ASSESSING THE LEVEL OF TRANSIT-ORIENTED DEVELOPMENT (TOD) AT TRANS SEMARANG TRANSIT POINTS

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Abstract

Semarang, a major metropolitan city in Indonesia, faces significant transportation challenges, including severe traffic congestion and air pollution, driven by a high societal reliance on private vehicles. In response, the city has implemented the Trans Semarang Bus Rapid Transit (BRT) system and has officially committed to Transit-Oriented Development (TOD) in its planning documents. However, a critical gap exists between this policy ambition and practical implementation, primarily due to a lack of quantitative tools to assess the existing level of TOD at its transit points. This study addresses this gap by developing and applying a comprehensive TOD Index to objectively evaluate the performance of 27 transit points along the Trans Semarang network. The research utilized a GIS-based Spatial Multi-Criteria Analysis (SMCA) approach, initially drawing 13 indicators rooted in the 5Ds TOD framework. A rigorous data suitability analysis, involving Kaiser-Meyer-Olkin (KMO) and Bartlett's tests, refined the model to a final set of 10 statistically robust indicators. Indicators weights were determined objectively using Principal Component Analysis (PCA) to ensure the resulting scores reflected the inherent structure of the spatial data. The results reveal a distinct monocentric spatial pattern of TOD performance, characterized by a concentration of high-scoring transit points within the dense, historic urban core, while stations on the suburban fringe consistently exhibit low TOD scores. A critical finding of this study is the apparent statistical independence among key TOD dimensions: urban form (density, design) was found to be disconnected from land-use diversity and transit service quality. This highlights a fundamental lack of integration in the city's current land-use and transportation planning efforts. Ultimately, this research provides the Semarang City Government with a valuable, data-driven diagnostic tool to identify underperforming areas, prioritize strategic investments, and formulate evidence-based policies. The findings underscore the urgent need for a more integrated approach to planning to achieve the city's sustainable development goals.

Keywords: Transit-Oriented Development (TOD), Trans Semarang, Spatial-Multi Criteria Analysis (SMCA), TOD Index, Bus Rapid Transit (BRT).

INTRODUCTION

As one of Indonesia's largest metropolitan areas, Semarang City has a population of 1.708.833 (Statistics Indonesia, 2024) and grapples with significant transportation challenges. These issues primarily stem from a high societal reliance on private vehicles over public transit. This preference is quantified by the continuous growth in vehicle ownership, as illustrated in Figure 1-1. Between 2022 and 2024, the number of motorcycles, the dominant mode of private transport in Semarang, rose steadily from 1.512.234 to 1.608.877, while car ownership also increased from 281.971 to 283.191. This escalating volume of private vehicles places immense pressure on the urban infrastructure, leading to severe road congestion, inefficient mobility during peak hours, and heightened air pollution.

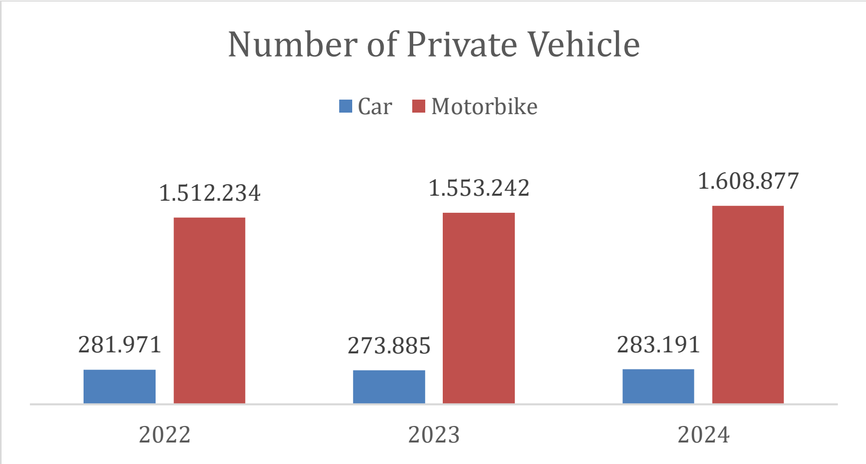

Figure 1. Private Vehicle Ownership in Semarang City, 2022-2024
Source: Semarang City Open Data Portal, 2024

In response, the Government of Semarang City launched the Bus Rapid Transit (BRT) system, Trans Semarang, in 2009. This system represents a strategic effort to provide an efficient and sustainable alternative to private vehicle. However, the success of such transit systems is not guaranteed by infrastructure alone, as it is deeply intertwined with the urban form surrounding it. Globally, Transit-Oriented Development (TOD) has emerged as a guiding principle for maximizing the effectiveness of public transport. According to the Institute of Transportation and Development Policy (ITDP), TOD aligns transportation systems with urban land use, to create dense, mixed-use, and walkable neighbourhoods around transit stations (ITDP, 2017). It aims to shift urban travel behaviour toward public transit by creating environments that are accessible, vibrant, and people centred. By integrating land use and transportation planning, TOD enhances transit efficiency while promoting inclusive and sustainable urban growth. A successful TOD strategy is expected to reduce private vehicle dependency, thereby curbing congestion and enhancing the efficiency of the public transportation system.

