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Article

Suburban transport complexity in Indonesia

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Abstract: This paper delves into the intricate dynamics of suburban transportation transformation within the Jakarta Metropolitan Area, with a specific focus on the evolution of the Commuter Line and Bus Rapid Transit (BRT) systems. Utilizing spatial analysis, qualitative descriptions, and stakeholder insights, the paper unveils self-organizing dynamics. It critically examines the role of transportation infrastructure in shaping the broader landscape of urban development. Unlike a traditional approach, the paper seeks to unravel the self-organization processes embedded in transportation planning, unveiling adaptive strategies crafted to tackle the distinct challenges of suburban transportation. By using autonomy, flexibility, adaptability, and collaboration frameworks, the paper contributes to a nuanced understanding of suburban transportation dynamics, with implications for policymakers, planners, and researchers grappling with similar challenges in diverse metropolitan regions.

Keywords: suburban transportation; transportation transformation; Jakarta metropolitan area; commuter line; bus rapid transit; self-organization

1. Introduction

Indonesian cities are experiencing rapid urbanization and industrialization, leading to complex challenges in urban and suburban development. As the country continues to grow economically, these cities grapple with issues such as traffic congestion, inadequate infrastructure, and environmental degradation. At the heart of these dynamics is Jakarta, the largest city of Indonesia, which serves as a microcosm of these broader trends. Jakarta's significance as one of Indonesia's major industrial hubs has profound implications for its surrounding suburban areas, including Bekasi, Depok, and Tangerang (Rahmawati, 2015). Together, these regions form the Jakarta Metropolitan Area, commonly referred to as Jabodetabek. This metropolitan area epitomizes the complexities of urbanization, industrialization, and transportation that characterize many Indonesian cities (Bappenas, 2011). The transformation of these suburban regions reflects broader national trends, including shifts in land use, population growth, and the increasing demand for efficient transportation systems.

The historical trajectory of Jakarta's urban development offers valuable insights into the interconnectedness between industrial growth, population expansion, and transportation challenges. In the late 1990s, the burgeoning industrial zones in East Jakarta, particularly in areas like Pulogadung, experienced rapid expansion, leading to congestion and traffic jams. This initial wave of industrialization prompted urban sprawl, with industries seeking new locations for expansion, ultimately giving rise to suburban areas like Cikarang and Bekasi (Hudalah et al., 2013). The expansion of industrial activities in Cikarang-Bekasi not only intensified traffic density but also

catalyzed discussions among stakeholders regarding the need for mass transportation systems connecting Jakarta with its surrounding industrial hubs. As Jakarta continues to grapple with transportation-related challenges, including traffic congestion, inadequate infrastructure, and disparities in transportation access, it serves as a microcosm of the broader issues facing Indonesian metropolitan cities.

Transportation plays a pivotal role in shaping the urban landscape of the Jakarta Metropolitan Area, yet it grapples with multifaceted challenges. The suburban areas of the Jakarta Metropolitan Area, including regions like Bekasi, Depok, and Tangerang, face a plethora of transportation-related issues that significantly impact the daily lives of residents (Farda and Lubis, 2018; Rukmana, 2018). Traffic congestion is rampant, exacerbated by inadequate infrastructure and the exponential growth of private vehicle ownership (Farda and Lubis, 2018; Muallimah and Mashpufah, 2022). Commuting within and between suburban areas and the city center is often arduous and time-consuming, leading to reduced productivity and quality of life for residents. Initiatives like the Commuter Line and Bus Rapid Transit (BRT) systems have been implemented to alleviate congestion and improve mobility in the region. However, these efforts have been insufficient to address the magnitude of the transportation challenges faced by suburban residents (Farda and Lubis, 2018; Muallimah and Mashpufah, 2022). The inadequate public transportation network, coupled with limited access to alternative modes of transportation, exacerbates the issue, particularly for those residing in outlying suburban areas. Residents in suburban areas also encounter disparities in transportation access, further hindering their mobility. This lack of equitable access disproportionately affects marginalized communities, including low-income households and those living in informal settlements (Alam, 2019). Furthermore, the transportation challenges exacerbate environmental concerns, such as air pollution and greenhouse gas emissions, contributing to the deterioration of air quality and public health in the region (Andrea, 2015). Addressing these transportation challenges is imperative for sustainable urban development in the Jakarta Metropolitan Area. Effective transportation planning and infrastructure development are essential to alleviate congestion, improve mobility, and enhance the overall quality of life for residents (Baidowi et al., 2020; Khafian, 2014). However, achieving these goals requires comprehensive strategies that take into account the unique needs and dynamics of suburban areas within the metropolitan region.

Initiatives like the Bus Rapid Transit (BRT) system and the Commuter Line play crucial roles in the transportation landscape of the Jakarta Metropolitan Area, aiming to alleviate congestion and improve mobility for residents. The BRT system, introduced in Jakarta in 2004, is a bus-based public transportation system designed to provide efficient, reliable, and affordable transportation services (Rukmana, 2018). It operates on dedicated lanes, allowing buses to bypass traffic congestion and provide faster travel times for passengers. The BRT system in Jakarta comprises several corridors, each serving different parts of the metropolitan area. These corridors connect major residential areas, business districts, and transportation hubs, providing commuters with convenient access to key destinations within the city. For example, the TransJakarta BRT system operates on corridors such as the Blok M-Kota corridor, serving passengers traveling between South Jakarta and Central Jakarta, and the Pulogadung-Harmoni corridor, connecting East Jakarta with Central Jakarta. Similarly,

the Commuter Line, operated by PT Kereta Commuter Indonesia (KCI), offers rail-based transportation services connecting Jakarta with its surrounding suburban areas (Farda and Lubis, 2018). The Commuter Line serves as a vital link for commuters traveling between the city center and outlying suburban regions like Bekasi, Depok, and Bogor. It provides a convenient and cost-effective transportation option for residents, reducing reliance on private vehicles and alleviating traffic congestion on roads leading into Jakarta. Despite their benefits, both the BRT system and the Commuter Line face challenges in meeting the growing demand for transportation services in the Jakarta Metropolitan Area. Issues such as overcrowding, service delays, and infrastructure constraints hinder their effectiveness and reliability (Khafian, 2014). Additionally, the expansion of these systems to cover more areas and serve a larger population remains a priority for transportation planners and policymakers (Andrea, 2015).

