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Transit-Oriented Development and Integrated Urban Transport Systems: Technical Assessment and Case Study of Cirebon Station, Indonesia

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Abstract. This study is an empirical case study that evaluates the potential for developing the area surrounding Cirebon Station into a Transit-Oriented Development (TOD) zone. The research uses a mixed-method approach, combining descriptive–qualitative spatial analysis with quantitative survey-based modeling. Spatial data were generated through field observation, interviews, and GIS mapping within an 800-meter radius of the station, while primary quantitative data were obtained from a purposive sample of 33 respondents (n = 33) who have direct involvement or knowledge of the station area. Descriptive statistics were used to describe existing conditions and respondent characteristics, while correlation and linear regression analyses were applied to examine the influence of TOD on the Integrated Urban Transportation System. The results show a moderate positive relationship between TOD and integrated transportation performance, with a correlation coefficient of r = 0.550. The regression model produces a coefficient of determination of $R^2 = 0.302$, indicating that 30.2% of the variation in the Integrated Urban Transportation System can be explained by TOD factors such as accessibility, transport mode integration, land-use optimization, and public facility provision, while the remaining 69.8% is influenced by other variables not captured in the model. Despite these positive results, the findings should be interpreted cautiously due to key limitations, including a small sample size (n = 33) and moderate instrument reliability (Cronbach's α = 0.602), which may constrain the statistical power and generalizability of the results. From an engineering and planning perspective, the results imply that prioritizing TOD-based interventions such as improving pedestrian access, integrating public transport modes, and coordinating land-use zoning around Cirebon Station can significantly strengthen urban transport integration and reduce reliance on private vehicles. Future work should expand the sample size, improve measurement reliability, and incorporate additional explanatory variables to develop more robust TOD implementation models for corridor-scale urban transport planning.

Keywords: Accessibility, cirebon station, integrated urban transport systems, transit-oriented development, urban planning

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1. Introduction

Rapid urbanization and increasing travel demand have intensified the challenges of urban transportation, particularly in developing countries where urban growth is often accompanied by rising dependence on private vehicles, traffic congestion, inefficient land use, and unequal access to public transportation. These challenges highlight the need for an integrated approach to urban development that coordinates transportation infrastructure, land-use planning, and the distribution of urban activities [1,2]. Rather than treating transportation networks and urban development as separate planning domains, contemporary urban planning increasingly emphasizes the integration of public transport systems with compact, accessible, and mixed-use urban environments [3].

Cirebon City is one of the key urban centers along the northern coast of West Java, Indonesia, serving a strategic role as a transportation hub within the national railway network and the Trans-Java highway corridor [4] . The presence of two major railway stations Cirebon Station (Kejaksan) and Prujakan Station provides a strong foundation for developing an integrated and sustainable urban transport system based on public transit. However, current urban growth in Cirebon is still characterized by a high dependence on private motorized vehicles, inadequate pedestrian and cycling infrastructure, and weak feeder-transport integration [5]. These conditions reduce system efficiency, increase energy consumption, and weaken the sustainability performance of the urban transport network. [6]

In this context, Transit-Oriented Development (TOD) has emerged as a strategic planning approach to improve urban transport efficiency and sustainability [7]. TOD integrates land use and public transport by promoting compact, high-density, mixed-use, and walkable development within a 400–800-meter radius of mass-transit stations [8–10] . Previous studies in large metropolitan areas have demonstrated that TOD can reduce private vehicle use, increase public transport ridership, improve energy efficiency, and stimulate local economic activity through improved accessibility and land-use synergy [11,12] . Quantitative TOD evaluation methods have also been widely developed, including GIS-based TOD indices [13] , multi-criteria spatial indicators [14] , 4D and 5D frameworks (density, diversity, design, destination accessibility, and distance to transit) [15,16], and accessibility-based modeling of travel behavior and transport system performance. [17,18]

Despite these advances, a clear technical and methodological gap remains. Most quantitative TOD studies have focused on large metropolitan cities with mature transit systems [11,15,16], while medium-sized cities with growing but less developed transit networks such as Cirebon remain under-studied [19,20]. As a result, there is limited empirical evidence on whether TOD indicators can statistically explain the performance of Integrated Urban Transport Systems in secondary cities. In particular, it is still unclear to what extent measurable TOD attributes such as accessibility, modal integration, land-use mix, and public facility support can predict or influence the quality of transport system integration in these contexts [17,21] .

