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MAPPING DENSITY TO REVEAL THE TOD POTENTIAL ON KA KRL AND KA BIAS RAIL CORRIDORS OF SOLO RAYA

Jufri Arif Widayat[1*], Agung Budi Sardjono[1]
[1]Architecture, Universitas Diponogoro, Jl. Prof. Soedarto, Tembalang, Kec. Tembalang, Kota Semarang, Jawa Tengah, Indonesia
*Email correspondence: jufriarifwidayat@students.undip.ac.id

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ABSTRACT

Spatial planning is greatly aided by the presence of the Adi Soemarmo Airport Train Link (KA BIAS) and the Electric Multiple Unit (KRL) commuter train that connects Solo and Yogyakarta as part of the mass transit system. Both KRL and KA BIAS have seen yearly increases in passenger numbers. The idea behind Transit Oriented Development (TOD) is to combine spatial organization with transportation infrastructures. Important nodes is the transportation network are the Solo Yogyakarta KRL stations that cross the KA BIAS route, such as Solo Balapan Station, Solo Jebres Station, an Palur Station. As stated in the Surakarta City Spatial Plan (RTRW), which clearly designates Solo Balapan ond Solo Jebres Station, as Transit Oriented Development zone, the purpose of this study is to evaluate the degree of TOD development compatibility across the Solo Yogyakarta KRL and KA BIAS stations. The variables for this study were indentified and determined using a quantitative method with a comparison approach based on pertinent previous studies. The TOD implementation at Solo Balapan. Solo Jebres, and Palur Stations served by both KRL and KA BIAS is the main subject of the analysis. The result show that optimal variable values across variety, density, design, and transit characteristics dominate TOD implementation at Solo Balapan Station, indicating substantial potential for Transit Oriented Area Development. Jebres Station is notable mainly in density and transit, but Palur Station scores higher in diversity and transit. Overall, the three case studies show clear distinctions that align with the Spatial Plan's goals for Transit Oriented Area Development.

Keywords: Station, Transit Oriented Development, Transportation

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INTRODUCTION

As a developing nation, Indonesia still faces a number of difficulties when it comes to managing and growing its cities. The fast rate of urbanization in large cities, which has raised the need for urban space, is one of the main issues. There are two primary factors that affect this phenomenon: push factors, which come from rural areas because of limited employment opportunities and inadequate public facilities and utilities, also pull factors, which refer to the appeal of urban areas offering greater employment opportunities and more adequate public facilities and utilities (Wijanarko, 2020). The issue urban sprawl has long been a concern for urban. To address this challenge, Peter Calthor developed the concept of Transit Oriented Development (TOD). This concept emphasizes the development of areas with a mix of land uses, relatively high density, and pedestrian friendly environments integrated with train stations or bus stops (Calthorpe, 1993). Through this approach, TOD aims to revitalize areas while simultaneously encouraging the creation of a new, healthier, comfortable, and safer lifestyle.

Density is not always a negative thing (Ayuningtias & Karmilah, 2019); on the contrary, if managed properly, density can create a more active, dynamic, and vibrant urban life. However, if not managed appropriately, density can turn into crowding a condition where people feel cramped, stressed, or uncomfortable due to overly limited space (Stokols, 1972). As the population continues to increase, the mobility of residents also rises and both within Solo Raya and between Solo Raya and other areas because to potentially leading to a higher number of private vehicle users. However, this high volume of movement has not yet been fully supported by adequate facilities and infrastructure. This condition is evident in the suboptimal utilization of train stations and their surrounding areas, even though these areas have the potential to be developed through the TOD concept.

Based on information provided by the President Director of KAI, Purnomo Sidi, the Solo Jogja Commuter Line (KRL) has made a highly significant contribution to increasing community mobility along the commuter corridor. Data indicates that in the first semester of 2024, passenger volume reached 4.7 million passengers. This figure rose to 5.2 million passengers in the first semester of 2025, representing a growth of 6.4%. According to the Vice President of Corporate Communications at KAI, Anne Purba, the number of KA BIAS riders increased from 300,271 passengers in the previous period to 375,032 passengers, reflecting a growth rate of 24.9%. The Solo Jogja KRL and KA BIAS passenger numbers have increased, indicating a growing public demand for public transportation services. This circumstance emphasizes even more how crucial it is to have public transportation systems that are adaptable reasonably priced, well maintained, and widely accessible. Therefore, urban development around transit hubs that promotes accessibility, connectivity, and integration between public transportation and urban activities must coincide with this increase in public transportation utilization. Solo Balapan Station and Solo Jebres Station have previously been recognized as Transit Oriented Development (TOD) stations in the Surakarta Spatial Plan (RTRW).

The application of sustainable development planning can address a number of urban transportation issues, especially when transportation systems can address a number of urban transportation issues, especially when transportation systems and spatial planning

are fully integrated. The goal of this strategy is to establish a pattern of regional development that can effectively and efficiently promote community mobility. Transit Oriented Development (TOD), a development model based on public transportation systems and intended to promote the creation of urban environments that are more connected, sustainable, and focused on community mobility, is one planning concept that permits such integration (Widodo, 2023). In an attempt to lessen reliance on private vehicles, the Transit Oriented Development (TOD) concept places a strong emphasis on maximizing the use of public transportation.

Through this strategy, negative environmental impacts such as traffic congestion, high energy consumption, and increased emissions can be minimized, thereby reflecting the application of a more environmentally conscious and sustainable urban development concept (Tanuwidjaja, 2023).

This study aims to identify the factors influencing the implementation of the Transit Oriented Development (TOD) concept at stations that serve as meeting points for the Solo Jogja Commuter Line (KRL) and KA BIAS corridors specifically Solo Balapan Station, Solo Jebres Station, and Palur Station. This research was conducted to determine the extent to which the urban characteristics around these three stations comply with TOD principles. Based on previous studies, further evaluation of transit area suitability is needed because different researchers have utilized varying variables and indicators, resulting in a lack of a comprehensive approach that integrates these diverse variables to assess TOD concept suitability. Raditya, 2022 identified the implementation of the TOD concept based on several aspects, including infrastructure completeness (pedestrian facilities, cycling facilities, public spaces, short route distances, and parking availability), diversity (open spaces and facility completeness), and density (indicated by relatively high-density levels). Meanwhile, Jati, 2017 evaluated TOD suitability based on variables such as density, mixed land use, walking and cycling facilities, interconnection, parking, and open spaces. A different approach was proposed by (Arrifa'i, 2024), who used a spatial approach to identify TOD suitability by considering geographical aspects, vegetation, road accessibility, residential area density, and area density. Furthermore, (Widodo, 2023) utilized TOD principles that include walking, cycling, pedestrian connectivity, integration with public transit, land use diversity, density, area compactness, and modal shift / accessibility. Based on these studies, a research gap exists in the form of differences in the selection and grouping of variables and indicators used to measure TOD suitability. These disparities indicate that there is not yet a standardized set of variables capable of comprehensively assessing transit area characteristics, particularly for stations acting as interchange points between the KRL and KA BIAS corridors. Therefore, this study seeks to integrate variables and indicators from prior research to develop a more comprehensive evaluation framework for identifying TOD concept suitability at Solo Balapan Station, Solo Jebres Station, and Palur Station.

TOD Area Structure

In the stages of area using the Transit Oriented Development (TOD) concept, it is necessary to carry out proper identification regarding the boundary between TOD and non-

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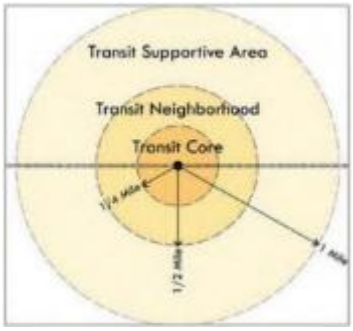

Figure 1. Delineation of Areas within the Transit Oriented Development (TOD) Zone
(Source : Pelham, 2021)

TOD areas in order to prevent uncontrolled area expansion (sprawl). According to (Cervero, 2004), TOD areas are divided into four zones, are described as follows:

a. Premium transit station: a transit point that serves high-quality mass transportation modes such as commuter trains, light rail, and bus rapid transit.
b. Transit core: the core area within a radius of approximately 400 meters from the main transit point, covering an area of about 50 hectares.
c. Transit neighborhood: the area surrounding the transit core, within a radius of approximately 500 meters from the main transit point, covering an area of about 151 hectares.
d. Transit supportive area: the supporting area within a radius of approximately one mile (1,600 meters) from the main transit point.