To provide a more comprehensive understanding of the transportation disparities in suburban areas, empirical studies have been conducted to analyze factors such as public transportation accessibility, travel times, and commuter patterns. For example, research by Farda and Lubis (2018) highlighted the challenges faced by suburban residents in accessing reliable transportation options, citing long travel times and limited public transportation coverage as significant barriers. Similarly, Rukmana (2018) identified disparities in transportation infrastructure development between urban and suburban areas, further exacerbating mobility challenges for suburban residents. Furthermore, statistical data on commuter patterns and transportation usage provide insights into the extent of transportation disparities in suburban areas. Studies have shown that residents in suburban areas rely heavily on private vehicles due to limited access to public transportation options (Muallimah and Mashpufah, 2022). This reliance on private vehicles not only exacerbates traffic congestion but also contributes to environmental degradation and public health issues in the region.

Existing research on suburban transport planning has made strides in addressing various aspects, including traffic congestion, land use, and mobility patterns (Crane, 1996; Deakin, 1990; Wunas et al., 2011). However, a significant gap persists in exploring the self-organizing nature of suburban transport systems. Recent studies have highlighted the disconnections between planning and daily mobility (Nenseth and Røe, 2024; Wikstrøm and Røe, 2024), but they have not fully addressed the adaptability required in suburban contexts. To bridge this gap, this paper focuses on investigating the mechanisms of self-organization in suburban transport planning, aiming to develop sustainable and responsive transportation solutions. Specifically, it explores the phenomenon of suburban self-organization within the context of transportation planning in the Jakarta Metropolitan Area, with a particular emphasis on the development of the Commuter Line and BRT systems.

In the following sections, we will delve into the literature on suburban transportation development and the framework of self-organizing transport systems. The next section explains the collecting data and analysis method. The finding and analysis section explores the symmetry break by analyzing the change in the urban Jakarta-Bekasi area, the feedback loops through autonomy, flexibility, adaptability, and collaboration, and the collective outcomes through the self-organizing suburban transport planning concept. The conclusion provides conclusion and recommendations

for sustainable transportation planning practices and future studies.

2. Literature review

2.1. Suburban transportation development

Suburban transportation transformation encompasses a multifaceted process that reflects the evolving urban landscape surrounding metropolitan areas. This transformation involves dynamic changes in transportation systems and infrastructure, deeply intertwined with the broader urbanization and expansion of the metropolitan region (Orski, 1985). While suburbs traditionally served as residential satellites to the city center, they have increasingly become centers of economic activity and population growth (Moon, 1990). This shift in land use patterns, characterized by the expansion of built-up areas, reflects the growing demand for residential, commercial, and industrial spaces in suburban regions (Moon, 1990). The suburban transportation dynamics are closely linked to this demographic and land use transformation, shaping the demand for efficient and accessible transportation options (Dock and Swenson, 2003). For instance, cities like Bangkok, Manila, and Kuala Lumpur share similarities with Jakarta in terms of rapid urbanization, population growth, and transportation challenges (Ahmad and Suratman, 2020; Cervero, 2017). These cities also grapple with issues such as traffic congestion, inadequate public transportation infrastructure, and urban sprawl. However, each city has its unique socio-economic, political, and geographical context, which influences the nature and severity of its transportation challenges.

The transportation infrastructure within the suburbs plays a pivotal role in shaping the transformation process. The Jakarta Metropolitan Area has witnessed the emergence of specific systems like the Commuter Line and Bus Rapid Transit (BRT), which cater to the unique needs of suburban commuters (Susantono, 2012). These systems are characterized by features such as increased connectivity, accessibility, and a focus on serving the spatial requirements of suburban development. Suburban transportation transformation involves a complex interplay of urbanization, changes in land use, population growth, and the strategic adaptation of transportation systems to meet the evolving needs of suburban areas (Orski, 1985).

Frameworks specific to suburban contexts highlight the significance of accessible and well-designed transportation networks. According to Nenseth and Røe (2023), efficient transportation infrastructure in suburban areas is instrumental in accommodating the spatial expansion and increasing population density associated with urbanization. The accessibility provided by transportation infrastructure plays a crucial role in determining the attractiveness of suburban areas for residential and commercial purposes (Cervero, 2017; Chi, 2012). Studies in suburban development frameworks emphasize the importance of strategic transportation planning to foster sustainable and well-connected suburban regions (Cervero, 2017; Chi, 2012).

Furthermore, Ahmad and Suratman (2020) underline the need for transportation systems that are tailored to the specific requirements of suburban commuters. The development of commuter-focused systems, such as the Commuter Line and Bus Rapid Transit (BRT), illustrates a deliberate effort to enhance transportation infrastructure to meet the demands of suburban development. In summary, previous

studies and frameworks provide a foundation for recognizing the integral role of transportation infrastructure in suburban development. The literature emphasizes the need for well-designed and accessible transportation systems that align with the unique characteristics and challenges posed by suburban contexts.

2.2. Framework of self-organizing suburban transport system

The self-organization approach in suburban transportation planning embodies specific concepts tailored to the unique characteristics of suburban areas. In this context, self-organization refers to the inherent adaptability of transportation systems to changing conditions, reflecting the dynamic nature of suburban environments (Gershenson, 2011). This concept acknowledges that transportation systems can autonomously reorganize and adjust their structures to better align with the evolving needs of suburban development. While the term "self" may suggest independence, the concept of self-organization does not imply complete autonomy but rather emphasizes collaboration, feedback, and deliberative methods (Boonstra and Boelens, 2011; Pessoa, 2021).

Adaptive planning strategies are central to the application of the self-organization approach in suburban transportation planning. Suburban landscapes undergo continuous changes in land use patterns and population dynamics (Nenseth and Røe, 2023; Orski, 1985). Therefore, the self-organization approach involves planning strategies that can flexibly adapt to these changes, ensuring that transportation systems remain efficient and responsive. By integrating collaborative frameworks and feedback mechanisms, the self-organization approach fosters a dynamic and iterative process of transportation planning that aligns with the diverse needs of suburban communities. The self-organization framework in suburban transportation planning underscores the importance of adaptive strategies, collaboration, and responsive governance mechanisms. While the term may imply autonomy, its conceptual application emphasizes the interconnectedness and iterative nature of transportation planning processes in suburban areas.

In the realm of suburban transportation, complexities encapsulate the intricate interplay of various factors shaping transportation patterns, infrastructure development, and user behavior within suburban areas (Boonstra and Boelens, 2011; Pessoa, 2021). These dynamics are characterized by a multitude of interconnected variables and processes that interact in non-linear ways, presenting challenges for prediction and management. Examples of such complexity include rapid population growth, evolving land use patterns, modal shifts, and multi-modal integrations (Nenseth and Røe, 2023; Orski, 1985). For instance, the interaction between population growth, land use changes, and modal shifts illustrates how suburban transportation planning must navigate the interdependencies between urban expansion, travel behavior, and transportation infrastructure provision. Addressing these complex dynamics requires holistic approaches that account for diverse stakeholder needs. Therefore, in the context of suburban transportation transformation in Jakarta-Bekasi, understanding and effectively managing these complex dynamics are essential for developing resilient, inclusive, and sustainable transportation systems.

