enhanced by the presence of curbs and buffers between the sidewalk and the roadway. Public amenities, including seating and trash bins, are readily available, contributing to the overall pedestrian experience. While the area benefits from adequate lighting and cleanliness, the vegetation, primarily trees, could be improved to provide better shading.

Segment B1, extending from the Tosari Lama Bus Stop to Kota Bumi Street, scores 69.03 on the PEQI. It features sidewalks that are 3.6 meters wide and free of physical barriers, though the absence of public amenities such as seating and trash bins could detract from pedestrian comfort. The segment is well-lit and clean, which enhances safety, although noise levels remain a concern. Despite these issues, pedestrian comfort is generally good, but there is room for improvement in terms of public amenities.

Segment C consists of three subsegments: Tanjung Karang Street (C1), Kota Bumi Street to Jenderal Sudirman Street (C2), and Street Blora (C3). Subsegment C1 scores 68.28, indicating good sidewalk conditions, although construction obstructions are present. While street lighting is adequate, noise and buffer issues persist. Subsegment C2 scores 61.19, characterized by narrower sidewalks of about 1.5 meters, which are well-maintained and free of obstructions. Vegetation and buffers enhance safety, yet public amenities are lacking. Subsegment C3 scores 72.01, offering wide, well-maintained sidewalks and adequate amenities. Although noise remains a challenge, the overall pedestrian experience in C3 is positive.

Segment D1, covering the area from Kendal Tunnel to the Jenderal Sudirman Statue, scores 68.28 on the PEQI. The sidewalks are sufficiently wide and clear of significant obstructions, complemented by adequate vegetation and street lighting. The segment is well-maintained in terms of cleanliness, but traffic noise is a notable concern. Enhancements in noise control and the addition of public amenities could further improve the pedestrian environment.

Segment E1, stretching from the Jenderal Sudirman Statue to Astra Tower, scores 72.39, reflecting a pedestrian-friendly environment. The sidewalks are adequately wide, smooth, and free of obstructions, with ample vegetation that creates a cooler and more comfortable atmosphere. Public amenities such as seating and trash bins are adequately provided, and the area is well-lit and clean. However, traffic noise remains a challenge, though the overall perception of walkability and safety is high.

Segment F includes Kendal Street to Kudus Street (F1), Kudus Street to the North Korean Embassy (F2), and Sumenep Street (F3). Subsegment F1 scores 48.51, indicating several challenges, including narrow, poorly maintained sidewalks with numerous obstructions. Vegetation is minimal, and cleanliness is compromised by illegal graffiti. Subsegment F2 scores 44.40, facing similar issues with narrow sidewalks and obstructions, such as streetlight poles, limited lighting, and poor aesthetic and safety conditions. Subsegment F3 scores 57.46, offering slightly better sidewalk conditions and fewer obstructions. While the lighting is adequate, noise and the lack of amenities remain issues.

The assessment of pedestrian environments across the ten segments reveals a diverse range of conditions and challenges. While some areas, such as Segments A1 and E1, exhibit high scores on the PEQI due to well-maintained sidewalks and ample amenities, others, particularly in Segment F, highlight significant room for improvement. Common issues include noise pollution, insufficient public amenities, and narrow sidewalks, which detract from the overall pedestrian experience.

3.4. Attribute perceptions

This analysis evaluates perceptions of pedestrian infrastructure in Dukuh Atas, focusing on sidewalk quality, street lighting, and vegetation. These elements are crucial components of the built environment, which significantly motivate walking and physical activity (Liao et al., 2020). By analyzing respondent feedback, the study identifies strengths and areas for improvement, offering insights into how these attributes affect pedestrian comfort and safety.

3.4.1. Sidewalk attribute perceptions

The analysis of sidewalk attribute perceptions in the Dukuh Atas area, as depicted in Figure 5, underscores the importance of well-designed and maintained pedestrian infrastructure in enhancing user experience. The data shows a favorable perception, with numerous routes rated as "very comfortable" or "comfortable." This positive feedback is particularly notable around major transit hubs such as the Sudirman Commuter Line Station and MRT Dukuh Atas, which likely benefit from targeted urban planning aimed at improving pedestrian accessibility and satisfaction. Routes like the one from Sudirman Commuter Line

Station to Thamrin Nine Tower consistently receive high comfort ratings, indicative of pedestrian-friendly features such as broad sidewalks and smooth surfaces that contribute to a superior walking environment.