(Pelham, 2021) further states that the TOD Station Area includes the transit core and the transit neighborhood. The following image 1 illustrates the division of areas in TOD based planning.

In Indonesia, Transit Oriented Development (TOD) is known as Kawasan Berorientasi Transit (KBT), which refers to areas designed as integration centers for intermodal connectivity and mode transfers within a radius of approximately 400 to 800 meters from the main transportation node. The implementation of this concept aims to reduce the community's dependence on motor vehicles, particularly private vehicles, by encouraging the use of public transportation and nonmotorized modes of transport. Additionally, KBT is expected to quality through emission reductions and better air quality, while also creating urban areas that are more interactive, easily accessible, and pedestrian oriented (Sanusi, 2023).

Density

Generally, density can be understood as the number of entities (population, buildings, or activities) within a given area. However, according to (Stokols, 1972), density should be seen as a complex assemblage of morphological, social, economic, and perceptual aspects. This means that two areas with the same density value can produce different spatial experiences, depending on how the relationships between the elements within them are arranged. Differentiating between sensory and physical density is crucial. These two factors need to be harmonized in architectural design so that a crowded space promotes social interaction and esthetic comfort rather than seeming oppressive. Density in Indonesia

grows naturally through social and economic dynamics rather than being planned methodically like in developed nations. This phenomenon is evident in TOD districts surrounding stations, where housing, commercial spaces, and station space combine to form a single, dense, dynamic, and functional spatial structure.

According to (Cervero, 2004), a TOD area must in principle fulfill three main aspects: density, diversity, and design. Density refers to a high level of land use intensity. Diversity relates to the variety of land uses and activities within the area. Meanwhile, design emphasizes the creation of an environment that supports pedestrian and cyclist comfort.

Transit Oriented Development (TOD)

The main characteristics of a Transit Oriented Development (TOD) area focus on several fundamental aspects, including high density land use and building development, the implementation of mixed use zoning to integrate various functions and activities within a single area, the provision of safe and comfortable infrastructure for pedestrians and cyclists, and the availability of collective parking facilities as an effort to improve land use efficiency and supple transportation system (Jati, 2017).

(in Primadani, 2024) The main principle of Transit Oriented Development (TOD) is to create areas that have high density, mixed land use, and integration with mass transit systems. The implementation of this concept is realized through several aspects, namely:

1. Placing commercial functions, residential areas, urban facilities, public facilities, and social facilities within walking distance of transit points.
2. Building a pedestrian friendly road network capable of connecting various local travel destinations safely and comfortably.
3. Providing housing options with a variety of types, density levels, and affordability to accommodate the diverse needs of the community.
4. Preserving natural habitats and high quality green open spaces as part of sustainable development.
5. Developing public spaces oriented toward community activities and building layouts that support social interaction and ease of access.

Transit Oriented Development (TOD) is an urban development approach that prioritizes mixed use and integrated land use, promoting a healthy lifestyle through walking and cycling activities, as well as increasing the use of mass public transportation (Kozlak, 2006). Presented below are Table 1, showing TOD indicators based on theory, and Table 2, showing TOD indicators based on previous research.

Table 1. TOD Variables / Indicators

Source	Variable / Indicator
Calthrope (1993)	1. Transportation Terminal 2. Public Space 3. Commercial Core Area 4. Residential Area 5. Secondary Area
Cervero (1997)	1 Density 2 Diversity 3 Design
ITDP (2014)	1 Walk 2 Cycle

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3	Connect
4	Transit
5	Mix
6	Densify
7	Compact
8	Shift

(Source: Ayuningtias, 2019)

Table 2. TOD Variables / Indicators from Previous Studies

Source	Variable / Indicator
Raditya (2022)	Infrastructure completeness includes pedestrian facilities, bicycle facilities, and parking areas Diversity includes open spaces and the availability of supporting facilities Relatively high density
Jati (2017)	Density Mixed Land Use Walking Cycling Interconnection Parking Open Space
Arrifa'i (2024)	Geographical Conditions Vegetation Street Accessibility Residential Area Density Employment Density
Widodo (2023)	Walking Cycling Pedestrian Connectivity Public Transit Mix Density Compact Shift

(Source: Author, 2026)

Table 1, the TOD variables are based on established standards, while Table 2 presents variables derived from previous relevant studies that support the current research. Areas that implement the Transit Oriented Development (TOD) concept are generally supported by the provision of safe and comfortable pedestrian pathways, bicycle lane networks, and various supporting facilities oriented towards the needs of pedestrians. From a social perspective, TOD also provides benefits by creating an integrated environment, allowing communities to live, work, and access various public facilities more easily through trips that can be made on foot or by using public transportation (Mustari, 2024). The existence of integrated public transportation transit nodes plays an important role in strengthening intermodal transportation connectivity and improving community accessibility. Such integration also supports the development of various public facilities more effectively and efficiently, thereby enhancing the quality of services, comfort, and well being of the community (Hartono, 2022). Success of TOD implementation is greatly influenced by the degree of intermodal transportation integration and the availability of infrastructure that supports active mobility, such as facilities for pedestrians and cyclists. In general, the main objective of TOD is to generate long term benefits from environmental, social, and

economic aspects through the integration of public transportation systems, reducing dependence on private vehicles, improving the quality of life of communities in urban areas, and mitigating traffic congestion (Kamilah, 2025).

Theoretical Framework

The variables used refer to the concept introduced by (Cervero, 2004), namely Density, Diversity, Transit, and Design. According to (Ayuningtias & Karmilah, 2019), these variables can be supplemented with the variables Transportation Terminal, Public Space, Commercial Core Area, and Residential Area as proposed by (Cervero, 2004). Additionally, standard TOD variables can be added, including Walk, Cycle, Connect, Transit, Mix, Densify, Compact, and Shift as proposed by (ITDP, 2017) These four variables were chosen because they concisely represent the main principles of TOD implementation. Regarding table 3 interrelationships between TOD variables, table 4 indicators used this study, and table 5 research indicators used in this study, a more detailed explanation of each variable can be found in the following table :

Table 3. Interrelationship Between TOD Variables

Variable	Source	Brief Explanation	Relationship with Cervero's 1997 Theory
Terminal / Station Open Space Residential Center Public Facilities	Calthorpe (1997)	Presence of transit point, open space, residential density, connected public facilities accessible by walking	Diversity (mixed land use/activity types encourage people not to use private vehicles)
Walk Cycle Shift	ITDP (2014)	Non motorized transport to reduce problems Shift in mobility from motorized vehicles to walking/cycling	Design (Diverse uses, high density intensity to enliven nonmotorized use supported by pedestrian friendly area design)
Connect		Availability of connections between roads and dense road networks	Design (TOD area design that is pedestrian friendly, integrated with short travel times)
Transit		Use of mass transportation for longer trips	-
Mix Density Compact		Compact, varied, high intensity land use can discourage private vehicle use	Diversity and Density (Mixed land use with varied activities and high land use intensity creates a compact area, minimizing private vehicle use and encouraging walking or cycling)

(Source: Ayuningtias, 2019)

Table 4. Interrelationship Between TOD Variables from Previous Studies

Variable	Source	Brief Explanation	Relationship with Cervero's 1997 Theory
Infrastructure completeness includes pedestrian facilities, bicycle facilities, and parking facilities	Raditya, 2022	The availability of interconnected pedestrian pathways, bicycle lanes, parking areas, and shared parking facilities.	The design integrates interconnected pedestrian pathways, bicycle lanes, and parking spaces.
Diversity encompasses open spaces and the availability of supporting facilities		It has educational, healthcare, and commercial facilities.	Land use diversity supports a compact area and reduces the need for

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Variable	Source	Brief Explanation	Relationship with Cervero's 1997 Theory
			long distance travel by vehicle
Relatively high density		The average density of the area is higher than that of the secondary area.	High density refers to a high level of land use intensity, typically characterized by the utilization of land to its maximum potential.
Density	Jati, 2017	Minimum Building Coverage Ratio (BCR) of 60%	Land use is typically limited to a maximum of 60%, while development is oriented toward vertical growth.
Mixed Land Use		A balanced proportion of residential areas, public facilities, and public spaces, along with the availability of retail facilities	Land use diversity refers to an area that meets the needs of the community, thereby reducing the need for long distance travel by vehicle.
Walkability		The availability of pedestrian facilities for pedestrians.	Design that supports the reduction of vehicle use.
Cycling		The availability of cycling facilities and infrastructure	Design that supports travel from transit points using environmentally friendly modes of transportation.
Interconnection		High average number of intersections	Interconnected roads that facilitate access to transit points.
Parking		The availability of shared parking facilities.	Design provides parking spaces to support transit activities, such as bicycle parking facilities.
Open Space		Open spaces that provide community hubs.	Design that accommodates community activities within public spaces.
Geographical Conditions	Arrifa'i, 2024	-	
Vegetation		-	
Street Accessibility		The availability of pedestrian pathways and active building frontages.	Design that supports adequate walking comfort.
Residential Density		Densely populated areas that require mobility for transit related activities.	Density refers to mixed land use with diverse types of activities and land use intensity that can contribute to creating a compact area.
Employment Density		Residential areas with easy access to workplaces for daily activities.	Land use diversity facilitates mode shifts from transit points.
Walkability	Widodo, 2023	A shift in mobility from motorized vehicles to walking and cycling.	Design strategies that support the reduction of private vehicle use within a minimum radius of 400 m.