The framework of a self-organizing transport system involves several key

components, including symmetry breaking, feedback loops, and collective outcomes (De Roo, 2016; Gershenson, 2011). In the context of suburban transportation transformation, these elements interact to shape the evolution of the transportation system. In the realm of suburban transportation transformation, symmetry breaking manifests as a perturbation of the previously balanced system. This perturbation arises notably from substantial alterations in both the built-up area and population dynamics of urban centers and suburbs (Boonstra and Boelens, 2011). The advancing urbanization process is visibly marked by a noteworthy expansion of built-up areas. This shift from non-built to built-up land disrupts the previously harmonious symmetry observed in land use patterns. Simultaneously, there is a significant surge in population, both within the urban center and its suburban extensions. This demographic upswing further disturbs the equilibrium, creating heightened transportation demands and reshaping traditional travel patterns (Chi, 2012; Hudalah and Firman, 2012). The interplay of these alterations in land use and population dynamics lays the groundwork for the observed symmetry break in the suburban transportation system.

Within the intricate tapestry of suburban transportation transformation, feedback loops emerge as pivotal mechanisms. These loops constitute processes wherein the output of a system influences and adjusts the input. In the specific context of suburban transportation, several critical elements contribute to these feedback loops. The expansion of the Commuter Line system, a response to escalating demand, establishes a positive feedback loop. The addition of more stations and tracks not only accommodates more commuters but also stimulates further urbanization, intensifying the need for efficient transportation (Cervero, 2017; Nenseth and Røe, 2023). Analogously, the Transjakarta Bus Rapid Transit (BRT) system operates within a feedback loop, with adjustments and expansions influenced by demand patterns that can either alleviate or exacerbate congestion. Additionally, other suburban train and bus services exhibit similar feedback loops, wherein increased ridership prompts adjustments such as more frequent services or the extension of existing routes. These feedback loops underscore the dynamic and interdependent nature of the transportation system's evolution.

The amalgamation of symmetry breaking and feedback loops culminates in the outcome of transportation planning guided by a self-organization approach. This outcome encompasses adaptive planning, where transportation planners systematically analyze data from feedback loops to optimize the transportation system dynamically (Gershenson, 2009; Pessoa, 2021). Dynamic decision-making becomes a hallmark of this approach, utilizing real-time data and community input to fine-tune routes, schedules, and infrastructure development in response to the evolving needs of the burgeoning population (Ahmad and Suratman, 2020; Rukmana, 2018; Susantono, 2012). The self-organization approach places a premium on efficiency and resilience. Transportation systems are not only designed to efficiently transport people and goods but also engineered to be resilient in the face of evolving urban dynamics and potential disruptions. This outcome signifies a departure from traditional top-down planning approaches, emphasizing the adaptability and responsiveness of transportation systems in suburban areas.

The framework of a self-organizing transport system in the Jakarta Metropolitan

Area involves symmetry breaking due to changes in urban centers and suburban areas, feedback loops through transportation services, and the outcome of adaptive and dynamic transportation planning with a focus on public transport performance. This mechanism highlights the intricate and interconnected nature of suburban transportation transformation, where disruptions in land use and population growth trigger dynamic feedback loops that shape the evolution of the transportation system (**Table 1**).

Table 1. Framework of Self-organizing suburban transport system.

Criteria	Indicator	Variable
Symmetry break	Suburbanization	Built-Up Areas
		Total population
Feedback-loops	Autonomy	Degree of decision-making power given to local transport entities
	Flexibility	The ability of the transport system to adjust routes and schedules
	Adaptability	Response mechanisms in place for sudden changes in demand or infrastructure
	Collaboration	Existence and effectiveness of partnerships among transport stakeholders
Outcomes	Self-organization of Suburban Transport Planning	Performance of Suburban Public Transport

3. Materials and methods

This section outlines the methodology employed in this paper to examine the suburban transportation transformation in the Jakarta Metropolitan Area, focusing on the case of Commuter Line and Bus Rapid Transit (BRT) development. Spatial analysis methods were utilized to examine the changes in land use, population distribution, and transportation infrastructure in the suburban areas of the Jakarta Metropolitan Area. Geographic Information Systems (GIS) were employed to analyze spatial data, including satellite imagery, land use maps, and population density maps. These methods helped identify the spatial patterns and dynamics of suburban development and its influence on the transportation system. The analysis of changes in land use provides insights into how suburban areas are evolving, including the expansion of residential, commercial, and industrial spaces. Understanding these changes is essential for transportation planning as it helps identify areas of increased demand for transportation services, potential congestion hotspots, and areas in need of infrastructure development. Similarly, analyzing population distribution allows researchers to assess how population growth and distribution patterns impact transportation demand and mobility patterns. High population density areas may require enhanced public transportation services, while low-density areas may face challenges in accessing transportation options.

In data collection process, stakeholders interviewed for this study included government officials, communities, and representatives from public transportation agencies in the Jakarta Metropolitan Area. The interviews were conducted over a period of six months, with a total of 20 stakeholders participating in semi-structured interviews. We conducted interviews with a diverse range of stakeholders involved in suburban transportation planning in the Jakarta Metropolitan Area. These stakeholders included representatives from various government institutions responsible for

transportation policymaking and infrastructure development. Specifically, interviews were conducted with officials from the Jakarta Provincial Government's Transportation Agency, the Ministry of Transportation, and local government agencies in suburban areas such as Bekasi Department of Transportation. In addition to government officials, we also interviewed representatives from public transportation operators, including the management teams of the Commuter Line and Bus Rapid Transit (BRT) systems. These interviews provided insights into the operation and management of existing public transit services and the challenges faced in providing efficient and reliable transportation in suburban areas. Furthermore, we engaged with community groups, non-governmental organizations (NGOs), and advocacy groups involved in transportation advocacy and community organizing. These stakeholders provided perspectives from the grassroots level and offered insights into the transportation needs and priorities of suburban residents, particularly those from marginalized communities.

Each interview session lasted approximately 60 to 90 min. The interview questions focused on various aspects of suburban transportation planning, including challenges faced, current initiatives and projects, stakeholder collaboration, decision-making processes, and future plans. Some sample questions included:

1) What are the main transportation challenges faced by suburban residents in the Jakarta Metropolitan Area?
2) Can you describe any ongoing or planned projects to improve public transportation infrastructure in suburban areas?
3) How do different stakeholders collaborate in the planning and implementation of transportation projects?
4) What factors influence decision-making in suburban transportation planning?
5) How do you envision the future of suburban transportation in the Jakarta Metropolitan Area?