This global trend toward TOD is explicitly reflected in the official policy of Semarang City. The city's Regional-Medium Term Development Plan (RPJMD) for 2025-2029 commits to promoting sustainable transportation through TOD-guided spatial policies, including the development of BRT-based TOD and the integration or park-and-ride hub. Despite these clear policy ambitions, a significant gap exists between intent and implementation: there is currently a lack of quantitative tools to assess the existing TOD level at the station level. Therefore, this study directly addresses that gap by developing and applying Geographic Information System (GIS)-based TOD index tailored to the Trans Semarang network. By providing an empirical baseline, spatially detailed measure of TOD performance at the station level, this research support evidence-based planning and helps align urban development strategies with the city's long-term transportation and land use goals.

Research Objectives

The overarching aim of this study is to assess the level of Transit-Oriented Development (TOD) at Trans Semarang transit points and to provide evidence-based recommendations that support urban planning and policymaking in Semarang. To achieve this aim, the study sets out the following research objectives:

1. To develop a comprehensive TOD index framework that reflects the local urban, spatial, and transportation characteristics of Semarang.
2. To quantify and evaluate TOD levels at Trans Semarang transit points using a GIS-based Spatial Multi-Criteria Analysis (SMCA) approach.
3. To analyse spatial variations and patterns in TOD performance across the Trans Semarang network.
4. To formulate specific, evidence-based recommendations for improving the TOD characteristics within transit point catchment areas.

Significance of the Study

The significance of this study is twofold, offering both practical contributions to urban governance and academic contributions to the field of urban and transportation planning. On the practical side, this study provides the Semarang City Government and related planning agencies with a robust, data-driven diagnostic tool to assess the level of TOD in transit points. This tool can assist policymakers in identifying underperforming stations that require targeted interventions, prioritizing investments in infrastructure such as pedestrian walkways, mixed-use zoning incentives, and establishing a measurable baseline for evaluating the effectiveness of future policies and development efforts. Ultimately, the research supports the alignment of Semarang's urban development with long-term sustainability goals outlined in key planning documents such as the city's Regional-Medium Term Development Plan (RPJMD). Academically, this study contributes to the broader discourse on TOD in the context of Southeast Asian cities, where empirical TOD studies remain limited. It addresses a contextual gap by developing and applying a TOD index tailored to the urban morphology, transportation system, and challenges specific to an Indonesian city. Furthermore, the study offers a valuable case example of BRT system integration within a rapidly motorizing urban environment, providing lessons that may be relevant to other mid-sized cities in the region. Methodologically, the research advances the application of GIS-based Spatial Multi-Criteria Analysis (SMCA) in TOD evaluation, enriching the set of analytical tools available to scholars and planners working at the intersection of land use and transport systems.

METHOD

Research Framework

The analysis in study follows a structured and spatially driven workflow to measure the Transit-Oriented Development (TOD) Index of Trans Semarang transit points. The process is illustrated in Figure 1 and comprises several sequential stages involving data acquisition, processing, normalization, spatial multi-criteria analysis, and interpretation.