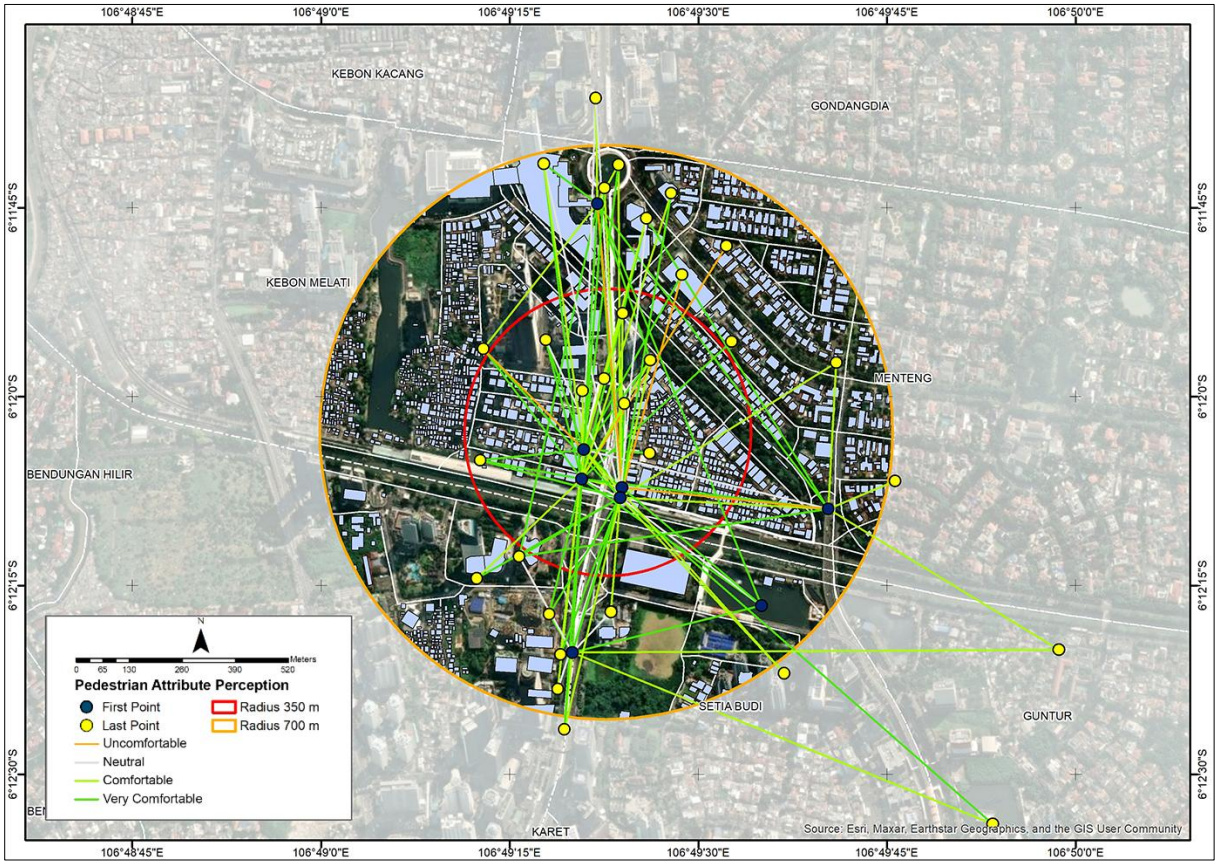


Figure 5. Commuter Perception Map Regarding Pedestrian Attribute

However, the presence of "neutral" and "uncomfortable" ratings on certain routes suggests areas where the infrastructure may fall short of user expectations. For instance, the path from MRT Dukuh Atas Gate B to Bundaran HI. Moreover, the infrequent "uncomfortable" ratings, particularly from the Transjakarta Latuharhari Bus Stop to Thamrin Nine Tower, point to significant deficiencies such as narrow sidewalks, uneven surfaces, or congestion, which deter pedestrian use.