Variable	Source	Brief Explanation	Relationship with Cervero's 1997 Theory
Cycling		A modal shift from motorized vehicles to walking and cycling.	Design strategies to reduce private vehicle use.
Pedestrian Connectivity		Connecting routes to facilitate travel to and from transit points.	Design strategies that support the reduction of private vehicle use by maximizing walking and cycling.
Public Transit		Interconnected transit services that improve accessibility to and from surrounding areas.	Design that provides routes to access surrounding cities.
Mix		Opportunities and services are located within walking distance.	Land use diversity creates a compact area by integrating complementary activities.
Densification		Residential and Employment Density	Mixed Use Density
Shift		Mode shifts facilitate the transfer between different modes of transportation, improving access to surrounding areas.	Design strategies that support the reduction of private vehicle use by maximizing walking and cycling.

(Source: Author, 2026).

Table 5. Research Indicators Used in This Study

No.	Cervero's Concept	Variable	Criteria
A	Density	Residential Area	Residential Area: 20% – 60%
		Densification	Density increases as the distance to the transit point decreases, with a minimum Building Coverage Ratio (BCR) of 60%.
		Job density	Work commute dynamics are also affected by mode transfers made during work related trips.
B	Diversity	Walkability and Connectivity	Pedestrian pathways with a minimum width of 1.5 m, with zebra crossings provided at intersections.
		Cycling	The provision of dedicated bicycle lanes.
		Parking Area	The provision of dedicated bicycle parking facilities.
		Public Transportation	The development of intermodal terminals or stations at activity centers, railway stations, mass transit shelters, and public transit terminals needs to be carried out in an integrated manner
		Mix	Mixed land use or diverse activity types.
		Shift	The use of motorized vehicles can be minimized.

(Source: Author, 2026)

METHODS

This study employs a quantitative method with a comparative approach to relevant previous studies to identify and determine the variables and indicators used in the research. Data were collected through field observations, literature reviews, and document analysis. The study begins by testing the principles of TOD areas along with their indicators. The subject of this discussion is the TOD planning concept at stations served by KRL and stations served by KA BIAS, totaling three stations: Solo Balapan Station, Solo Jebres Station, and Palur Station. The objective is to identify and determine the potential of untapped public spaces for the TOD concept, as well as to enhance social interaction. Through the stages of Cervero's theory Density, Diversity, and Design as well as TOD

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variables according to (Ayuningtias & Karmilah, 2019), variables proposed by Calthorpe and ITDP can be added, which have become a suitable method for improving the quality of TOD concept implementation assessment. Observation and identification were conducted within a 600 meter radius from the station point, and field data were analyzed based on their relationship with aspects of the TOD concept, specifically the Transit Neighbourhood type and its characteristics according to (Cervero, 2004), as well as the concept of technical criteria for designing and planning TOD areas. The analysis is presented descriptively based on the eight urban design principles in Transit Oriented Development. The collected data were then analyzed to assess the level of conformity of transit areas in Greater Solo with the TOD concept.

This study is based on Cervero's theory, which encompasses three main dimensions Density, Diversity, and Design as well as the TOD variables proposed by Ayuningtias & Karmilah, 2019. Furthermore, the research variables were developed by considering the findings of previous studies: Raditya, 2022 regarding TOD implementation concepts; (Jati, 2017) regarding the evaluation of TOD concept suitability; Arrifa'i, 2024, who utilized a spatial approach to identify TOD area characteristics; and Widodo, 2023 regarding TOD suitability variables. Based on the review of prior literature, a set of relevant variables and indicators was derived to identify characteristics and evaluate the suitability of TOD based areas. This research on the KRL and KA BIAS corridors subsequently integrates the variables that have been used and tested in previous studies. The integration process was conducted by considering the alignment of each variable with the spatial and functional characteristics of the KRL and KA BIAS corridors, particularly at Solo Balapan Station, Solo Jebres Station, and Palur Station. A more complete set of research variables for characterizing transit area features is anticipated as a result of this integration. The integrated variables are then used to determine the potential for TOD based development along the KRL and KA BIAS routes as well as to analyze the degree of area suitability versus TOD principles.

This study evaluates each variable's degree of conformance using a scoring analysis technique. This analysis's goal is to ascertain whether a transportation region satisfies the requirements using the study variables. While each indicator is given a score of 0 if it falls into the "non-conforming" category and a score of 1 if it falls into the "conforming" category, each variable is given a numerical weight based on its features. A Guttman scale with a dichotomous scoring method was used to measure the assessment in this study. "Yes" (score of 1) and "No" (score of 0) are the two different response alternatives produced by this method. A "yes" response shows that the observed indication satisfies the predetermined standards or criteria, while a "no" response shows that the indicator does not.

This approach was chosen to provide objectivity, clarity, and decisiveness in evaluating the availability and fulfillment of indicators in the field (Sugiyono, 2013). Furthermore, the data obtained from the Guttman scale scoring were calculated to determine the percentage of criteria fulfillment. The total score obtained was then compared against the ideal mean score and interpreted based on specific criteria to draw the final conclusion.

$$\text{Percentage Score} = \frac{\text{Total Area Score}}{\text{Maximum Possible Score}} \times 100\%$$

Figure 2. Calculate Percentage Score
(Source: Sugiyono, 2013)

The total score calculation for each variable of the transit area is then used as a basis for analyzing the level of conformity of the transit area to the TOD concept. The analysis technique for assessing the conformity of transit areas to TOD areas is conducted to evaluate the extent to which a transit area meets the criteria for a transit oriented area. The analysis process begins by summing the scores for each area, then converting the results into a percentage using the following formula (Figure 2). The percentage results of the area scores are then grouped into the Guttman scale range (Sugiyono, 2013) as follows:

- If the transit area score is in the range of 0 – 49%, the area is categorized as "approaching non-conforming" to the TOD concept.
- If the transit area score reaches 50%, the area is considered "approaching conforming and approaching nonconforming" to the TOD concept.
- If the transit area score is in the range of 51 – 100%, the area is said to be "approaching conforming" based on the TOD concept.

RESULT AND DISCUSSION

The analysis of the implementation of the Transit Oriented Development (TOD) concept was conducted by examining case studies based on the literature review that had been carried out, Table 6 below presents the results.

Solo Balapan Station

Based on the analysis of Transit Oriented Development (TOD) suitability at Solo Balapan Station, several variables have met the established indicators, while others still require improvement. Regarding the Density aspect, the percentage of residential area surrounding Solo Balapan Station reaches 20%. The TOD requirements, which stipulate a minimum residential area share of 20%, are satisfied by this number. In the meantime, the Solo Balapan Station area satisfies the minimum BCR requirements of 60% for the building density indicator based on the Building Coverage Ratio. There are pedestrian amenities within 400 meters of Solo Balapan Station within the design elements, particularly for the walking variability. However, there are a number of problems with the state of these walkways, such as street sellers invading pedestrian pathways and damage to some areas from poor upkeep image 2,3, and 4. This suggest that optimal quality and usefulness are still lacking in pedestrian infrastructure. In terms of the cycling variable, there aren't any integrated bike lanes in the Solo Balapan Station region.