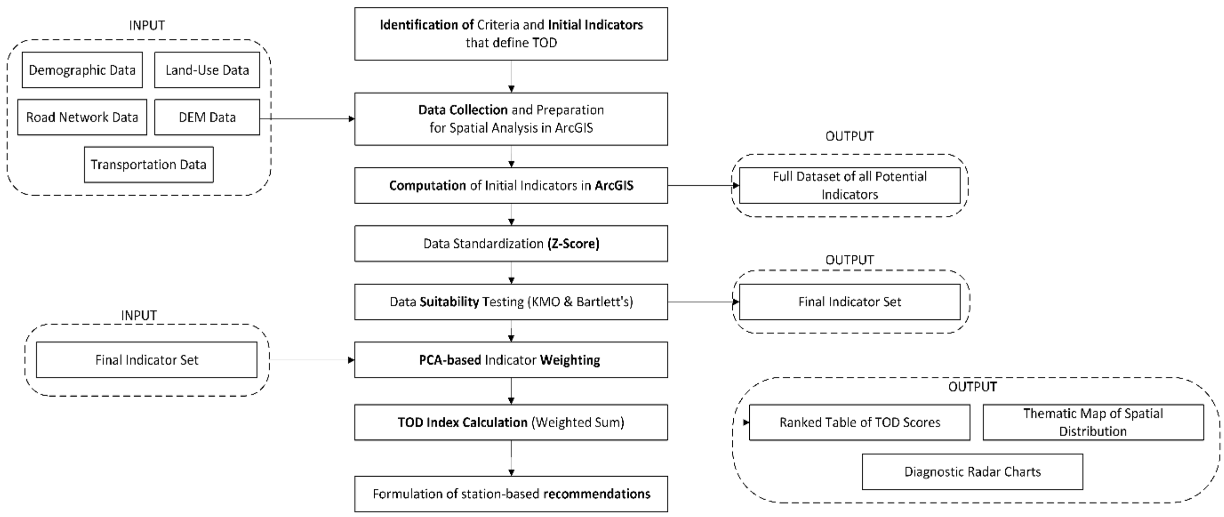

Figure 2. Research Framework

As outlined in this study's framework, the process begins with a literature review to identify relevant indicators that define TOD, based on widely accepted 5D framework: density, diversity, design, destination, accessibility, and distance to transit; as well as local contextual adaptations relevant to Semarang, such as slope or topography. These criteria are then translated into a set of measurable indicators. Following this, data collection and preparation is conducted using various geospatial and attribute datasets, including:

- Demographic data (population density)
- Land-use data (to assess land-use diversity and mixed-use patterns)
- Road network data (for walkability and connectivity)
- Transportation data (frequency, route, the type of transit stops)
- Digital Elevation Model (for slope analysis)

Study Area

The study focuses on the Trans Semarang Bus Rapid Transit (BRT) system, which serves as the backbone of public transport in Semarang City, Central Java Province, Indonesia. The system began operations in 2009 and consists of multiple corridors connecting key urban zones across coastal, central, and highland regions of the city. The Trans Semarang operates on using 3 distinct types of buses: large buses (with a passenger capacity of 30 seats and 50 handgrips); medium buses (with a passenger capacity of 21 seats and 20 handgrips); and micro-sized buses with a passenger capacity of 20 seats. At present, there are a total of 137 operational fleets of large and medium buses and 20 operational fleets of micro-sized buses. Furthermore, in 2019, the Semarang City Government commenced the operation of feeder routes, to enhance the coverage of public transportation services. Presently, there are a total of 8 operational corridors for Trans Semarang, which are:

1. Corridor 1: Mangkang - Penggaron
2. Corridor 2: Terboyo – Ungaran
3. Corridor 3A: Pelabuhan – Kagok
4. Corridor 3B: Pelabuhan - Elisabeth
5. Corridor 4: Tantular – Cangkiran
6. Corridor 5: PRPP - Meteseh
7. Corridor 6: Undip - Unnes
8. Corridor 7: Genuk – Pengapon
9. Corridor 8: Simpang Lima – Cangkiran

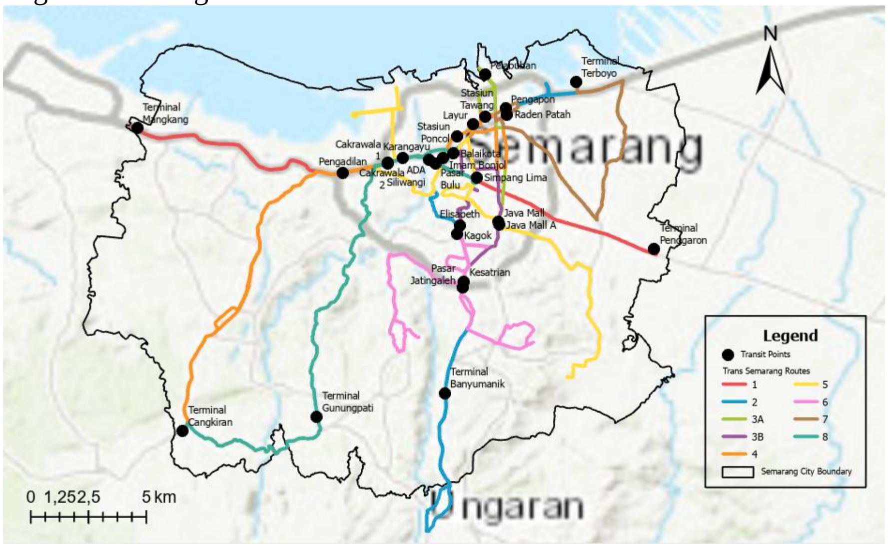

Figure 3. Map of Trans Semarang Routes

Trans Semarang operates through two types of bus stops: transit points, where passengers can transfer routes without buying a new ticket, and non-transit points, where route changes require a new ticket. The study focuses on station catchment areas using an 800-meter pedestrian buffer around 27 transit points across 8 corridors, representing diverse urban settings. Several routes integrate with other transportation modes, including Trans Jateng, buses, trains, airplanes, and ships. Feeder services also support mobility in areas difficult for large buses to access, with a new feeder system introduced in 2020. Semarang's varied topography—coastal lowlands and steep highlands—affects pedestrian accessibility and is incorporated into TOD evaluation through slope analysis.