Subsequently, a qualitative descriptive approach was employed to analyze the interview transcripts and identify recurring themes, patterns, and insights related to suburban transportation planning. The analysis involved coding the data, categorizing responses, and identifying key findings and implications.

In addition, document analysis was conducted to review relevant policy documents, planning reports, and academic literature related to suburban transportation transformation in the Jakarta Metropolitan Area. This analysis provided valuable context and background information for the study and helped identify existing strategies, policies, and interventions aimed at addressing transportation challenges in suburban areas.

4. Results and discussion

In this section, we analyze the suburban transportation landscape of Bekasi City through three key aspects: Symmetry Break, Feedback Loop, and Collective Outcome. We examine suburbanization's impact on land use patterns and population dynamics. Then, we explore the dynamic nature of the public transportation system, focusing on autonomy, flexibility, adaptability, and collaboration. Finally, we investigate how self-organization influences collective outcomes in suburban transport planning. Through

this analysis, we gain insights into the complex interplay of urbanization, infrastructure development, and planning initiatives in Bekasi City's suburban transportation transformation.

4.1. Symmetry break: The suburbanization of Bekasi city

The spatial analysis conducted in this paper highlights a notable phenomenon: the expansion of built-up land within Jakarta over the analyzed period (see **Figure 1**). This significant increase underscores the dynamic urban growth occurring in the region, as non-built land is converted into residential, commercial, and industrial zones. The expansion of built-up areas necessitates careful consideration in transportation planning, as it points to the increasing demand for efficient and sustainable transportation systems to cater to the mobility needs of the growing population. Furthermore, the analysis specifically illuminates the changes in land use patterns in suburban areas, with a particular focus on Bekasi City. These suburban regions exhibit a transition from agricultural and non-built land to built-up areas, signaling the emergence of new residential and commercial activities (see **Figure 2**). These transformations underscore the importance of thoughtful transportation planning to ensure connectivity and accessibility for the suburban population, as they experience shifts in land use that impact their daily lives and commuting patterns.

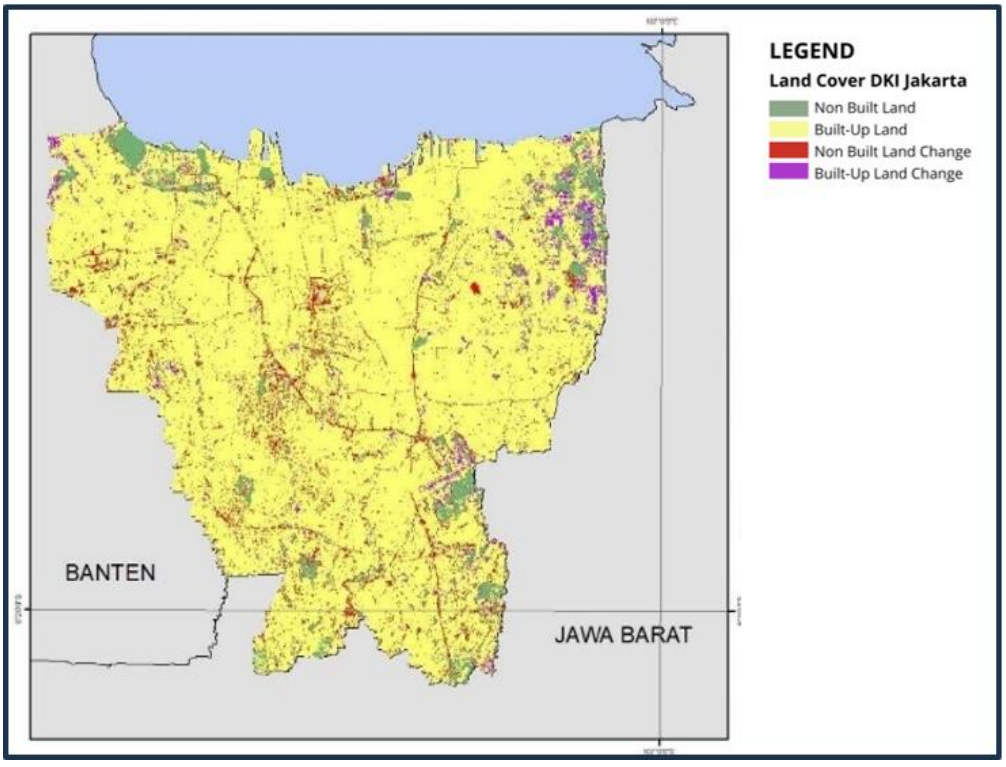

Figure 1. Map of Land Cover Change Jakarta 2015–2019.
(Source: Analysis, 2022).

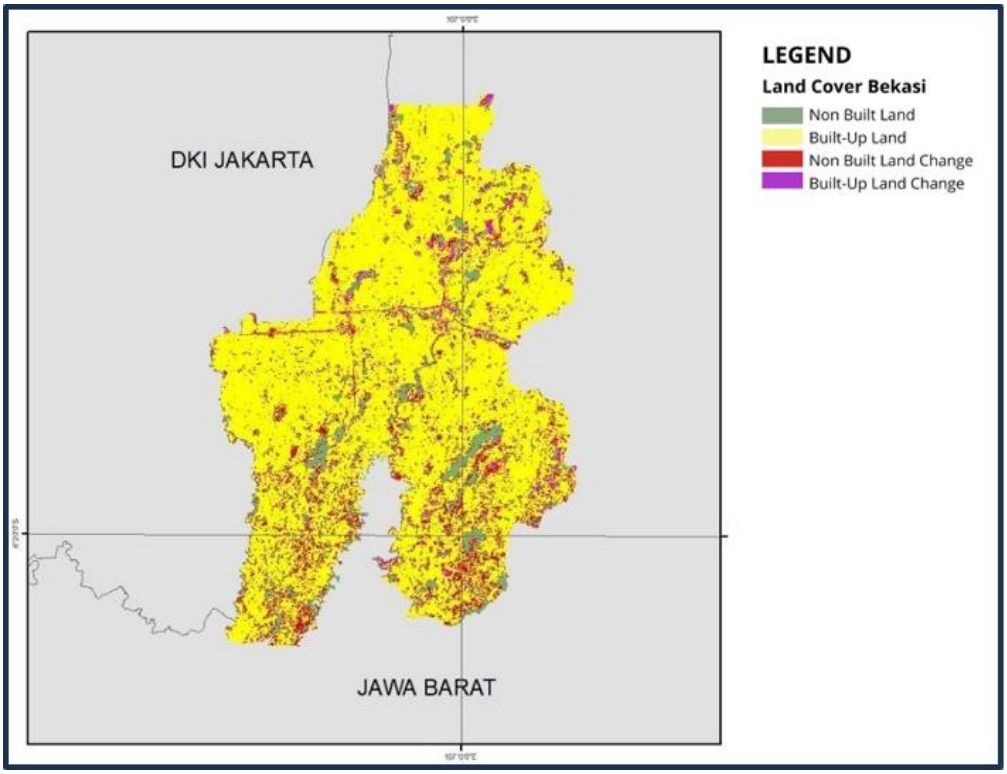

Figure 2. Map of Land Cover Change Bekasi City 2015–2019.