Table 6. Density Indicator Statistics Indonesia/BPS

	Population	Standard (Person/m²)	Residential Area (ha)	Residential Land Use (ha)	Area (km²)	Percentage	Ha
Kec. Banjarsari Stasiun Solo Balapan	188.919	9	170,0271	283,4	15,26	20%	1.526

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Kec Jebres Stasiun Solo Jebres	151.117	9	136,0053	226,7	14,38	16%	1.438
Kec Jaten Stasiun Palur	83.414	9	75,0726	125,1	25,55	5%	2.555

(Source: BPS Kota Surakarta Kec. Jebres, 2024, BPS Kota Surakarta Kec. Banjarsari, 2024, BPS Kab. Karanganyar Kec. Jaten, 2024)

Bicycle parking is available at the station, making up 1% of the overall parking space in figure 5. Private car parking occupancy reached over 75% during observation, according to field survey result, indicating a comparatively strong demand for private vehicle parking in figure 6 and 7. Batik Solo Trans is one of the public feeder services that serve Solo Balapan Station and the adjacent communities in terms of transit integration in figure 10 and 11. Additionally, the railroad station's interaction with other transportation networks in strengthened and intermodal connectivity is improved by the skybridge that links it to the Tirtonadi Bus Terminal in figure 8 and 9. In terms of land use diversity, the Solo Balapan Station area has a combination of public amenities and residential uses.

Nearby facilities include commercial centers Ayu Balapan Market in figure 12, medical services Triharsi Hospital in figure 13, and educational institutions Marsudirini Vocational High School. A more diynamic transit precinct is supported by the variety of urban activities that are fostered by this functional diversity. Lastly, the Solo Balapan Station compound's parking occupancy was almost 80% when it came to the mode shift / parking management variable. However, field inspections showed that no vehicles were using road shoulders or parking illegally, and road network operates effectively. This illustrates how internal parking management successfully lowers the possibility of cars spilling onto nearby public roads.

Figure 2. Pedestrian Facilities at Solo Balapan Station (Source: Author, 2026)

Figure 3. Pedestrian Facilities at Solo Balapan Station (Source: Author, 2026)

Figure 4. Pedestrian Facilities at Solo Balapan Station (Source: Author, 2026)

Figure 5. Bicycle Parking Space at Solo Balapan Station (Source: Author, 2026)

Figure 6. Car Parking at Solo Balapan Station
(Source: Author, 2026)

Figure 7. Motorcycle Parking at Solo Balapan Station Balapan
(Source: Author, 2026)

Figure 8. Transfer Space at Solo Balapan Station and KA BIAS
(Source: Author, 2026)

Figure 9. Bridge to Tirtonadi Terminal
(Source: Author, 2026)

Figure 10. BST Bus Stop in Front of Solo Balapan Station
(Source: Author, 2026)

Figure 11. BST Bus Stop in Front of Solo Balapan Station
(Source: Author, 2026)

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Figure 12. Ayu Balapan Market
(Source: Author, 2026)

Figure 13. Triharsi Market
(Source: https://rstriharsi.com/, 2026)

Solo Jebres Station

According to examination of Solo Jebres Sations's appropriateness for Transit Oriented Development (TOD), a number of factors satisfy the TOD requirements, even though some aspects have not yet reached the predetermined indications. In terms on density, just 16% of Solo Jebres Station's surroundings are residential. The residential density surrounding the station does not currently meet the minimum TOD criterion of 20% as indicated by this value. On the other hand, the Solo Jebres Station precinct meets the minimum BCR criterion of 60% for the bulding density indicator based on the Building Coverage Ratio. There area pedestrian amenities within 400 meters of Solo Jebres Station under the design element, particularly for the walking variable.

However, the area around the station is not completely covered by pedestrian infrastructure in figure 14 and 15. Walkways that lead directly into residential neighborhoods are still discontinous, but existing trails run along key roadways. Additionally, street merchants occupy portions of the pedestrian network, which decreases pedestrian comfort and walkway functionality. This indicates that the pedestrian network surrounding Solo Jebres Station has to be improved in terms of both quality and connectivity. In terms of the cycling variable, there are currently no designated bike lanes that facilitate travel to and from the stations precinct. The bicycle parking area accounts for 1% of the vehicle parking area shown in figure 16, 17, and 18. In terms of transport integration, Batik Solo Trans public busses serve Solo Jebres Station and have a service radius of about 400 meters. In terms of transport integration, Batik Solo Trans public busses serve Solo Jebres Station and have a service radius of about 400 meters.

Nevertheless, there isn't a specific transit hub or terminal in the region that is connected to Solo Jebres Station, This suggests that intermodal integration needs to be strengthened even more in order to enable smooth transitions for users of public transportation. Solo Jebres Stations is situated in area where housing predominates and is bolstered by a number of public amenities, according to the Diversity of Land Use variable. These facilities include junior high school educational institutions and business establishments like Jebres Market in figure 19, which is situated right in front of the station. However, field surveys showed that there were no medical services close to the station,

suggesting that the variety of public amenities surrounding the transportation area is still lacking.

Lastly, the Solo Jebres Station area's parking occupancy achieved almost 90% in relation to the mode shift / parking management variable. The high occupancy rate highlights the heavy reliance on private automobiles. Additionally, there is traffic congestion due to the relatively small road network surrounding the station, especially in the area between Solo Jebres Stations and Jebres Market. The transit zone may experience traffic conflicts and congestion as a results of this circumstance. Therefore, in order to facilitate the introduction of TOD at Solo Jebres Station, more integrated traffic and parking management measures are needed.

Figure 14. Pedestrian Facilities at Solo Jebres Station
(Source: Author, 2026)

Figure 15. Road Leading to the Residential Area
(Source: Author, 2026)

Figure 16. Bicycle Parking at Solo Jebres Station
(Source: Author, 2026)

Figure 17. Vehicle Parking at Solo Jebres Station
(Source: Author, 2026)

Figure 18. Vehicle Parking at Solo Jebres Station
(Source: Author, 2026)

Figure 19. Jebres Market
(Source: Author, 2026)

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Palur Station

According to the analysis of Palur Stations's eligibility for Transit oriented Development (TOD), a number of factors satisfy the TOD requirements, however several indicators still fall short of the predetermined benchmarks. In terms of density, only 5% of Palur Stations's surroundings are residential. This number show that the residential density surrounding Palur Station does not currently meet the minimum TOD criterion of 20%. In the meantime, the Palur Station area effectively satisfies the minimum BCR requirement of 60% with a maximum BCR value of 60% for the building density indicator based on the Building Coverage Ratio. There are pedestrian pathways within 400 meters of Palur Station under the Design aspect, particularly for the walking variable in figure 20 and 21.

These walkways are still only accessible on the major thoroughfares, though. There is currently no infrastructure specifically designed for pedestrians on secondary routes that go to Palur Terminal in figure 25. This indicates that Palur Station's pedestrian network is not fully connected, especially when it comes to connecting the station to other nearby transit hubs. In terms of the cycling variable, there area no designated bike lanes in the Palur Station precinct to facilitate bicycle travel to and from the transit zone. Regarding parking, 1% of the total parking land area at Palur Station is dedicated to bicycle parking in figure 24.

According to the results of a field survey, almost 70% of vehicles were parked at Palur Station, indicating that private automobiles are still often used to access the station area in figure 22 and 23. In terms of transit integration, Palur Terminal in figure 26, which is around 500 meters away from the station, and Batik Solo Trans (BST) public bus services assist Palur Station, Beyond BST, Palur Terminal provides service to a number of local transit services that span the neighboring areas. There is a great deal of potential to improve multimodal connection and integration in the Palur Station region due to the close proximity of these two transport hubs. Palur Stations is located in an area that blends business and residential activity on the Diversity of Land Use variable.

Palur Market and supermarkets are among the nearby commercial establishments in figure 27. However, the closest healthcare facilities are still unavailable, and the closest educational institutions are more than 400 meters away from the station. This shows that in order to support community activities within a typical TOD service radius, the variety of public amenities surrounding the transit area needs to be substantially improved. Lastly, the mode shift / parking management variable show that private automobiles are still regularly used to access the station, as evidenced by the 70% parking occupancy in the Palur Station area.

Nevertheless, the presence of Palur Terminal just 500 meters away serves as a key opportunity to encourage modal shift and reinforce TOD implementation within the precinct.

Figure 20. Pedestrian Facilities at Palur Station
(Source: Author, 2026)

Figure 21. Pedestrian Facilities at Palur Station
(Source: Author, 2026)

Figure 22. Pedestrian Facilities at Palur Station
(Source: Author, 2026)

Figure 23. Pedestrian Facilities at Palur Station
(Source: Author, 2026)

Figure 24. Bicycle Parking at Palur Station
(Source: Author, 2026)

Figure 25. Road to Palur Terminal
(Source: Author, 2026)

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Figure 26. Palur Terminal
(Source: Author, 2026)

Figure 27. Palur Supermarket
(Source: Author, 2026)

Table 7. Diversity Indicator

TOD	Density			Diversity					
				Design			Transit		
Variables	Residential Area	Densifi-cation	Employment Density	Walkability Connectivity	Bicycle Lanes	Parking Facilities	Public Transportation	Mixed Land Use	Shift
Balapan Station	1	1	0	1	0	0	1	1	1
Jebres Station	0	1	0	0	0	0	0	0	1
Palur Station	0	1	0	1	0	0	1	0	1

(Source: Author, 2026)

From the three data in Table 7, each station has a prominent value in it's respective category. In the density indicator data, Solo Balapan Station has the highest score, followed by Solo Jebres Station, with Palur Station having the lowest score due to low population density and the area still largely consisting of (Protected Rice Field) land. For the diversity indicator data, Solo Balapan Station has the highest score, followed by Palur Station, and lastly Solo Jebres Station.