Research supports these findings, demonstrating that wider sidewalks (exceeding 3 meters) improve pedestrian satisfaction and safety perceptions, especially when integrated with green spaces (Park & Kwon, 2023). Conversely, narrower sidewalks can create congestion and insecurity, particularly for vulnerable groups like parents with children (Corazza et al., 2016; Kweon et al., 2021). Poorly maintained pavements further deter pedestrian use and contribute to unsafe walking behaviors. Landscaping elements, such as trees and buffer strips, enhance perceived safety and encourage walking (Kweon et al., 2021; Park & Kwon, 2023). These insights underscore the need for tailored urban planning strategies that address the diverse needs and contexts of urban populations.

3.4.2. Street light attribute perceptions

Regarding street lighting, as illustrated in Figure 6, the respondent perceptions in the Dukuh Atas area highlight the critical role of illumination in ensuring pedestrian comfort and safety. The general positive feedback, with many routes rated as "very comfortable" and "comfortable," suggests that well-lit environments significantly enhance the pedestrian experience by making urban spaces safer and more

inviting. Notably, key routes such as those from Sudirman Commuter Line Station to Thamrin Nine Tower often receive the highest ratings, implying effective street lighting that improves visibility, safety, and the aesthetic appeal of these areas, encouraging pedestrian activity during evening hours.