(Source: Analysis, 2022).

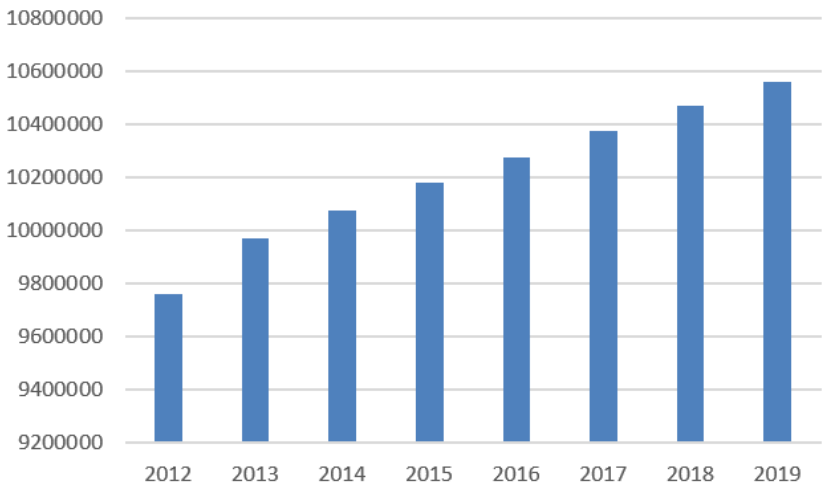

Figure 3. Population Growth of Jakarta in 2012–2019.

(Source: Statistical Center of Jakarta, 2022).

The examination of population dynamics in the paper reveals a substantial and noteworthy increase in the population of Jakarta and its surrounding suburban areas. The population growth depicted in **Figures 3** and **4** underscores the urgent necessity for efficient transportation systems capable of meeting the escalating demand for mobility while seamlessly connecting residents to vital hubs such as employment centers, educational institutions, and essential services. For instance, in Jakarta, areas like Sudirman Central Business District (CBD), Senayan, and Kuningan have experienced significant growth in employment opportunities and commercial activities, necessitating robust transportation infrastructure to facilitate commuting for

the workforce. Similarly, in Bekasi, industrial zones such as Jababeka and Lippo Cikarang have witnessed rapid expansion, leading to a surge in employment opportunities and economic activities. However, the lack of efficient transportation systems in these areas poses challenges for residents in accessing employment centers and essential services. Addressing these transportation gaps is crucial to ensuring equitable access to opportunities and enhancing the overall livability of both Jakarta and Bekasi.

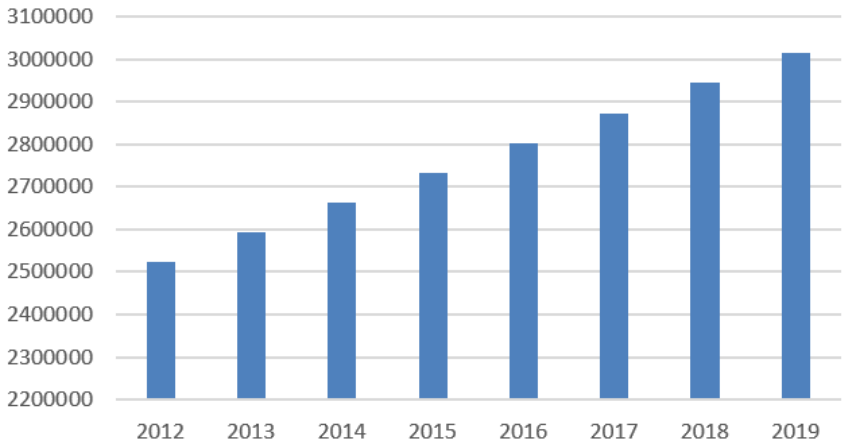

Figure 4. Population growth of Bekasi city.
(Source: Statistical center of Bekasi city, 2022).

The spatial analysis further unveils insights into urban sprawl and commuting patterns within the region. It identifies areas characterized by high residential densities and significant commuting flows, shedding light on the necessity for transportation infrastructure that facilitates seamless and convenient commuting experiences. This understanding is crucial for crafting transportation solutions that align with the evolving urban landscape and meet the demands of the population.

The implications of these findings are far-reaching. The expansion of built-up areas in both Urban Jakarta and Bekasi has led to a noticeable increase in travel demand. With more people residing in these areas and businesses establishing themselves, there is a growing need for transportation services to facilitate daily commuting, business activities, and leisure travel. Consequently, addressing last-mile connectivity becomes a significant challenge as residential areas sprawl, and commercial centers grow. The increased distances between homes, workplaces, and transportation hubs necessitate effective last-mile solutions to ensure accessibility and convenience for commuters. Additionally, changes in population and land use mix influence commuter patterns. In the case of Bekasi City, many residents commute to work in Urban Jakarta, resulting in a substantial daily influx of commuters into the core city. This commuter flow places additional stress on transportation infrastructure, including the Commuter Line and Transjakarta BRT systems. Therefore, transportation planners must adapt to these shifts in demand by optimizing routes and service frequencies to accommodate changing commuter patterns.

The analysis of the symmetry break due to changes in the built-up area and population in Urban Jakarta and Bekasi highlights the intricate dynamics of suburban transportation transformation in the Jakarta Metropolitan Area. The expansion of built-

up areas and population growth disrupts previous symmetry in land use and population distribution, leading to increased travel demand, last-mile challenges, evolving commuter patterns, and the need for adaptive transportation planning. These insights provide a foundation for understanding the transportation dynamics and challenges associated with urbanization and suburban expansion in the region.

4.2. Feedback loop: Dynamic of suburban public transportation system

Autonomy, as a characteristic of self-organization, manifests in the feedback-loop dynamics of suburban transportation transformation in Jakarta-Bekasi. Autonomy refers to the system's ability to self-regulate and adapt based on internal processes and feedback mechanisms. One illustrative example of autonomy in the feedback loop is the operation of the Commuter Line system. The autonomy is reflected in how the Commuter Line system, in response to increased demand, autonomously expands its rail lines, establishes new stations, and enhances train frequency and capacity such as the development of double-double tracks in 2017. This expansion is not solely driven by external directives but is a result of the system autonomously responding to the changing transportation needs within the suburban areas.