Solo Balapan Station

The suitability of the Solo Balapan Station area for TOD development. One of the long distance transit modes, namely KRL and KA BIAS, is the transit area of Solo Balapan Station. One of the government's efforts to reduce congestion is using mass transportation, namely trains.

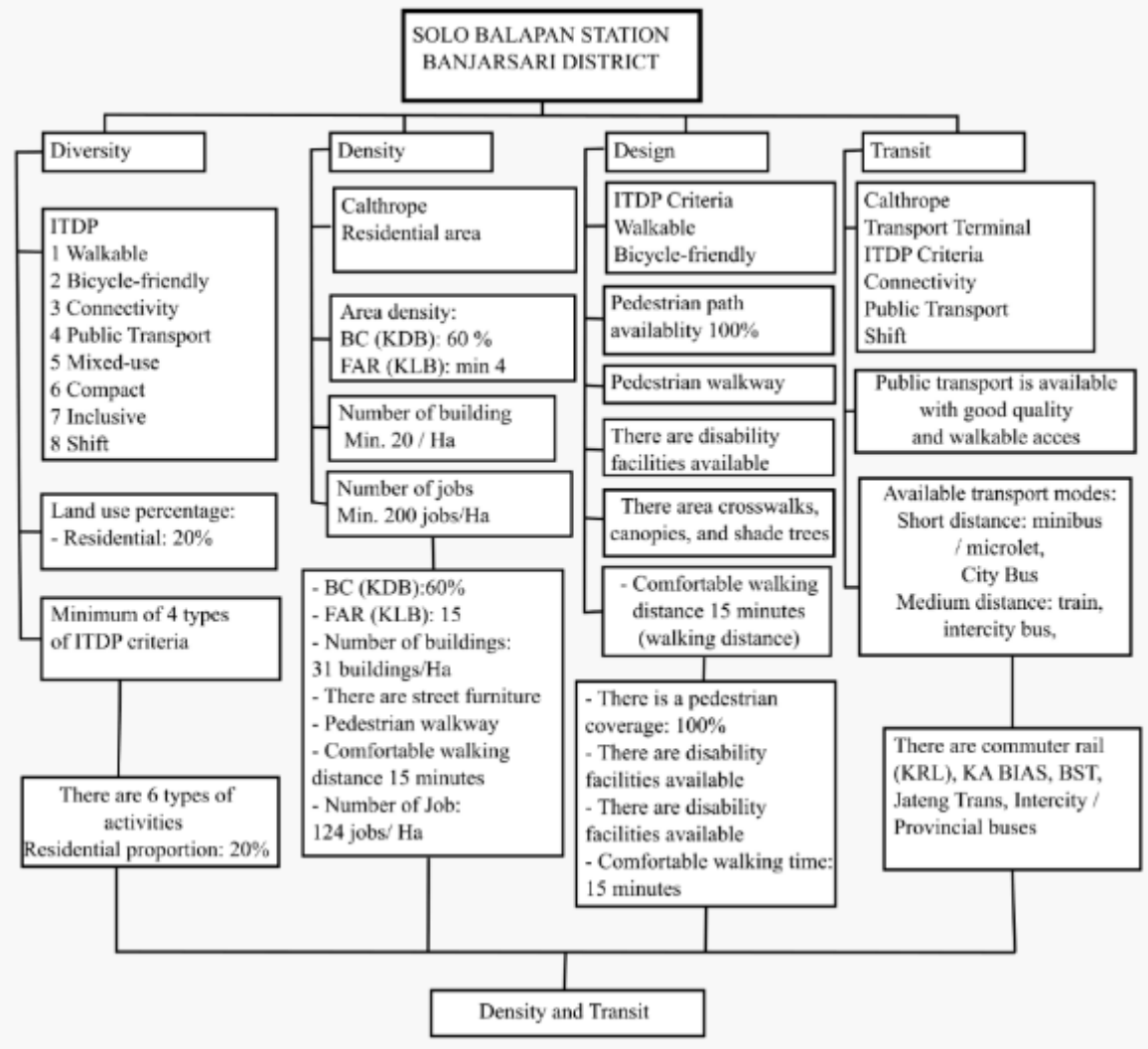

Figure 28. Diagram of TOD Implementation at Solo Balapan Station
(Source: Author, 2026)

The TOD implementation chart for Solo Balapan Station is shown in figure 28, it contains detailed information about TOD indicators. The diversity variable in TOD implementation is determined by indicators of land use proportion, 20% for residential functions and the presence of at least four types of activities. In the existing condition, the transit area at Solo Balapan Station shows 6 types of activities with a land use composition of 20% residential. For the density variable, the indicators used include building intensity with a Building Coverage Ratio (BCR) of 60% and a minimum Floor Area Ratio (FAR) of 2, building density of 20 units/ha, and employment density of 124 jobs/ha.

The design variable includes the quality and quantity of pedestrian facilities, including the availability of pedestrian paths up to 100%, facilities for persons with disabilities, shade trees, and a walking time of at least 15 minutes. In the existing condition, Solo Balapan Station provides pedestrian paths, a bridge connected to Tirtonadi Terminal, disability access facilities, and a travel time to activity centers of approximately 15 minutes. For the transit variable, the indicators focus on the availability of quality public transportation modes that are easily reachable or accessible on foot. Solo Balapan Station

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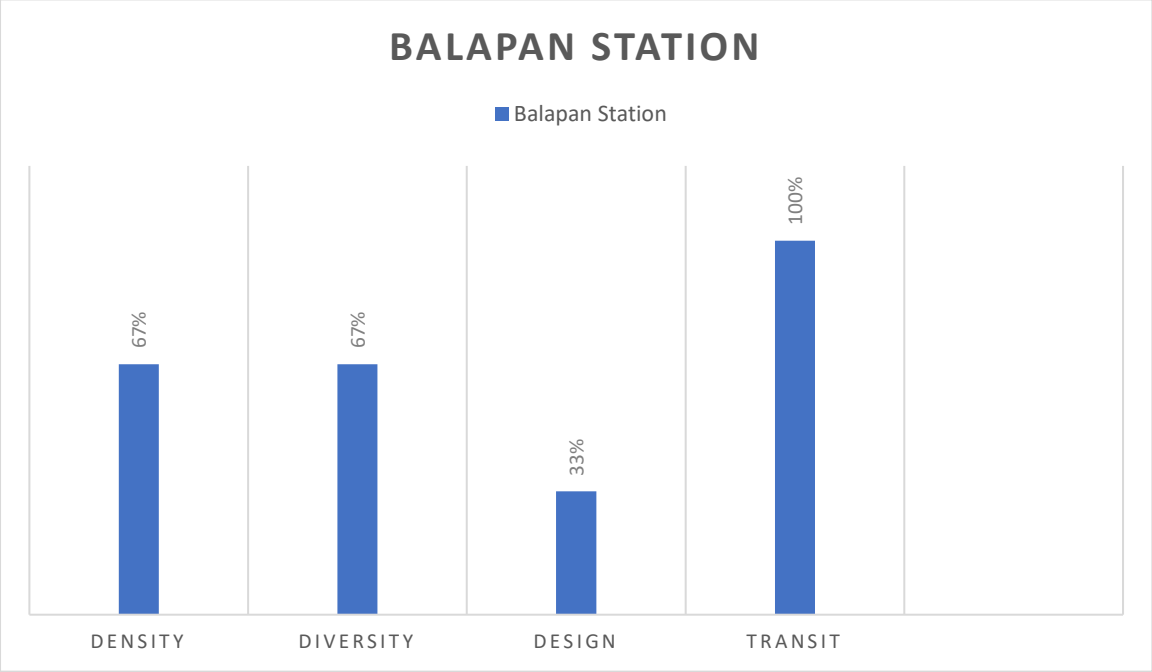

Figure 29. Graph of Transit Oriented Development (TOD) in the Solo Balapan Station Area (Source: Author, 2026)

has met these indicators because various modes are available, such as BST, Trans Jateng, and inter city / inter provincial buses.