Data Processing Techniques

To assess the Transit-Oriented Development level at each Trans Semarang transit point, a composite TOD index was constructed by integrating multiple indicators under the GIS-based Spatial Multi-Criteria Analysis (SMCA) approach. SMCA is a decision-support tool that integrates multiple spatial indicators to evaluate complex geographic phenomena. In the context of this research, GIS-SMCA is used to combine spatial and non-spatial indicators into a single composite index that reflects the TOD level around each Trans Semarang transit point. To standardize the unit of analysis, all indicators are calculated within an 800-meter buffer zone around each Trans Semarang transit points, representing a walkable catchment area. The indicators represent core TOD dimensions, including density, diversity, design, accessibility, and transit service. Each indicator value was normalized and weighted to reflects its relative importance in influencing TOD potential, allowing for a holistic and comparable evaluation across locations. Spatial computations are carried out in ArcGIS Pro, using tools, such as Buffer, Intersect, Dissolve, Zonal Statistics.

Weighting Method
Data Standardization

Once the indicators are calculated, they must be rescaled to a common scale before being aggregated, due to its different units and value ranges. In this study, Z-score standardization is applied, prior to Principal Component Analysis (PCA) weighting to ensure comparability across variables. This method converts each indicator to have mean of 0 and a standard deviation of 1 using the formula:

$$x' = \frac{x - \mu}{\sigma}$$

Where:
x = the original value
μ = the mean of the indicator
σ = the standard deviation of the indicator
x’ = the standardized value (Z-score)

This approach ensures that all indicators contribute equally in terms of variance, without being biased by differences in measurement units or scale. Standardization is particularly important for PCA, as it is sensitive to the relative variances of the input variables. With Z-score standardization, each indicator is centred and scaled, allowing PCA to objectively determine component weights based on structure rather than magnitude.

Principal Component Analysis (PCA)-Based Weighting

Subsequently, a weighting scheme is applied to reflect the relative importance of each indicator. In this study, Principal Component Analysis (PCA)-based weighting is used to assign weight. This step reflects the relative importance of each indicator in contributing to TOD. PCA is a dimensionality reduction technique that transforms a set of possibly correlated indicators into a similar set of uncorrelated components (called principal components). These components capture the maximum variance in the data, reduces the dimensionality of the data by identifying principal components, combinations of indicators that explain the most variance in dataset. The next step in PCA, extracts the loading scores of each indicator on the dominant components. Then, calculate indicator weights based on the normalized eigenvector contributions of the components. These weights reflect the statistical significance of each indicator in shaping TOD performance and are applied to guide the overlay process.

TOD Index Calculation

Once normalized and weighted, the indicators are integrated into a single TOD index using a formula:

$$TOD\ Index_i = \sum_{j=1}^{n} w_j \,.\, x_{ij}$$

Where:
$TOD\ Index_i$ = TOD score for transit point i,
w_j = the weight of indicator j (from PCA),
x_{ij} = the normalized value of indicator j for transit point i,
n = the total number of indicators

The result is a composite TOD score for each transit point, representing the overall transit-oriented performance within its 800-meter catchment area.

RESULTS AND DISCUSSION

This chapter shows the findings from a data analysis undertaken to assess the Transit-Oriented Development (TOD) performance of 27 Trans Semarang transit stops. It starts by describing how to test data appropriateness and choose indicators. This is followed by a descriptive analysis of the final indicators, PCA weighting findings, and final TOD index scores. Finally, the chapter analyses how these findings were interpreted and offers specific, station-level recommendations to help with urban design in the city.

Data Suitability and Final Indicator Selection

The TOD index begins with a collection of 13 theoretically developed indicators. A number of data appropriateness tests were carried out to confirm the statistical validity of weighting with a Principal Component

Analysis (PCA). An initial study of all 13 indicators yielded a mediocre Kaiser-Meyer-Olkin (KMO) score of 0.60. The KMO test examines sampling adequacy, and while 0.60 is a common minimum threshold, some independent indicators had low MSA values, indicating that they did not share enough common variance to be combined into a single coherent factor. To develop a more robust and dependable index, indicators with low individual MSA values were gradually removed. After successively deleting three indicators (Transit Point Type, Land Use Mixedness, and Walkability Score), the final 10-indicator dataset had a Kaiser-Meyer-Olkin (KMO) rating of 0.74, indicating "good" sampling adequacy.

Bartlett's Test of Sphericity revealed statistical significance for the final 10-indicator set ($\chi^2 = 307.25$, $p < 0.001$). This refutes the null hypothesis that the variables are uncorrelated. These results demonstrated that the final 10-indicator dataset was appropriate for Principal Component Analysis. The remainder of this chapter concentrates on the analysis of these ten chosen indicators.

Descriptive Statistics of Final TOD Indicators

Table 1 presents a summary of the descriptive statistics for the ten indicators utilized in the final model. This offers a fundamental comprehension of the baseline urban attributes across the 27 transit points in the study area.