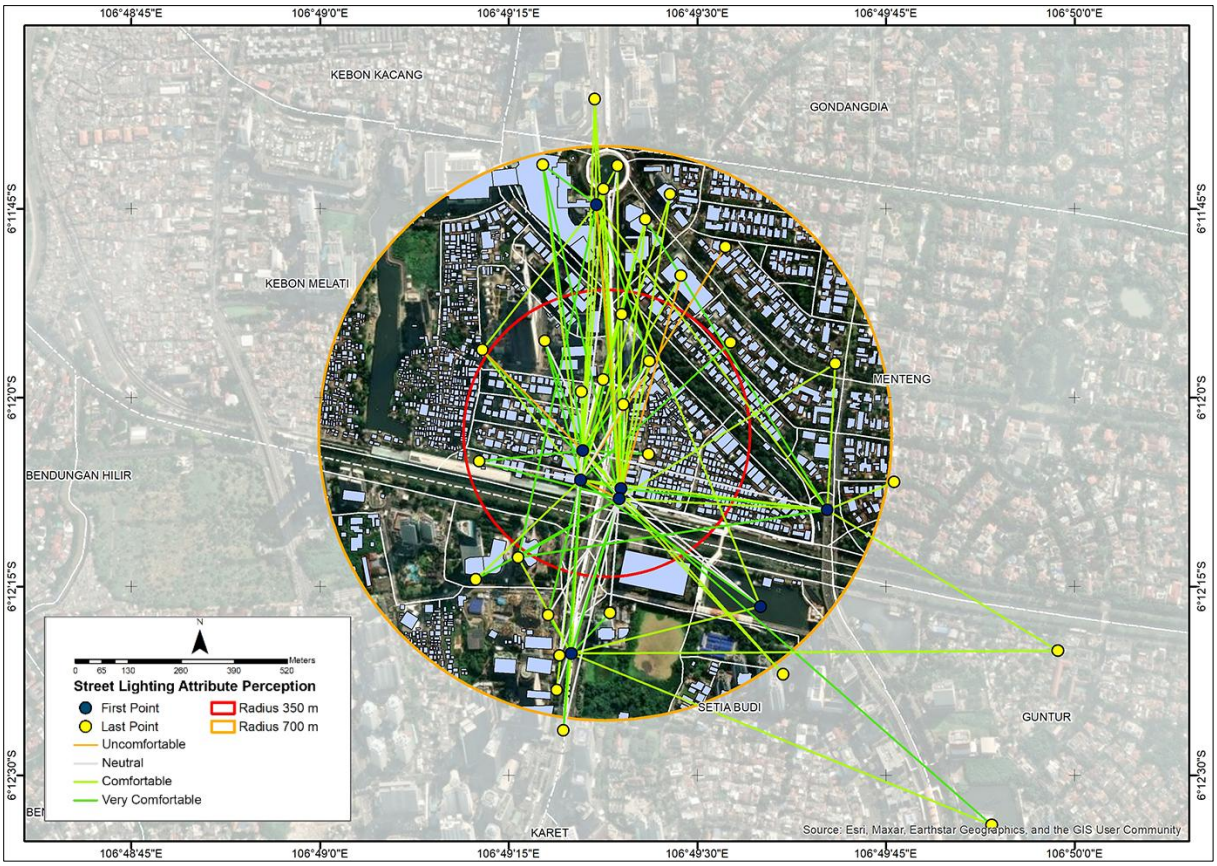


Figure 6. Commuter Perception Map Regarding Street Lighting Attribute

On the other hand, "neutral" and "uncomfortable" ratings on certain routes indicate potential inadequacies in lighting, possibly due to insufficient or poorly maintained fixtures. Areas like the route from MRT Dukuh Atas Gate B to Bundaran HI, which frequently receives neutral feedback, could benefit from energy-efficient lighting solutions that enhance visibility and reduce maintenance costs. Routes receiving "uncomfortable" ratings, such as from Sudirman Commuter Line Station to Grand Indonesia Shopping Mall, highlight critical deficiencies where poor lighting may discourage pedestrian use and compromise safety.

In the context of Jabodetabek, the composition of commuters by gender is 67.3 percent male and 32.7 percent female (Badan Pusat Statistik, 2024). Research conducted by Arshad et al. (2016) in Malaysia show that perceptions of safety differ by gender, highlighting the need to consider gender in pedestrian infrastructure.

Furthermore, good lighting is crucial for preventing accidents and reducing crime risk (Demdoum et al., 2024; Fotios et al., 2015; Walia et al., 2024). Pedestrians feel safer in well-lit areas, especially with a color temperature around 4500 K (Llinares et al., 2020). Optimal lighting conditions not only support pedestrian safety but also contribute to crime prevention efforts. According to the principles of Crime Prevention Through Environmental Design (CPTED), strategic lighting improves visibility and discourages crime (Kim et al., 2024). Thus, gender-sensitive lighting improvements are essential for enhancing pedestrian safety and comfort while supporting crime prevention.

3.4.3. Street vegetation attribute perceptions

Lastly, the perceptions of street vegetation attributes, as shown in Figure 7, emphasize the impact of greenery on pedestrian comfort and urban aesthetics. The map reveals predominantly positive feedback, with many routes rated as "very comfortable" or "comfortable." This suggests that the presence of well-maintained vegetation along these pathways considerably enhances the pedestrian experience, making the urban environment more pleasant and inviting. Routes like those from Sudirman Commuter Line Station to Thamrin Nine Tower, which frequently receive the highest ratings, are likely adorned with well-kept trees and landscaped areas that provide shade and improve air quality.