Overall, it can be concluded that the implementation at Solo Balapan Station is more prominent in the density and transit aspects. Density in Banjarsari District shows horizontal or landed density, although vertical density development is still limited, it continues to grow along with development. The many transit nodes served by various transportation modes result in increasingly optimal implementation of the TOD concept. For the diversity and design variables, the local government continues to implement policies aligned with the TOD concept as stipulated in the Spatial Planning Regulation (RTRW) of Surakarta City, so that the Solo Balapan Station area as a transit point with TOD concept implementation achieves optimal or ideal conditions.

The Surakarta City Spatial Plan states that Solo Balapan Station is designated for transit oriented development (TOD). Based on the dynamic variables evaluated across four indicators using field results in image 29, the density, diversity, and transit indicators are already supportive. However, the design indicator is not yet supportive, as its score remains below average. Under the design variable, the absence of dedicated bicycle lanes and the fact that bicycle parking accounts for only 1% of total parking area demonstrate a lack of public awareness regarding walking and cycling.

Solo Jebres Station

The suitability of the Solo Jebres Station area for TOD development. One of the long distance transit modes, namely KRL and KA BIAS, is the transit area of Solo Jebres Station. Solo Jebres Station is a strategic Type C station that supports the main station, Solo Balapan.

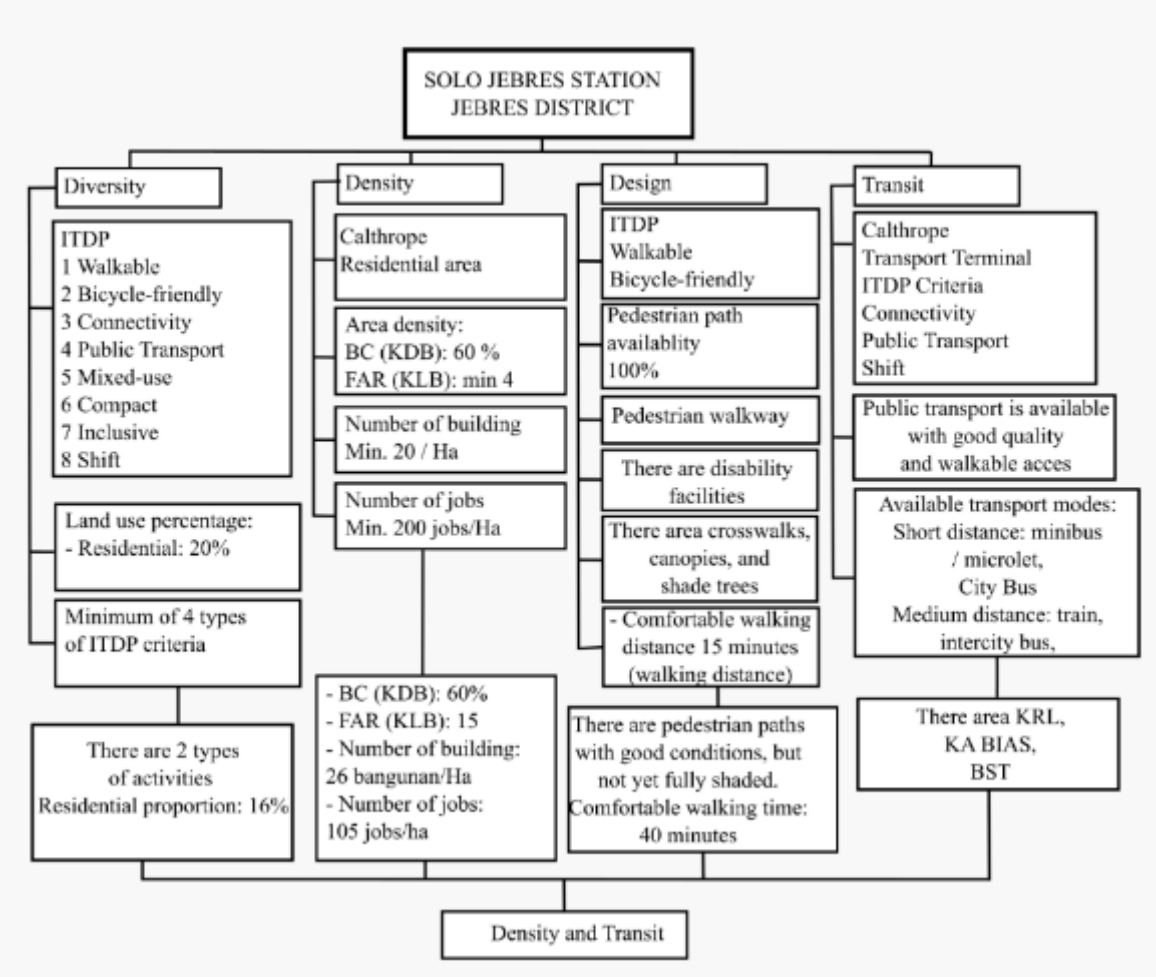

Figure 30. Diagram of TOD Implementation at Solo Jebres Station
(Source: Author, 2026)

The TOD implementation chart for Solo Jebres Station is shown in figure 30, it contains detailed information about TOD indicators. For the diversity variable in TOD implementation at Jebres Station, it is determined by the indicator of land use for residential purposes of at least 20%, while the calculation of residential land in Jebres District only reaches 16%. Additionally, the minimum of four types of activities based on ITDP indicators. The transit area of Jebres Station has an indicator value of 2. Mixed use is in a commercial and residential area, compacting where the land area has a BCR of 60% and a high FAR value of 15, in line with the Surakarta City RTRW 2021-2041.

For the density variable, the indicators of BCR 60% and FAR 15 are in accordance with the Surakarta City RTRW 2021-2041, but residential use is <20% at only 16%, with an employment density of 105 jobs/ha. For the design variable, Jebres Station as a TOD transit area in terms of pedestrian path quality through the availability of pedestrian facilities is still inadequate because within a 600m radius to reach Jebres Station, many pedestrian paths are broken and partially used for trading activities. For the transit variable, indicators include the availability of quality public transportation modes that are easily accessible on foot. Currently, Jebres Station is only served by one public transportation

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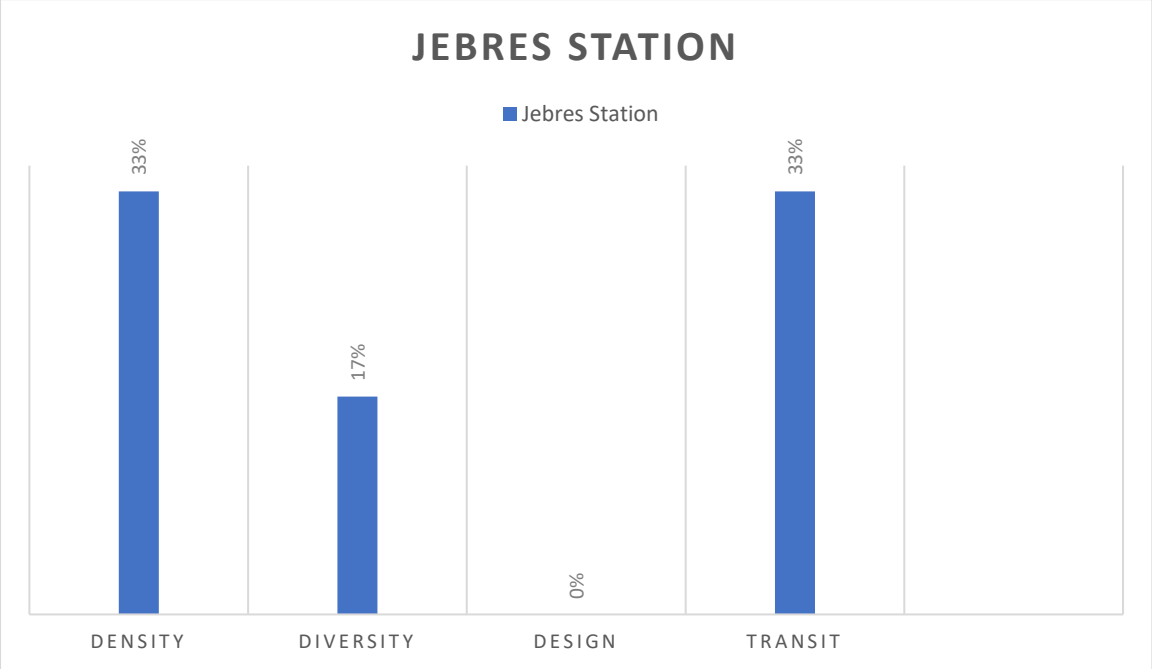

Figure 31. Graph of Transit Oriented Development (TOD) in the Solo Jebres Station Area
(Source: Author, 2026)

mode, the Batik Trans Solo Bus, with a 6 minute walk to the BST Bus Stop and 30 minutes to Tirtonadi Terminal.