Table 1. Descriptive Statistics of Final TOD Indicators

No	TOD Indicator	Min	Max	Mean	Std. Dev.
1	Population Density	905.424	14182.608	8508.815	3869.470
2	Commercial Density	0.001	0.428	0.240	0.125
3	Land Use Diversity	0.173	0.850	0.631	0.143
4	Total Walkable Path Length	7664.469	57838.767	35427.551	14770.246
5	Intersection Density	12.458	229.818	123.513	59.396
6	Walkability Density	3.978	28.771	18.025	6.810
7	IPCA Ratio	0.234	0.773	0.569	0.146
8	Interchange to Different Routes	1	7	3.111	1.672
9	Interchange to Other Modes	0	3	1.148	0.818
10	Frequency of Service	3	28	13.370	6.806

The analysis, as presented in Table 1, indicates substantial variance in urban form features among the 27 transit sites. Population density, varies significantly from a minimum of 905.4 to a maximum of 14,182.6 persons/square kilometre, accompanied by a substantial standard deviation of 3869.5, indicating considerable discrepancy between densely populated urban centres and sparsely populated suburban areas. Intersection Density ranges from 12.5 to 229.8 intersection/square kilometre, signifying that certain regions possess a densely interconnected street grid, whereas others feature extensive, unwalkable blocks.

PCA-Based Weighting

Prior to conducting the weighting analysis, all ten selected indicators were standardized using the Z-score method to ensure equal variance and prevent scale-related bias in the principal component analysis. The PCA results demonstrated a strong underlying structure, with the first principal component (PC1) accounting for 57.42% of the total variance. This dominant component represents the shared dimensions across all TOD indicators and serves as the basis for deriving the objective weights.

Table 2. Loadings on the First Principal Component (PC1)

TOD Indicator	PC1
Population Density	-0.35566
Commercial Density	-0.31045
Land Use Diversity	-0.13625
Total Walkable Path Length	-0.39816
Intersection Density	-0.37743
Walkability Density	-0.39248
IPCA Ratio	-0.28445
Interchange to Different Routes	-0.27458
Interchange to Other Modes	0.279099
Frequency of Service	-0.26332

Table 2 presents the loading values of each indicator on PC1. These loadings indicate both the strength and direction of each variable's contribution to the principal component. Indicators with larger loading magnitudes regardless of the sign, exert greater influence on the shared TOD dimension. In this study, walkability-related indicators, including Total Walkable Path Length, Walkability Density, and Intersection Density, exhibited the highest loading magnitudes, highlighting the importance of pedestrian network characteristics in shaping TOD performance areas across Trans Semarang transit points.

Table 3. Final Indicator Weights

TOD Indicator	Weight
Population Density	0.11578
Commercial Density	0.10106
Land Use Diversity	0.04435
Total Walkable Path Length	0.12962
Intersection Density	0.12287
Walkability Density	0.12777
IPCA Ratio	0.092599
Interchange to Different Routes	0.08939
Interchange to Other Modes	0.09086
Frequency of Service	0.08572

To generate the final indicator weights used in the TOD Index calculation, the absolute values of the loadings were normalized so that the weights sum to one. The resulting weights are shown in Table IV.3. Consistent with the loadings, walkability-based indicators emerged as the most influential components of the TOD Index: Walkability Density (0.12777), Intersection Density (0.12287), and Total Walkable Path Length (0.12962) ranked highest. These result underscore the critical role of pedestrian accessibility and network connectivity in the overall TOD assessment. Overall, the PCA-based weighting confirms that TOD performance in the Semarang context is driven most strongly by spatial design attributes, aligning with global TOD principles that emphasize compact, accessible, and pedestrian-oriented environment.

Final TOD Index Scores

The final TOD index scores for all 27 transit points were calculated using the weighted indicators derived from the PCA procedure. Table IV.4 presents the transit points in descending order based on their overall TOD performance. The resulting index values range from 0.758684 at the highest-performing transit point to -1.344238 at the lowest. Because the index is constructed from standardized variables, the values represent relative TOD performance rather than absolute benchmarks. Positive scores indicate that a transit point performs above the study-wide average in terms of TOD characteristics, while negative scores reflect below-average conditions.

Table 4. Ranking of Transit Points Based on TOD Index Score

Rank	Transit_ID	TOD Index
1	Karangayu	0.758684
2	Balaikota	0.706740
3	Layur	0.704328
4	Raden Patah	0.555602
5	Simpang Lima	0.502163
6	Java Mall	0.494843
7	Imam Bonjol	0.494011
8	Java Mall A	0.489159
9	Cakrawala 1	0.425341
10	ADA Siliwangi	0.416949
11	Stasiun Poncol	0.362324
12	Stasiun Tawang	0.349894
13	Pengapon	0.339385
14	Cakrawala 2	0.329294
15	Pasar Bulu	0.302349
16	Kagok	0.060010
17	Elisabeth	0.026486
18	Terminal Banyumanik	-0.032067
19	Kesatrian	-0.092252
20	Pasar Jatingaleh	-0.117386
21	Pengadilan	-0.240573
22	Terminal Mangkang	-0.927073
23	Terminal Penggaron	-1.098658
24	Terminal Gunungpati	-1.102704
25	Terminal Cangkiran	-1.179514
26	Pelabuhan	-1.183095
27	Terminal Terboyo	-1.344238