> "Before the changes to the railway system it became double-double tracks, from year 1980–2015 commuter line still use double track. And the double-double track work began to be planned from 2016 and began operating in 2018 at Jatinegara (Jakarta)-Cikarang (Bekasi) stations, for Manggarai (Jakarta)-Jatinegara (Jakarta) stations it is still in the construction process which is estimated to be completed in 2025" (Head Division of Infrastructure at Railway Engineering Authority, 2022).

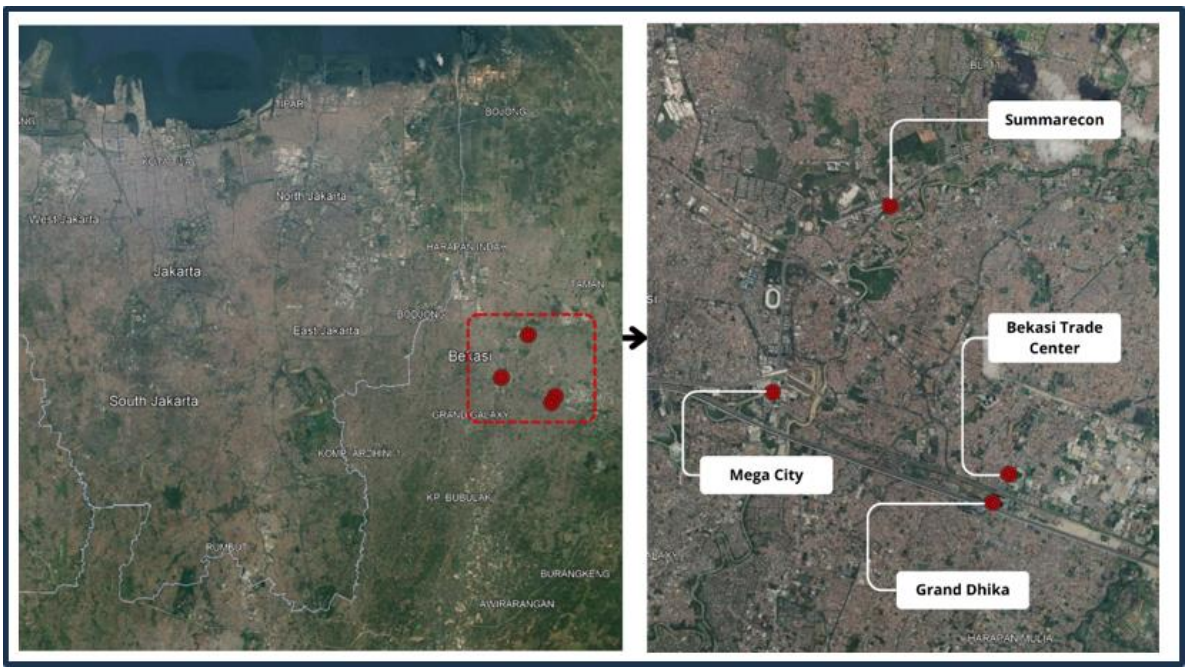

Figure 5. Demands of new BRT routes in Jakarta suburban transportation.

Additionally, the autonomy in the feedback loop is observed in the decision-

making process related to route changes and additions. The introduction of new routes and stations by the Transjakarta Bus Rapid Transit (BRT) system is influenced by the system's autonomy to dynamically adjust to evolving demand patterns. For instance, the routes from Summarecon, Megacity, Bekasi Trade Center, and Grand Dhika (**Figure 5**) in 2016 can be seen as a new demand (President Director of Transjakarta in Kompas News, 2016). This autonomous decision-making ensures that the transportation system remains responsive and efficient, adapting to the complex dynamics of suburban transportation transformation without constant external intervention. Autonomy in the feedback-loop dynamics allows the suburban transportation system in Jakarta-Bekasi to independently adjust, expand, and optimize its operations based on the continuous feedback it receives, exemplifying a self-organizing characteristic.

Flexibility refers to the system's capacity to adapt and modify its responses based on changing conditions and demands. In the feedback loop of suburban transportation, flexibility is exemplified by how transportation systems, such as the Commuter Line and Transjakarta BRT, adjust their operations and infrastructure in response to dynamic conditions. One key aspect of flexibility is observed in the modification of routes and services. For example, the Commuter Line system may flexibly alter its routes based on shifting commuter patterns, emerging urban developments, or changes in demand for specific destinations especially in Bekasi Station, Tambun Station, Cibitung Station, and Cikarang Station as new growth centers (Vice President Corporate Communication Secretary KAI Commuter in Kompas News, 2022).

Moreover, flexibility is evident in the response of the Transjakarta BRT system to varying levels of congestion and demand. The system may flexibly introduce new routes, change existing ones, or modify service frequencies to ensure optimal efficiency and address congestion issues. For instance, the development of premium bus rapid transit to attract middle-income passengers to reduce the use of private vehicles. This adaptability is crucial for maintaining a smooth and effective transportation system in the face of dynamic and unpredictable conditions (Operational Director of Transjakarta in Tribun News, 2021). The flexibility characteristic also extends to infrastructure development. Transportation planners demonstrate flexibility by adjusting plans for new stations, tracks, or other facilities based on real-time data and evolving transportation needs. Such as special facilities on the bus or train for women, disabilities, and the elderly, the development of multimodal infrastructure like bridges and escalators, and other programs to adapt to the changing needs.

> "In commuter line, from year to year there are indeed changes in both stations, trains, and even the facilities provided by the commuter line itself, such as route changes (Bogor line-Tanah Abang, Bekasi line), additional stations (East Bekasi station, Tambun, Cibitung, Cikarang) in 2018, as well as changes to existing facilities at stations such as lifts at all stations, escalators, and health care/health posts at several stations" (Interview with commuter line users, 2022).

This transformation ensures that the transportation infrastructure remains aligned with the changing dynamics of suburban areas. Flexibility in the feedback-loop dynamics allows the suburban transportation system in Jakarta-Bekasi to dynamically alter its operations and infrastructure, showcasing a self-organizing characteristic that

responds effectively to the complexities of transportation transformation.