Overall, for Jebres Station, the most prominent aspect in TOD implementation is transit, with a minimal value, and transit is only served by the BST Bus. The diversity, density, and design variables have not shown significant values.

In the spatial plan for Surakarta city, Solo Balapan Station is designated for transit oriented development. In Image 31, based on the specified variables across the four indicators and in accordance with field results, the indicators for density, diversity, and transit are already supportive. However, the design indicator is not yet supportive as its value remains below average. Within the design variable, the unavailability of bicycle lanes and a bicycle parking percentage of only 1% of the total parking area demonstrates a lack of public awareness regarding walking and cycling.

Palur Station

The suitability of the Palur Station area for TOD development. One of the long distance transit modes, namely KRL and KA BIAS, is the transit area of Palur Station.

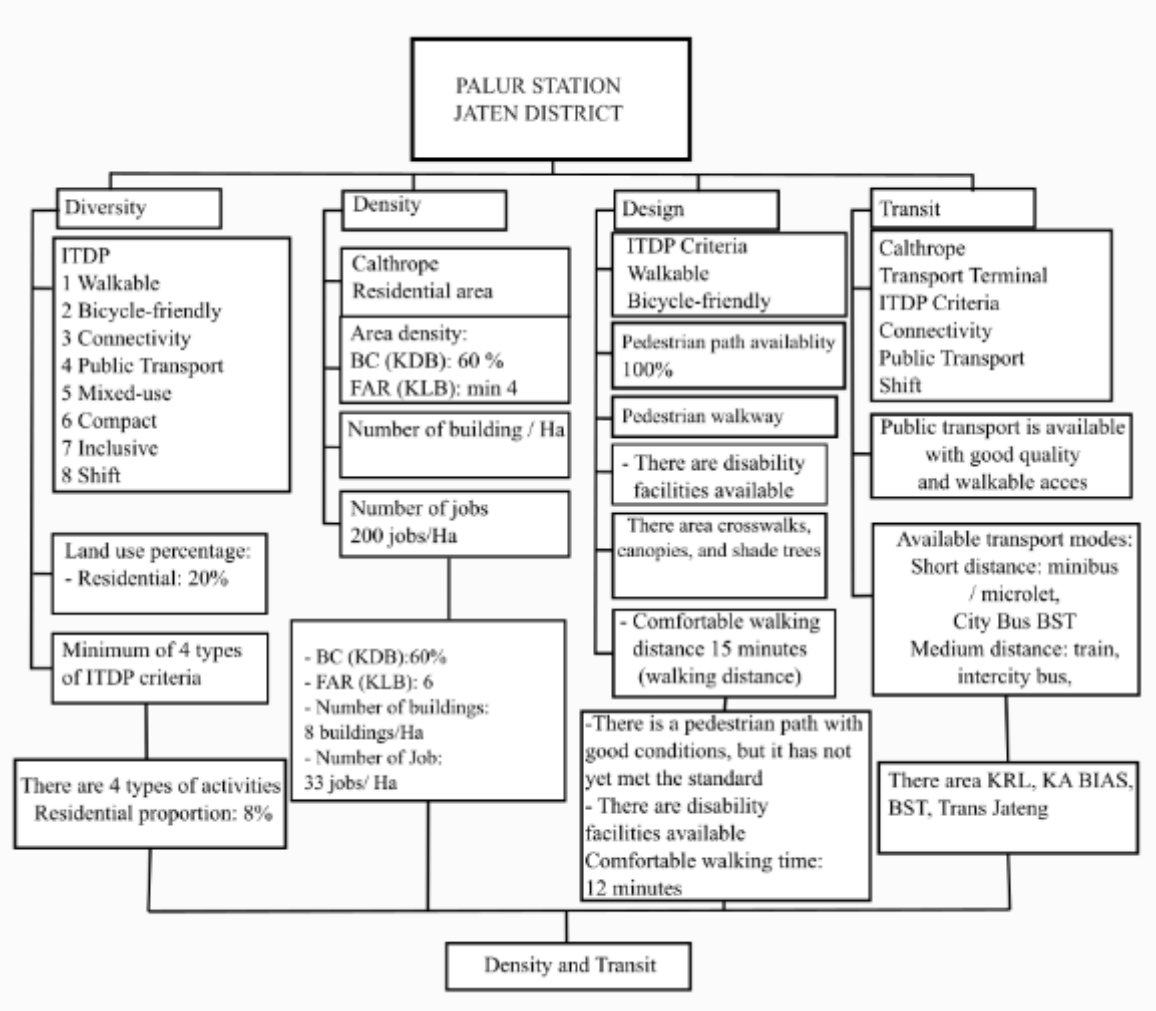

Figure 32. Diagram of TOD Implementation at Palur Station
(Source: Author, 2026)

The TOD implementation chart for Palur Station is shown in figure 32, it contains detailed information about TOD indicators. In the diversity variable, the analysis results were derived from predetermined variables based on a 20% residential land use component and a minimum of four activity types according to ITDP indicators. The transit area includes indicators such as walkability and public transport connectivity due to its proximity to the Palur Terminal, as well as density, where the site area exhibits high BCR (Building Coverage Ratio) and FAR (Floor Area Ratio) values. However, the proportion of residential area remains low at 8%. For the density variable, the established indicators include land use intensity with a minimum BCR of 60% and a minimum FAR of 4, and building density of 50 units per hectare. In actual conditions, the area has a BCR of 60%, an FAR value of 6, and a building density of 8 buildings per hectare because there is still much agricultural land, with an employment density of 33 jobs/ha. For the design variable, the indicators used are safe and comfortable pedestrian paths, equipped with disability facilities, public street lighting, canopies, shade trees, and a walking distance to activity centers of 15 minutes. However, the existing conditions indicate that pedestrian facilities have not yet met comfort standards and are not fully connected throughout the transit area, although the walking time is still within 12 minutes. Regarding the transit variable, which

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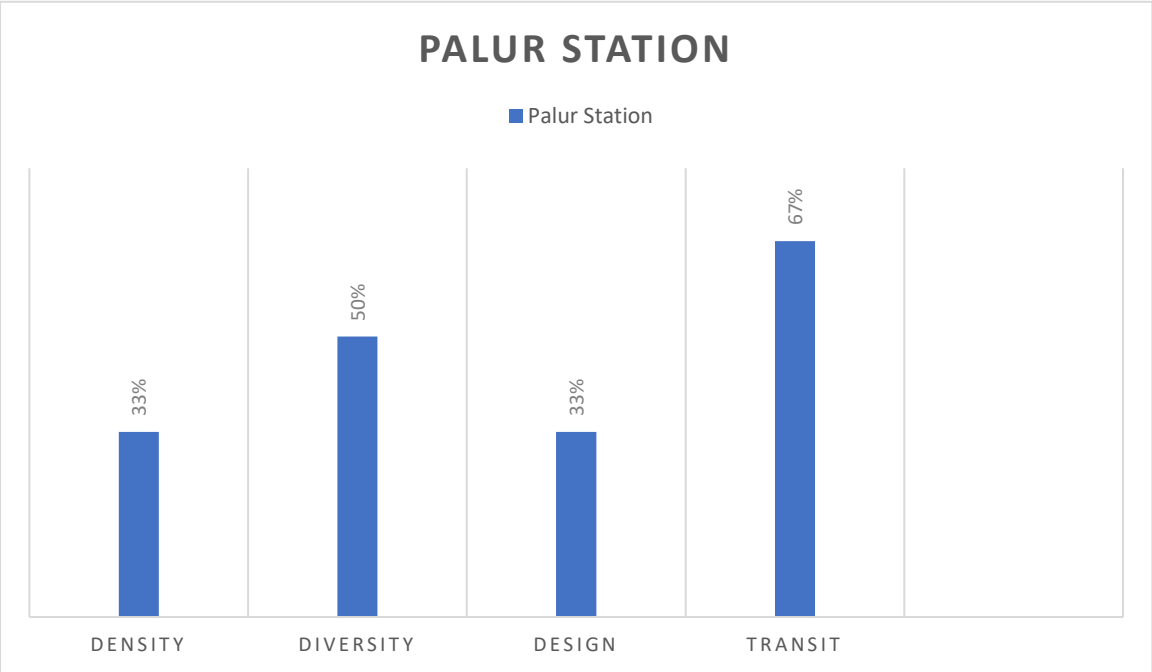

Figure 33. Graph of Transit Oriented Development (TOD) in the Palur Station Area
(Source: Author, 2026)

requires the availability of quality public transportation that is easily accessible to walk. At Palur Station, access to Palur Terminal is easy, such as the Batik Trans Solo bus, Trans Jateng bus, and inter city buses. In conclusion, the implementation of the TOD concept in the transit area of Jaten District at Palur Station is more prominent in the transit aspect because it is supported by Palur Terminal for reaching areas around the vicinity. However, it is not yet supported by density because much of the land use in Jaten District is still protected paddy fields. Furthermore, the population density is higher in Banjarsari District (Solo Balapan Station) and Jebres District (Solo Jebres Station).