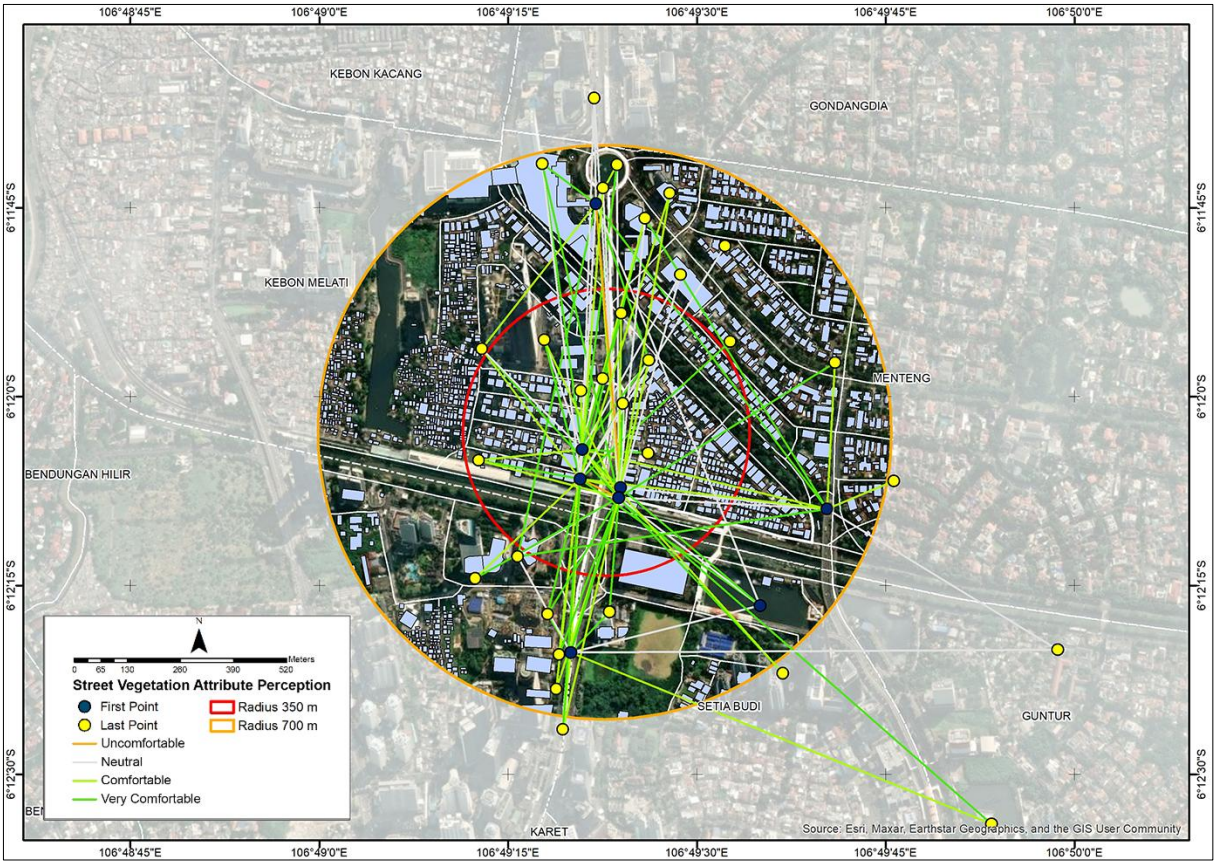


Figure 7. Commuter Passenger Perception Map Regarding Street Vegetation Attribute

Conversely, routes with "neutral" and "uncomfortable" ratings highlight areas lacking sufficient or well-maintained vegetation. For example, the route from MRT Dukuh Atas Gate B to Bundaran HI, often receiving neutral feedback, may benefit from increased landscaping efforts to boost its visual appeal and environmental benefits. Moreover, the less frequent "uncomfortable" ratings, such as those from Sudirman Commuter Line Station to Grand Indonesia Shopping Mall, indicate significant issues like limited shade and unattractive surroundings, which can detract from the pedestrian experience and discourage use.

The importance of vegetation in urban environments extends beyond providing natural shade, it also has a significant impact on the microclimate and air quality. The shading and transpiration processes from trees can reduce surrounding air temperatures by up to 1.3°C in areas with dense canopy coverage (Segura et al., 2022). Furthermore, vegetation plays a role in improving air quality by absorbing pollutant particles (Wang et al., 2024). Effective integration of vegetation in urban planning is crucial for creating a healthier and more comfortable environment for the community.

Continuous investment in pedestrian infrastructure is essential for a vibrant, accessible urban environment. While positive feedback on sidewalk quality, street lighting, and vegetation reflects successful planning, areas with neutral or negative perceptions highlight opportunities for targeted improvements. Addressing these deficiencies can optimize pedestrian pathways, improve quality of life, and encourage walking as a sustainable transportation mode.

4. CONCLUSION

This research has analyzed the Dukuh Atas TOD area with a focus on commuter behaviors, first- and last-mile connectivity, walkability conditions, and perceptions of pedestrian infrastructure attributes. The findings demonstrate that Dukuh Atas functions primarily as a central business district, with work-related travel dominating commuter patterns and a strong reliance on public transportation modes facilitated by the TOD infrastructure. Significantly, the study identifies health as the dominant motivation for walking, surpassing cost-saving considerations. This underscores the potential of FLM connectivity to function as a catalyst for active commuting. To sustain this health-driven behavior, the quality of specific street attributes becomes paramount. While general perceptions of pedestrian infrastructure were positive, prioritizing improvements in thermal comfort (via increased vegetation) and safety (via adequate street lighting and continuous sidewalks) is essential to support walkers' physical well-being. These results provide scientific justification for prioritizing integrated transport planning and pedestrian infrastructure improvements in urban centers. The insights from this research can inform urban planners and policymakers in optimizing TOD areas to support sustainable mobility, encourage public transportation use, and create lively accessible urban environments. Further research may build upon this study by examining other TOD areas or investigating the long-term effects of infrastructure improvements on commuter behavior and the overall quality of urban life.

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