Typologies of commuter train stations: A case study Jakarta Kota – Bogor agglomeration in Indonesia

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Abstract. Commuter rail is critical for sustainable mobility in suburban and urban areas. Categorizing commuter rail stations from a TOD perspective become typology can provide valuable references for developing, planning, and managing commuter rail station areas. However, limited commuter rail stations at the neighborhood scale must be identified based on TOD factors, specifically in relation to ridership travel patterns. This study addresses this gap by developing a neighborhood-scale TOD typology for station areas using a cluster-multilevel modeling approach to analyze the relationship between TOD factors and passenger travel patterns. This analysis identifies whether a station functions as a trip generator or an attraction point for passengers. A two-step cluster analysis of spatial data from 24 stations along the Jakarta Kota–Bogor rail line resulted in three neighborhood types. Identifying commuter rail station typologies is crucial for policymakers to propose different strategies. These strategies may include small projects to improve public spaces and promote eco-friendly mobility or more substantial changes requiring a density redistribution around the stations. This approach challenges the rigid definition of transit-oriented development and adapts decisions to the specific context of each station area.

1 Introduction

Rapid metropolitan expansion in cities like Jakarta has been accompanied by sprawling peripheral growth, dispersed land-use patterns, and increasing dependence on private vehicles, all of which have exacerbated congestion, travel inefficiencies, and environmental degradation [1]. In particular, commuter rail systems that serve peripheral core connections remain underutilized due to the spatial mismatch between transit infrastructure and the surrounding built environment. Amid these challenges, Transit-Oriented Development (TOD) has emerged as a planning paradigm that integrates compact, mixed-use, and walkable urban form with high-capacity public transport to improve accessibility and promote sustainable mobility [2]. TOD principles emphasize five built environment dimensions density, diversity, design, destination accessibility, and distance to transit (commonly known

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as the 5Ds) which influence individual travel decisions and overall transit performance. Urbanization has become a phenomenon of urban transformation marked by migration from rural areas to cities. This phenomenon has become one of the urban challenges worldwide as it drives random growth in urban and rural areas [3]. It has also spurred rapid population growth in suburban areas and expanded job opportunities in urban regions [4]. In general, commuter rail systems are primarily oriented toward connecting peripheral and suburban areas with the central city, making them a more efficient mode of transportation [5]. Another critical point is that commuter rail systems in metropolitan areas are significantly influenced by the characteristics of the stations' surroundings [6]. Commuter train stations are critical infrastructure nodes that serve as gateways for journeys from suburban areas to city centers, support suburban urbanization, and shape the surrounding environment [7]. However, many unsustainable development issues have arisen in commuter train station areas. Particularly in the Jakarta Kota - Bogor corridor, there are prominent problems related to the lack of integration between transportation and land use, such as low intracity accessibility, insufficient spatial vitality in station areas, and passenger travel behavior [8].

Fostering the integration of transport and land use in commuter train station areas requires a thorough classification of commuter train stations from this standpoint [9]. The classification of commuter train stations has several uses, including helping planners avoid making uniform decisions across stations and providing optimization strategies for various types of stations [10]. However, there have been few studies on the classification of commuter train stations from the perspective of transport and land-use integration. Previous research has primarily focused on transportation stations within metropolitan areas [11]. Some studies have focused solely on transportation single aspects or land use [12]. Development of transport and land-use integration employs the node–place model approach to renew railway station areas in Europe [13]. This model has been widely applied to evaluate and classify transport stations, with various adaptations to suit different research objectives. However, it has primarily been used to classify commuter rail stations in metropolitan areas [14]. The classification results form a typology across various scales, namely the metropolitan, corridor, district and the neighborhood scale. Understanding and shaping the various typologies of these station areas is essential for optimizing transit-oriented development (TOD) and ensuring that these hubs effectively meet the needs of the passengers they serve [15].

In recent decades, transit-oriented development (TOD) has been established as a new approach to address the relationship between transportation systems and land use planning. This approach can also be used as a planning tool to support denser, more compact urban environments with diverse eco-friendly transportation options while promoting active travel. Ideally, TOD primarily aims to reduce urban sprawl, private vehicle mobility, and their associated impacts. On the other hand, TOD aims to promote sustainable development and enhance sustainable mobility [16][17][18]. Extensive literature exists on the topic, examining various modes of transportation and the areas surrounding their stations. These studies go beyond the TOD perspective, exploring diverse methodologies for analyzing urban structures and assessing the effects of transport infrastructure on land use and activities [19]. The implementation of the TOD concept in cities across America generally focuses on centralizing density and organizing areas around transit stops [20][21] [22]. Meanwhile, in European cities, TOD implementation is more oriented toward redeveloping neighborhoods to support active transportation behaviors such as walking, cycling, and using public transit [23][24][25]. On the other hand, advanced cities in Asia have further developed the TOD concept as a land value capture (LVC) strategy to distribute metropolitan growth along transit stop corridors [7][26][27][28].