The ranking shows a clear differentiation in TOD performance across the Trans Semarang network. Several centrally located transit points including Karangayu, Balai Kota, Layur, and Raden Patah, achieved the highest scores, reflecting their strong land-use diversity, pedestrian network connectivity, and accessibility to multiple routes. Conversely, transit points located in peripheral or topographically constrained areas, including Terminal Terboyo, Pelabuhan, Terminal Cangkiran, and Terminal Gunungpati, exhibited negative index values, indicating weaker TOD-supportive environments. Overall, the distribution of TOD Index scores underscores significant spatial disparities in TOD readiness across the network. High-performing locations exhibit strong walkability and multimodal accessibility, while lower-performing sites correspond to areas with limited pedestrian infrastructure, greater slope constraints, or lower land-use intensity. These results provide a quantitative basis for identifying priority locations where targeted interventions most needed to enhance TOD outcomes.

Spatial Distribution and Discussion

This section visualizes the results, interprets their meaning, and translates them into actionable recommendations for urban planners and policymakers in Semarang. The spatial distribution of the TOD Index score is visualized in Figure 4.

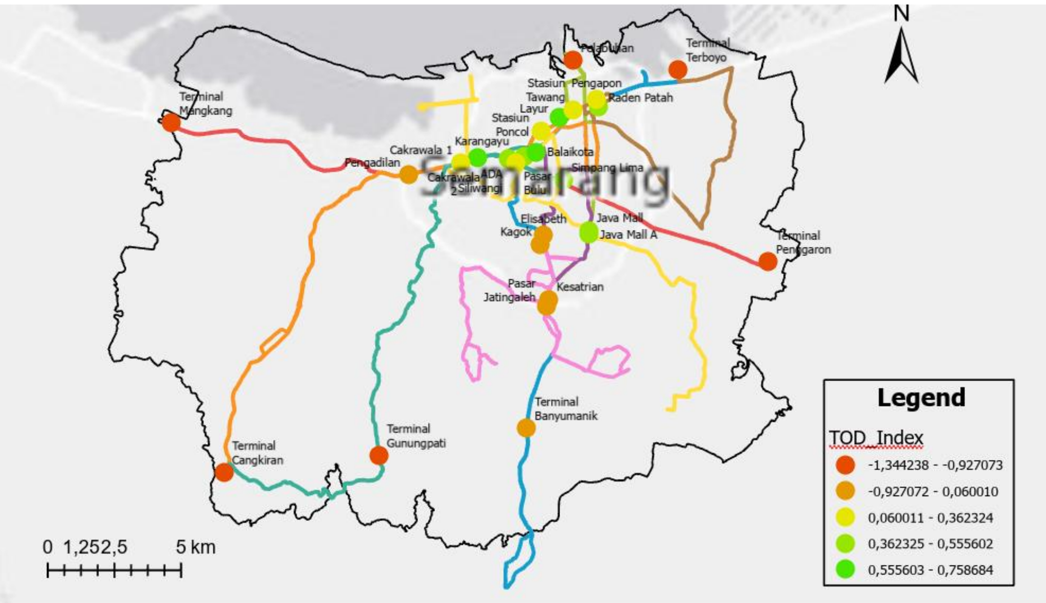

Figure 4. Spatial Distribution of TOD Index Scores Across Trans Semarang Transit Points

As visualized in figure 4.1, a distinct spatial pattern emerges from the analysis. There is a clear-concentration of high-performing transit points (shown in green) within the central urban core of Semarang. In contrast, the lowest-performing transit points (shown in red) are predominantly located on the urban fringe and in suburban corridors, suggesting a strong monocentric pattern of TOD characteristic in the city. This trend aligns with Semarang's historical evolution. The urban centre, mostly established prior to the extensive use of automobiles, inherently displays attributes of effective Transit-Oriented Development (TOD). An examination of the indicator data substantiates this: transit hubs in the city centre, such as *Java Mall*, have some of the highest metrics for Population Density and Intersection Density. In contrast, the regions on the metropolitan periphery were probably created more recently with an emphasis on automobile-centric transportation, resulting in reduced population densities and fewer interconnected street networks, as evidenced by the low ratings of stations such as *Pelabuhan*. A comparison between the highest- and lowest-scoring stations effectively illustrates this disparity. The highest-performing station, *Karangayu*, is situated in the urban centre and demonstrates elevated values for critical metrics such as Population Density and Intersection Density. Conversely, the lowest-performing station, *Terminal Terboyo*, is marked by minimal density and inadequate street connectivity, culminating in the lowest score within the network and underscoring its reliance on automobiles.