Adaptability, as a key characteristic of self-organization, is evident in the feedback-loop dynamics of suburban transportation transformation in Jakarta-Bekasi. Adaptability refers to the system's capability to adjust and modify its behavior, structure, or functions in response to changes in its environment. While flexibility relates more to proactive adjustments, adaptability refers to reactive responses. In the context of suburban transportation, adaptability is reflected in how transportation systems respond to evolving conditions such as changes in commuter patterns, urban development, or variations in demand. For instance, the existence of Omprengan as informal transport in Bekasi had developed in evolving conditions such as new routes, new developments, or new demands to meet the dynamic needs of suburban commuters in Bekasi (Kusumaningrum, 2013). This dynamic approach ensures that the suburban transportation infrastructure remains resilient and responsive to the evolving demands of the population. Such as real-time information from official accounts of social media and platforms such as C-Access, commuters can demand new facilities and the commuter line will adjust the condition according to the information (Interview with Commuter Line User, 2022). The adaptability characteristic in the feedback-loop dynamics of suburban transportation in Jakarta-Bekasi reflects the self-organizing nature of the system. It enables the transportation infrastructure to continuously evolve and respond effectively to the complex and dynamic urban environment.

Collaboration, as a fundamental characteristic of self-organization, plays a crucial role in the feedback-loop dynamics of suburban transportation transformation in Jakarta-Bekasi. Collaboration refers to the capacity of different elements within a system to work together towards shared goals, fostering a collective and adaptive environment. Collaboration is manifested in the coordination between various stakeholders, including transportation authorities, urban planners, residents, and businesses. It involves shared decision-making processes and collective efforts to enhance the efficiency and effectiveness of transportation systems. One illustrative example of collaboration in the feedback loop is the coordination between transportation authorities and the community to address emerging challenges. For instance, if a specific route experiences congestion issues during peak hours, collaborative efforts may involve communication and information from commuter communities such as Anak Kereta (Anker) to gather inputs (Interview with Commuter Line User, 2022).

In practical terms, this could entail Anak Kereta members reporting congestion hotspots or delays through dedicated communication channels established by transportation authorities such as X (Twitter) or other social media. Subsequently, transportation management stakeholders can analyze this feedback and implement targeted interventions to alleviate congestion, such as adjusting scheduling, deploying additional trains, or optimizing route configurations. Moreover, user feedback has been instrumental in identifying safety concerns and infrastructure deficiencies, especially related to sexual harassment in public transport, prompting authorities to undertake maintenance, upgrade projects, or new policies to enhance the overall reliability and safety of the transportation network. Anak Kereta (Anker) is a notable community platform that serves as a valuable resource for commuters within the

Jakarta Metropolitan Area. Available across various online platforms and social media channels, Anak Kereta offers a centralized space for commuters to share insights, experiences, and information related to the transportation system, particularly the Commuter Line. The platform has been instrumental in fostering a sense of community among commuters, enabling them to exchange tips, updates, and recommendations regarding routes, schedules, and service disruptions. Anak Kereta provides a wide range of information, including real-time updates on service status, announcements from transportation authorities, and user-generated content such as reviews, complaints, and suggestions. Through its active presence on platforms like Twitter (X), Facebook, and dedicated online forums, Anak Kereta has become a go-to source for commuters seeking timely and relevant information about the transportation network. Established several years ago, Anak Kereta has steadily gained popularity and credibility among commuters, garnering a sizable following and engagement from users across the Jakarta Metropolitan Area. Its longevity and sustained relevance attest to its effectiveness as a community-driven platform that fulfills the needs of commuters and contributes to the improvement of the transportation experience in the region. This collaboration helps transportation planners gain insights into the unique needs and preferences of the community, informing adjustments to routes or schedules.

Moreover, collaboration is evident in the integration of different modes of transportation. In the feedback loop, transportation planners may collaborate with other sectors, actors, and scales to create seamless connections between train services, bus routes, and private vehicles. This collaborative approach aims to provide commuters with a variety of transportation options, promoting sustainable and integrated mobility. The emphasis on collaboration also extends to the iterative nature of the feedback loop. Regular communication and collaboration between stakeholders allow for continuous improvements. For instance, the development of a new station in Cikarang, and ongoing collaboration with the community help in monitoring its impact and making necessary adjustments based on real-time feedback (Interview with commuter line user, 2022). Collaboration as a characteristic of self-organization in the feedback-loop dynamics of suburban transportation in Jakarta-Bekasi underscores the importance of collective decision-making, shared responsibilities, and continuous engagement among diverse stakeholders. This collaborative approach enhances the adaptability and responsiveness of the suburban transportation system to the evolving dynamics of the metropolitan region.

4.3. Collective outcome: Self-organization of suburban transport planning

The optimization of suburban public transport performance is a multifaceted process shaped by the dynamic interplay of autonomy, flexibility, adaptability, and collaboration. Autonomy, when bestowed upon local transport entities, emerges as a linchpin factor influencing decision-making processes. The decentralization of decision-making empowers these entities to tailor transportation services with acute sensitivity to the unique needs and characteristics of their specific communities. This localized autonomy facilitates a more responsive, community-centric public transport system. The orchestration of collective outcomes in suburban public transport hinges

on the nuanced integration of autonomy, flexibility, adaptability, and collaboration. Autonomy, when devolved to local transport entities, becomes a catalyst for tailored decision-making. For instance, empowering a suburban transport authority to determine routes and service frequencies based on community needs leads to a more responsive and demand-driven public transport system. The Greater London Authority's devolution of transport powers to Transport for London (TfL) serves as a pertinent example, where local decision-making contributes to a more finely tuned transport network (Cottis and Barham, 2006; Utting, 2015).

Flexibility stands as another cornerstone in achieving an optimally performing suburban transport network. The capability to make real-time adjustments to routes and schedules proves pivotal in accommodating the fluid nature of commuter patterns and unforeseen events. A flexible transport system exhibits agility, swiftly adapting to changes in urban dynamics, thereby optimizing efficiency and aligning with the evolving demands of the population it serves. Flexibility, another vital dimension, manifests in the system's capacity to recalibrate in real time. Consider a scenario where sudden road closures or events alter commuter patterns. A flexible public transport system would swiftly adjust routes and schedules to mitigate disruptions, as seen in the dynamic responses of cities like Tokyo, where transport schedules adapt rapidly to accommodate diverse events and changing urban dynamics (Narayan et al., 2020).

Adaptability assumes heightened significance, particularly in the face of unforeseen challenges or crises. A resilient suburban public transport system must exhibit the capacity to respond effectively to events such as pandemics, natural disasters, or sudden population surges. The ability to navigate and overcome unforeseen circumstances without compromising overall performance is a hallmark of an adaptable transport infrastructure. Adaptability is crucial, especially in the face of unforeseen challenges. Take the example of the COVID-19 pandemic, which prompted many cities worldwide to reassess public transport operations. Those with adaptable systems swiftly implemented measures such as contactless payment, revised seating arrangements for social distancing, and enhanced sanitation protocols (Downey et al., 2022; Kłos-Adamkiewicz and Gutowski, 2022; Lucchesi et al., 2022). This adaptability ensured that public transport remained a viable and safe option during an unprecedented health crisis.