Regarding Palur Station, Image 33 shows that based on the evaluated variables across the four indicators and field results, the diversity and transit indicators are already supportive. However, the density and design indicators are not yet supportive, as their scores remain below average. The density variable falls below average because population density and employment density have not yet met TOD standards. Under the design variable, the lack of dedicated bicycle lanes and the fact that bicycle parking accounts for only 1% of the total parking area demonstrate a low level of public awareness regarding walking and cycling.

Research Results

Based on the case studies presented above, the Research Results were formulated and are presented in detail in the following table 8, which can also be used as a basis for comparison:

Table 8. Research Result

TOD	Indicator			
	Variable	**Palur Station**	**Jebres Station**	**Balapan Station**
Density	Population Density Residential density of more than 20 units/ha	Residential density of 8 units/ha, Maximum Building Coverage Ratio	Residential density of 16 units/ha, Maximum Building	Residential density: 20 units/ha, Maximum Building Coverage Ratio (BCR): 60%

	Minimum Building Coverage Ratio (BCR) of 60% Minimum Floor Area Ratio (FAR) of 2 Employment density of 200 jobs/ha.	(BCR) of 60%, Maximum Floor Area Ratio (FAR) = 6, Employment density of 33 jobs/ha.	Coverage Ratio (BCR) of 60%, Maximum Floor Area Ratio (FAR) = 15, Employment density of 105 jobs/ha.	Maximum Floor Area Ratio (KLB): 15 Employment density: 124 jobs/ha
Diversity	Mixed Land Use and Diversity Based on ITDP • Walking • Cycling • Connectivity • Public Transportation • Mixed Use • Densify • Compact • Shift	The availability of pedestrian pathways, stations connected to terminals that provide access to surrounding areas, and users who can access nearby destinations by cycling and walking.	There are users who access the surrounding areas by cycling and walking.	The availability of pedestrian pathways, stations connected to terminals that provide access to surrounding areas, residential areas equipped with public facilities, healthcare facilities, and educational facilities, as well as users who access nearby destinations by cycling and walking.
Design	The availability of pedestrian pathways and active façades along the streets. The availability of bicycle lanes. Shared parking spaces and minimizing the percentage of private vehicle use.	The availability of pedestrian pathways equipped with street lighting (PJU), the absence of dedicated bicycle lanes, and the high percentage of parking space utilization.	The pedestrian pathway is only available along the arterial road and is not connected to the residential areas.	The availability of pedestrian pathways equipped with street lighting (PJU), the absence of dedicated bicycle lanes, and the high percentage of parking space utilization.
Transit	Public transportation that can be accessed on foot to reach the surrounding areas. Terminal: Minibus, city buses, and Batik Solo Trans (BST). Station: KRL, KA BIAS, and long distance trains.	Located near Palur Terminal. The availability of minibuses, city buses, and Batik Solo Trans (BST). Railway services connected to KRL, KA BIAS, and long distance trains.	Only Batik Solo Trans (BST) is available, located approximately 500 m from the station. The railway station is connected to KRL, KA BIAS, and long distance train services.	Located near the terminal. The availability of minibuses, city buses, and Batik Solo Trans (BST). The railway station is connected to KRL, KA BIAS, and long distance train services.

(Source: Author, 2026)

Based on the table 8, it can be seen that each station has differences in the degree of fulfillment of TOD indicators. These differences show that each station has potential for TOD development. The TOD concept is not only determined by the presence of public transportation, but also by the integration between land use, area density, pedestrian and bicycle accessibility, as well as intermodal integration.

Challenges of TOD Implementation

A. Palur Station

- Land use around the transit area is still dominated by nonresidential functions; the area is still developing and growing horizontally, so the level of activity diversity exists but is not yet optimal due to the presence of paddy fields.
- The density structure of the area is still landed or horizontal, which impacts public access to facilities and is less supportive of pedestrian mobility.
- The community's routine of walking or cycling has not yet been strongly established.

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- Pedestrian path facilities and adequate transportation modes, both in terms of quality and quantity.
- The area's connectivity between Palur Station, Palur Terminal, the market, offices, and horizontal residential areas.

B. Jebres Station

- The area around Jebres Station is still developing horizontal, so public access to various activities is not yet optimal.
- The spatial planning structure still applies a zoning system that separates residential, commercial, and industrial areas, which ultimately extends travel distances and reduces the interest in walking.
- Land use in the transit area is still dominated by residential functions.
- The community's mindset still prioritizes the use of private vehicles, which poses a challenge, as changing behavior towards more sustainable transportation modes requires a long time.
- Developing a quality and adequate transportation system, both in terms of service and infrastructure, requires large investments and a lengthy development process.

C. Solo Balapan Station

- The TOD development area has been dominated by settlements, requiring a replanning process regarding land use changes and density arrangement around the transit area. This effort has the potential to cause conflicts over affected land or building ownership.
- The spatial planning pattern still applies a zoning system that separates residential, commercial, and industrial areas, causing travel distances to become longer and more difficult to reach by walk, thereby reducing the interest in walking.
- Relatively high land prices cause the provision of pedestrian and cyclist infrastructure to be considered a lower priority.

CONCLUSION

Based on four key indicators density, diversity, design, and transit the application of the Transit Oriented Development (TOD) concept in the vicinity of Balapan Station, Jebres Station, and Palur Station demonstrates differing degrees of preparedness.

From the Density aspect, Balapan Station recorded the rating closest to the ideal criteria for a TOD, reaching a residential density of 20 units/ha and a job density of 124 jobs/ha. Conversely, Palur Station and Jebres Station remain below the ideal standard of 20 units/ha; Palur District recorded only 8 units/ha with a job density of 33 jobs/ha, while Jebres recorded a residential density of 16 units/ha with a job density of 105 jobs/ha. Nevertheless, all three stations meet the maximum threshold for the Building Coverage Ratio (KDB) of 60%. In terms of the Diversity indicator, Balapan Station excels with the most diverse land use. This area not only facilitates pedestrian and bicycle movement toward the station, but is also directly connected to the bus terminal as well as residential areas equipped with public, healthcare, and educational facilities. Meanwhile, Palur Station and Jebres Station lack pedestrian network connectivity and bicycle access to their surrounding areas. Regarding the Design dimension, all station areas still face challenges

in the form of a high proportion of land used for private vehicle parking and the absence of dedicated bicycle lanes. Palur Station and Balapan Station are equipped with supporting facilities such as pedestrian paths and public street lighting. On the other hand, Jebres Station has the most limited design quality because its existing pedestrian paths only connect to the arterial road and do not yet reach residential areas.

Lastly, Balapan Station and Palur Station provide the best intermodal integration from a transit perspective. Both locations are fully linked with rail transport modes (KRL commuter line, KA BIAS airport train, and long distance trains), have close access to bus terminals, and offer a range of feeder transport alternatives (minibuses, city busses, and BST) Jebres Station, on the other hand, offers fewer transit choices, mostly limited to BST busses and rain. The Surakarta City Spatial Plan (RTRW) already includes Balapan Station, which is the location closest to the ideal TOD concept based on the analysis of these four TOD indicators derived from prior research. Although it still needs to be optimized in terms of density and nonmotorized infrastructure design, it has significant advantages in terms of residential / job density, land use diversity, and full transportation integration. Despite being part of the Surakarta City Spatial Plan, Jebres station has the lowest level of TOD readiness because it lacks feeder transit accessibility and pedestrian linkage to residential neighborhoods. The results of this study are intended to be a crucial factor and empirical basis for local goverments when creating and assessing Spatial Plants (RTRW), especially with regard to the design and growth of Transit Oriented Development areas.

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