A Key Finding: The Independence of TOD Dimensions

A significant discovery of this study arose during the data appropriateness assessment. Three theoretically indicators: Transit Type, Land Use Mixedness, and Walkability Score were eliminated from the final index because of their weak statistical link with the primary set of urban form variables. This represents not a methodological failure, but a substantial empirical discovery regarding the characteristics of urban development in Semarang. It indicates that the various dimensions of TOD are inadequately integrated. The absence of Land Use Mixedness suggests that densely populated places may lack a diverse integration of residential, commercial, and other functionalities. This indicates possible zoning problems that result in densely populated yet singularly functional districts. The omission of Transit Type indicates that the quality of station infrastructure and amenities may not correspond with the Transit-Oriented Development potential of the adjacent area. The removal of the slope-based Walkability Score indicates that development patterns have insufficiently addressed the city's distinctive terrain. This disconnection constitutes a significant obstacle to realizing the city's Transit-Oriented Development objectives outlined in the Regional-Medium Term Development Plan (RPJMD), indicating that merely augmenting density will not inherently foster the diversified, walkable, and well-serviced settings characteristic of successful TOD.

Station-Based Recommendations for TOD Improvement

The TOD index and its constituent indicators provide a diagnostic tool to formulate targeted recommendations for underperforming transit points. By analysing the specific indicator values for low-scoring stations, tailored interventions can be proposed.

Regarding *Terminal Terboyo* (Lowest TOD Score):

Analysis: This station obtained the lowest TOD index score within the network. An examination of its standardized indicator data indicates that it operates below the network average on nine out of 10 metrics. Its sole advantage is a high rating for Interchange to Other Modes, which is rational considering its role as a principal hub for intercity and interprovincial transportation. Nonetheless, its principal shortcomings are an exceedingly low IPCA Ratio and a markedly low Population Density. This profile exemplifies a sizable, secluded, automobile-centric terminal that operates primarily as a transfer point rather than an integral component of a pedestrian-friendly city.

Recommendation: A dual-faceted approach is necessary. To rectify the inadequate IPCA Ratio, the planning department must perform a pedestrian network analysis to identify and eliminate physical impediments that restrict walk-in access to the terminal. Secondly, to mitigate low density, enduring zoning regulations ought to focus on redeveloping the unused area adjacent to the terminal, such as expansive parking lots, into denser, transit-oriented residential and commercial developments.

Regarding *Pelabuhan* (Second Lowest Score):

Analysis: The Pelabuhan transit stop demonstrates the second-lowest Transit-Oriented Development performance within the network, as all 10 indicators fall below the network average. This is rational considering its position within a designated port zone, primarily characterized by transportation and industrial activities. The primary deficiencies include an exceedingly low Land Use Diversity score and an almost negligible Commercial Density. The region exemplifies monofunctional, non-residential land use that fundamentally contradicts the main concepts of Transit-Oriented Development (TOD).

Recommendation: Although converting a port into a complete Transit-Oriented Development (TOD) is impractical, some interventions can enhance circumstances for employees and visitors. The city may consider implementing laws to permit small-scale, ancillary commercial activities within the port area, including canteens, convenience stores, or small shops, to enhance Commercial Density and deliver necessary services. Moreover, enhancing pedestrian infrastructure to establish secure and direct walking routes from the transit stop to essential job hubs within the port is a vital initial measure.

Regarding *Terminal Cangkiran* (Third Lowest Score):

Analysis: Terminal Cangkiran's low TOD score is rational, underscoring a distinct planning issue as a vital suburban feeder terminal. All 10 indicators have negative Z-scores, indicating its position in a low-density, automobile-reliant region. The primary deficiencies are markedly low ratings for Walkability Density and Total Walkable Path Length. This signifies a sparse street network with minimal pedestrian facilities, characteristic of a suburban centre where the majority of people access it through feeder services or private vehicles rather than on foot.
Recommendation: The objective for a station such as Terminal Cangkiran is not to duplicate the urban core, but to enhance its role as an effective suburban interchange. Recommendations should concentrate on enhancing last mile connection. The city must prioritize investments in establishing secure, direct, and protected pedestrian routes within the terminal complex, linking the feeder bus bays and park-and-ride facilities to the main Trans Semarang platform. Enhancing the fundamental sidewalk infrastructure on the principal thoroughfares next to the terminal would rectify its core deficiencies and bolster safety for the limited number of local pedestrians.

CONCLUSION

This concluding chapter integrates the entire research effort, encapsulating the principal findings and examining their wider implications for urban planning in Semarang. It finishes by recognizing the study limitations and proposing options for future exploration in Transit-Oriented Development.

Summary of Findings

This study was initiated to tackle the substantial transportation issues confronting Semarang, a prominent Indonesian city struggling with traffic congestion due to a considerable dependence on private vehicles. The principal objective of this research was to create and implement a quantitative instrument, a Transit-Oriented Development (TOD) Index, to objectively assess the level of TOD at 27 transit locations within the Trans Semarang Bus Rapid Transit (BRT) network.