Collaboration, the fourth key determinant, underscores the imperative of a networked and cooperative approach among diverse stakeholders. Effective collaboration involves forging strategic partnerships between public and private entities, actively engaging with local communities, and fostering cooperative efforts among different levels of government. This collaborative synergy contributes to the development of a holistic and comprehensive transport planning strategy, drawing upon a diverse range of expertise and resources. Collaboration emerges as the linchpin that binds these elements together. Effective collaboration involves stakeholders at various levels, fostering partnerships between public and private entities. A striking illustration is the collaborative approach in Zurich, Switzerland, where public transport is seamlessly integrated with other modes, like shared bicycles and car-sharing services, presenting a holistic and interconnected urban mobility system (Nash et al., 2020; Pettersson et al., 2017).

The collective outcomes of a well-functioning suburban public transport system are intricately woven into the fabric of these key elements. When autonomy, flexibility, adaptability, and collaboration are seamlessly integrated, they collectively pave the way for a robust and high-performing transport system. Such a system not only caters to the immediate needs of the community but also showcases resilience and adaptability in the face of the complex and dynamic challenges inherent in suburban environments. This holistic approach ensures that suburban public transport is not merely a service but a dynamic, responsive, and integral aspect of urban infrastructure.

Among the key policymakers involved in suburban transportation planning efforts are representatives from government agencies at both the local and regional levels. This includes officials from the Jakarta Provincial Government, as well as municipal authorities in suburban areas such as Bekasi, Depok, and Tangerang. These policymakers are responsible for developing and implementing policies related to transportation infrastructure, urban planning, and public transit systems, with the overarching goal of improving mobility and connectivity in suburban regions. Additionally, policymakers from relevant ministries and regulatory bodies, such as the Ministry of Transportation, Jabodetabek Transportation Management Agency (BPTJ), and the National Development Planning Agency (Bappenas), are also engaged in suburban transportation planning initiatives. These policymakers provide strategic direction, allocate resources, and coordinate efforts to address transportation challenges at the national level, thereby influencing suburban transportation policies and initiatives. Furthermore, collaboration with non-governmental organizations (NGOs), community groups, and advocacy organizations is integral to the self-organization of suburban transportation planning. These stakeholders often work in partnership with policymakers to identify local needs, advocate for policy changes, and mobilize resources to support transportation infrastructure projects and initiatives in suburban areas.

Our article provides a comprehensive analysis of suburban transportation dynamics in the Jakarta Metropolitan Area and offers valuable insights that align with existing policies and initiatives aimed at improving transportation in the region. Firstly, our paper contributes to the understanding of transportation disparities and challenges faced by suburban residents, which is consistent with the goals outlined in JakLingko. The JakLingko emphasizes the importance of addressing transportation inequalities and improving accessibility to public transit services for all residents, particularly those in suburban areas. By identifying disparities in transportation access and mobility, our article supports the objectives of the JakLingko and provides evidence to inform targeted interventions to enhance transportation equity. Furthermore, our analysis of spatial changes, population dynamics, and transportation challenges in suburban areas aligns with the objectives of Jakarta Smart City: Smart Mobility (JSC:SM). The JSC:SM aims to develop a comprehensive and integrated transportation system that accommodates the needs of a growing population and fosters sustainable urban development. Our paper findings contribute to the evidence base used to inform the development and implementation of transportation infrastructure projects and initiatives outlined in the JSC:SM such as the expansion of public transit networks and the improvement of transportation connectivity in suburban regions.

5. Conclusion

This paper set out to explore the multifaceted landscape of suburban transportation transformation in the Jakarta Metropolitan Area, with a specific focus on the development and dynamics of the Commuter Line and Bus Rapid Transit (BRT) systems. Through a combination of spatial analysis, qualitative descriptions, and engagement with stakeholders, the paper aimed to decipher the self-organizing processes inherent in transportation planning within the suburban context. Reflecting on the findings, the pivotal role of autonomy in shaping suburban transportation emerges prominently. The decentralization of decision-making power to local transport entities, as seen in the case of the Commuter Line system, illustrates the positive impact on system responsiveness and adaptability. This resonates with the works of researchers (Cottis and Barham, 2006; Utting, 2015) who argued for localized decision-making in transport systems to enhance efficiency and alignment with community needs.

Flexibility, a key attribute highlighted in this paper, is crucial for suburban transport systems to navigate the complexities of changing urban dynamics. The dynamic adjustments made by the Commuter Line system in response to evolving infrastructure needs and population density underscore the significance of flexibility. This aligns with contention of Narayan et al. (2020) that flexibility is a cornerstone for sustainable and adaptable urban transportation. Moreover, the paper delved into the intricate feedback loops within transportation systems, particularly examining the infrastructure components of the Commuter Line and BRT. Drawing on the systems thinking approach, the analysis showcased how infrastructure changes reverberate through the entire system, influencing modes, frequencies, and capacities. This aligns with systems-oriented perspective of Downey et al. (2022), emphasizing the interconnectedness of transportation components.

The exploration of collective outcomes, influenced by autonomy, flexibility, adaptability, and collaboration, shed light on the mechanisms that lead to a well-performing suburban public transport system. Autonomy, when coupled with effective collaboration, fosters a sense of ownership and stakeholder engagement, exemplified by the participatory decision-making processes observed in the development of the Commuter Line. This collaborative autonomy aligns with proposition of Pettersson et al. (2017) that community engagement is pivotal for the success of urban transport initiatives.

In synthesizing these findings, it’s imperative to recognize that suburban transportation transformation is not a one-size-fits-all endeavor. The unique dynamics of each metropolitan region necessitate context-specific strategies. While this paper provides valuable insights into the Jakarta Metropolitan Area, it is crucial to acknowledge the contextual variations that may influence the applicability of these findings to other regions. Looking ahead, there are several promising avenues for future research that can build upon the insights generated in this study. Firstly, comparative studies across diverse suburban contexts can offer valuable insights into the factors shaping transportation dynamics and the effectiveness of various policy interventions. By examining similarities and differences between various metropolitan regions, researchers can identify transferable lessons and best practices that can inform

transportation planning efforts in similar contexts. Furthermore, exploring the implications of emerging technologies on suburban transportation is an area ripe for further investigation. Technologies such as autonomous vehicles, ride-sharing platforms, and smart transportation systems have the potential to revolutionize how people move within suburbs. Future research can examine how these technologies can be harnessed to enhance accessibility, equity, and sustainability in suburban transportation systems.

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