TOD typology is the segmentation of neighborhoods with similar urban structures [29]. Classifying commuter train stations into typologies can support the identification of

development potentials and necessary adaptations in the planning process. Each TOD typology formed has specific characteristics such as density, land-use mix, connectivity, and transportation functions, enabling the typology to support optimal TOD design at a given location [30]. This typology can help answer policy-level questions such as: "What type of transportation system is suitable? What kind of neighborhood is needed to enhance TOD success?" The classification results provide a precise benchmark of urban structure factors, serving as a foundation for TOD development [31]. According to recent literature, there are two approaches to conceptualizing and developing TOD typologies [32]. The first is the qualitative approach, where typologies are defined and labeled based on the geographical and functional characteristics of the surrounding environment [16][29][15]. Urban TOD refers to high-density areas within a half-mile distance of major transit lines. At the same time, neighborhood TOD encompasses low- to medium-density residential areas within ten minutes of travel to local or feeder bus lines.

The second approach involves the quantitative development of typologies based on existing TOD factors [13][33][25]. Some researchers have recognized that TOD can take various forms, and each neighborhood may have a different urban structure. Research on developing advanced typologies can be carried out using several empirical methods [29]. Some researchers have applied various methods such as hierarchical clustering [34], two-step clustering [31][35], and latent class clustering [36] to TOD factors to generate typologies. Higgins & Kanaroglou [32] classified 372 rapid transit station areas in Toronto into 10 TOD types using latent class clustering of TOD factors. This study validated the typology by examining statistical differences among socio-demographic and travel behavior variables.

Atkinson-Palombo & Kuby, (2011) proposed five TOD types for 27 station areas of the light rail transit (LRT) system in Phoenix, USA, using hierarchical clustering. Validation of the typology in this study employed three independent ANOVA tests on the mean values of TOD factors.

Kamruzzaman et al. [31] divided 200 districts in Brisbane into four TOD types: activity center TOD, potential TOD, residential TOD, and non-TOD, using two-step clustering analysis. The resulting clusters were then validated using a multinomial logit model on travel behavior data from residents living in the Brisbane area.

Subjective TOD development is often not timely and fails to measure urban structures and spatial diversity accurately, making it less precise for appropriate TOD development [24]. Therefore, quantitative typology development is more relevant as it is testable, comparable, and systematic in TOD area planning. Existing studies indicate that TOD typology is not a "one-size-fits-all" approach [31]. In other words, typologies developed for one context may not apply to another. However, available typologies for various contexts can serve as reference tools when designing typologies for other contexts [35].

Research on the development of typologies in transit areas has been conducted quantitatively in many developed countries [31][35]. However, in developing countries such as Indonesia, particularly in Jakarta and its agglomeration areas, no such studies have been carried out. Some researchers have examined the relationship between built environment areas and travel behavior across various typologies [32]. This study contributes to filling this gap by developing an empirically grounded typology of commuter rail station areas based on key TOD indicators and analyzing their influence on passenger ridership. Methodologically, the study combines spatial clustering and multilevel regression modeling to uncover typology-specific determinants of trip generation. Theoretically, it advances TOD literature by bridging spatial form classification with behavioral transit modeling at the neighborhood scale. Practically, the findings provide a decision-support tool for urban planners and policymakers to design place-based TOD strategies that reflect the unique structural and functional attributes of each station area. Based on gaps in the literature, this study contributes

to the body of work on neighborhood typologies and their relationship with passengers in commuter train station areas from a TOD perspective. The development of traditional typologies expands the node-place-passenger model to address two main questions: How are typologies formed in commuter train station corridors using the two-step cluster method?

2 Method

This paper focuses on commuter train stations at the neighborhood scale. The study area is along the Jakarta Kota–Bogor commuter rail line (KRL), which includes 24 stations. This rail line connects the megapolitan city of Jakarta with the city of Bogor in Indonesia. Of the 24 stations, 16 are located in the Province of DKI Jakarta, while 8 are in the Province of West Java. Along this line, Manggarai Station serves as the central transit hub for passengers transferring to other routes. Jakarta Kota Station and Bogor Station act as the starting and ending points of commuter journeys.