This research utilized a GIS-SMCA based approach, beginning with 13 theoretically derived indicators grounded in the 5D TOD framework. A comprehensive data suitability analysis, employing the Kaiser-Meyer-Olkin (KMO) and Bartlett's tests, resulted in the refining of the initial set to a final, statistically robust model comprising 10 indicators. The weights for this index were objectively determined by Principal Component Analysis (PCA) to guarantee that the final scores accurately represented the data's inherent structure. The study's principal conclusions are dual in nature. The analysis indicated a pronounced monocentric pattern of Transit-Oriented Development (TOD) performance, characterized by a distinct concentration of high-scoring, well-integrated transit nodes within the historic urban core. In contrast, stations located on the urban periphery and along suburban corridors demonstrated markedly lower TOD scores, underscoring a pronounced discrepancy in urban morphology throughout the city. Secondly, and potentially more importantly, the study revealed a statistical independence between the fundamental features of urban form (density, street design) and other essential elements of Transit-Oriented Development (TOD) such as land-use diversification and transit service quality. This indicates a substantial disjunction in Semarang's planning and development, wherein the many elements of effective Transit-Oriented Development are not being harmonized.

Policy Implications and Recommendations

The results of this research present multiple clear policy implications for the Semarang City Government and its planning bodies, especially concerning the objectives specified in the Regional Medium-Term Development Plan (RPJMD). The TOD index functions as a diagnostic instrument that can facilitate more precise and efficient urban planning. The primary proposal is for a targeted, region-specific policy strategy. Policy Area 1: Safeguard and Augment the Urban Core. The efficient transit hubs in the city core constitutes a significant benefit. Policy should prioritize the preservation of these neighbourhoods against automobile-centric redevelopment while significantly augmenting their pedestrian-friendly attributes. This entails upholding zoning that facilitates density and investing in the enhancement of public places. Policy Area 2: Revitalize Inefficient Suburban Corridors. A uniform strategy is inadequate for low-performing stations on the urban periphery, such as *Terminal Terboyo* and *Terminal Cangkiran*. Chapter 4's station-based analysis offers a framework for customized solutions. This includes specific zoning modifications to enhance population density, public works initiatives to improve street connection, and investments in last-mile infrastructure such as secure pedestrian walkways to more effectively integrate these hubs into their adjacent towns. Policy Area 3: Require the Integration of Transit-Oriented Development Dimensions. The study's conclusion that urban form, land use, and transit service are disjointed is a significant alert. Future planning strategy must expressly require their integration. Any request for up-zoning to enhance density near a transportation station must contain stipulations for mixed-use development and superior pedestrian linkages. This inhibits the development of dense, monofunctional, and unwalkable neighbourhoods.

Limitations of the Study

Recognizing the limitations of this research is crucial for contextualizing the findings.

1. Quantitative Scope: The established index serves as a quantitative instrument grounded in quantifiable spatial data. It fails to encompass significant qualitative dimensions of the urban environment, like the perceived safety of nighttime pedestrian zones, convenience of using Trans Semarang for people with disabilities, all of which impact a resident's travel decisions.
2. Static Analysis: This research offers a cross-sectional capture of Transit-Oriented Development circumstances at a certain moment in time. It fails to encapsulate the dynamic essence of urban growth, thus rendering it incapable of evaluating whether conditions surrounding specific stations are enhancing or deteriorating over time.
3. Data Constraint: The analysis relied on the accessibility of official government data. This data may inadequately represent informal economic activities, or complex land uses common in numerous Indonesian towns. Moreover, the omission of the slope-based walkability score, although statistically requisite, results in the final index failing to comprehensively address Semarang's distinctive topographical challenges.

Suggestions for Future Research

This study's findings and limitations suggest multiple possibilities for future research that could enhance the comprehension of TOD in Semarang.

1. Qualitative Case Study: Future study may enhance this quantitative index through the execution of comprehensive qualitative case studies. This may entail conducting on-site observations and interviews with residents and

commuters at both high and low-scoring stations to comprehend the lived experiences and perspectives that the index fails to capture.
2. Longitudinal Analysis: A longitudinal analysis is advised to mitigate the static characteristics of this investigation. By recalibrating the TOD index at regular intervals (e.g., every five years), researchers might monitor the effects of specific planning measures and furnish critical input to policymakers regarding the efficacy of their policies.
3. Establishing a Multi-Dimensional Framework: This research demonstrated the autonomy of several TOD dimensions. Future endeavours may focus on creating a more intricate evaluation framework that evaluates each feature (e.g., Urban Form, Land Use Mix, Transit Service Quality) independently, offering a multi-dimensional report for each station rather than consolidating them into a singular score. This would provide a more thorough diagnostic tool for planners.

Concluding Remarks

This thesis has illustrated the significance of a data-driven methodology for comprehending and assessing the principles of Transit-Oriented Development within the context of Semarang. This research has established a comprehensive TOD index that quantifies spatial inequality in the city's urban structure and reveals a significant disjunction among the many aspects of effective TOD. The results furnish a definitive and evidence-based resource for planners and policymakers, presenting a strategy for enhanced integration in planning and, ultimately, a more sustainable and accessible urban future for the inhabitants of Semarang.

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