2.1 Data analysis

The analysis in this study using qualitative method, to establish neighborhood typologies using cluster analysis, and second, to conceptually test the relationship between urban structure and KRL transit trip generation across typologies using multilevel regression. Cluster analysis facilitates direct identification of segments within neighborhoods that share similar TOD profiles [38]. Various techniques exist for cluster analysis, with recent studies often employing two-step clustering for several reasons. The two-step clustering method is a widely used tool for typology analysis in recent literature and is more efficient for continuous data [35]. This study uses two-step cluster analysis on TOD factors, including population density, building density, entropy, network density, sidewalk design width, and distance to the CBD, to determine possible TOD profiles at the neighborhood level in station areas along the Jakarta Kota–Bogor KRL line. All input variables in the two-step clustering method are assumed to be normal and independent. The main advantage of this method is its ability to automatically estimate the optimal number of clusters based on Akaike Information Criteria (AIC). Cluster validation is conducted in three ways. First, predictors of all input variables should approach 1, indicating that all input variables equally contribute to forming a cluster.

3 Result and discussion

DKI Jakarta is a megapolitan city with a population of 30 million, making it the second-largest city after Tokyo. Population density is concentrated in several urban areas, particularly around station zones. This study's urban structure representing TOD factors measures population density within an 800-meter buffer area from the central point of KRL stations. In addition to population density, the *Floor Area Ratio* (FAR), as a measure of building density based on its function, is closely linked to the success of TOD areas [39].

Land use diversity is measured using the entropy index. Land uses in this study are grouped into several types: residential, office and commercial, government, socio-cultural, industrial, and trade. Juanda Station has an entropy index of 0.8, nearing 1, indicating excellent mixed land use in the Juanda Station area. In contrast, Tebet Station shows a lower entropy index of 0.3, reflecting a buffer area dominated by office and commercial functions. The entropy factor is crucial as it indicates TOD levels at the neighborhood scale [24]. Diverse land uses and street connectivity around stations can foster positive behaviors, such as encouraging walking to destinations and facilities [40]. A prosperous TOD area at the neighborhood scale should be walkable for visitors and residents, reducing long-distance

travel and promoting active transportation, thereby alleviating congestion [41]. A well-connected street and pedestrian network offering multiple routes to the CBD or other areas' destinations can stimulate active travel, such as walking and cycling [42]. In this study, pedestrian pathways and street length are variables used to identify the urban structure dimensions of TOD at the neighborhood scale, highlighting its TOD potential. The Jakarta Kota-Bogor KRL corridor features various types of sidewalks. Stations located in urban areas, such as Jakarta Kota Station, Juanda Station, Cikini Station, and Gondangdia Station, already have pedestrian plazas leading to them, with sidewalk widths ranging from 5-7 meters and 3-4 meters. Continuous sidewalks connect stations along the corridor, such as between Gondangdia Station and Cikini Station and between Lenteng Agung Station and Universitas Pancasila Station. Figure 3 shows the transit ridership dataset for each station along the Jakarta Kota-Bogor KRL corridor. At Manggarai Station, a discrepancy is observed between inbound and outbound passenger numbers due to its role as a transit hub for other corridors. A similar phenomenon occurs at Depok Baru Station, where its location near a BRT terminal and city transport hub leads to different modal choices. Commuter trips are vital to daily travel within a megapolitan city. According to the Jabodetabek Commuter Survey 2019, 11% of the population commutes for various trips and activities. This is reflected in the passenger data at stations in Jakarta's satellite areas, such as Depok Station, Bogor Station, and Jakarta Kota Station, where inbound and outbound numbers are approximately equal. Cluster 3, named "potential suburban TOD," is characterized by moderate population density around the buffer area, low land-use diversity (diversity index of 0.55), an average sidewalk design of no more than 1.7 m², and station locations situated in Jakarta's suburban areas. The number of passengers boarding and alighting at these stations is consistent daily, reflecting suburban-to-urban commuting patterns. Previous research [43] shows that residents in traditional suburban areas have limited commuting options. This could lead to a complete transition to public transportation if pedestrian network environments are significantly improved.

4 Conclusion

This study demonstrates the gap by quantitatively developing neighborhood-scale typologies and analyzing their relationship with the number of passengers boarding and alighting at station areas. Three clusters were identified based on quantitative data for each TOD factor within the urban structure: Urban Mixed Core, Residential Transit, and Traditional Suburban. To better understand urban mass transit mobility patterns in potential TOD neighborhoods, this study finds that increasing FAR for other functions and residential functions can boost passenger trip generation in transit areas. This finding should be implemented to assist in developing Transit-Oriented Development (TOD) plans and to predict station passenger patterns using information about surrounding land use. Furthermore, applying the potential typology from this study can be integrated with models for estimating daily passenger numbers at the station level based on surrounding land use patterns [44]. This could promote TOD development in other station areas across Indonesia. For further research, studies could focus on other commuter rail station networks with broader land-use data, as well as mobility patterns and mode choice for accessing stations or reaching other destinations. Such assessments could provide valuable insights into the quality of the urban environment.

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