To address this research gap, this study employs an empirical case study that combines GIS-based spatial analysis, structured survey data, and inferential statistical modeling to evaluate TOD performance in a medium-sized Indonesian city. Unlike descriptive TOD case reports [22,23] , this study applies quantitative indicators and regression analysis to measure the strength of the relationship between TOD and transport system integration.

By providing a quantitative, indicator-based, and transferable framework for assessing TOD in medium-sized cities, this study contributes new engineering-oriented knowledge for sustainable urban transport planning that can be applied beyond Cirebon, particularly in other secondary cities in developing countries. This study offers a methodological and empirical contribution by quantitatively examining the relationship between Transit-Oriented Development (TOD) attributes and Integrated Urban Transport System performance in a medium-sized city context, which remains underrepresented in TOD research. While prior studies have predominantly focused on large metropolitan areas with mature transit systems, this research addresses that gap by applying GIS-based TOD indicators, structured survey data, and inferential statistical analysis to evaluate whether measurable TOD characteristics such as accessibility, modal integration, land-use mix, and public facility provision are

statistically associated with transport system integration around Cirebon Station. The primary objective of this study is to test the hypothesis that higher TOD scores are positively associated with improved urban transport system integration in secondary cities, thereby providing context-specific, evidence-based insights to support TOD-oriented transport and infrastructure planning beyond major metropolitan regions.

2. Methods

This study employed a quantitative survey-based design framed as an expert-informed empirical case study of Transit-Oriented Development (TOD) in the Cirebon Station area [24,25]. A purposive sampling technique was applied to select respondents who possess direct knowledge or involvement in the planning, management, operation, or daily use of the station area, resulting in 33 respondents (n = 33). The sample consisted of urban and transport planners, transport operators, local business and property managers, and regular transit users, allowing the TOD constructs of accessibility, transport integration, land use, and public facility support to be evaluated from technical, operational, economic, and user perspectives. Because the sample is expert-oriented and relatively small, the results are interpreted as analytical evidence rather than population-representative estimates.

Data were collected using a structured questionnaire with Likert-scale items that were aggregated into composite scores by unweighted summation: 25 TOD items (X; possible range 25–125) covering accessibility, transport mode integration, land use, and public facilities, and 15 Integrated Urban Transport System items (IUTS, Y; possible range 15–75). The summed scores were used in all statistical analyses (Tables 1–6); 0–100 normalized scores were derived only for descriptive interpretation. Content validity was ensured through expert review, and the refined instrument achieved a Cronbach's alpha of 0.602, which is acceptable for exploratory planning research. Spatial conditions were analyzed using GIS-based mapping (QGIS 3.28) within an 800-meter walking buffer around Cirebon Station. The data were analyzed using descriptive statistics, Pearson correlation, and simple linear regression, selected to test the hypothesized influence of TOD on transport system integration under small-sample conditions.

Spatial analysis was carried out in QGIS 3.28. The main entrance of Cirebon (Kejaksan) Station (6.70486°S, 108.55364°E) was used as the reference point, and all layers were projected to WGS 84 / UTM zone 49S (EPSG:32749). An 800 m buffer (2.01 km²) was generated around the station, and OpenStreetMap roads, building footprints, and land-use polygons were clipped to it. Network-based walking distances within 800 m were computed with the QNEAT3 OD-matrix tool. Building density was calculated as total building footprint area divided by buffer area, land-use mix was measured with an entropy index, and feeder-transport stops and public facilities were located through a GPS field survey. These indicators were used to describe station-area conditions and to estimate the ITDP TOD Standard score discussed in Section 3.2; they were not entered into the regression model, which relies on the survey-based composite scores.

2.1 Research Questionnaire (Appendix A)

The questionnaire was administered in Bahasa Indonesia; the English version is reproduced below. Part I records the respondent group, Part II contains 25 Transit-Oriented Development (TOD) items (variable X), and Part III contains 15 Integrated Urban Transport System (IUTS) items (variable Y). All items in Parts II and III are positively worded statements rated on a five-point Likert scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree.

Table A1. Part I – Respondent group

Question	Response options
Which group best describes your involvement with the Cirebon Station area?	Urban/transport planner; transport operator; business or property manager; regular transit user

Table A2. Part II – Transit-Oriented Development items (Variable X, 25 items)

Code	Statement	1–5
A. Accessibility (items 1–7)		
TOD_01	Walking up to 800 m to the station is comfortable.	
TOD_02	Sidewalks around the station are continuous.	
TOD_03	Zebra crossings near the station are safe.	
TOD_04	Access for people with disabilities is available.	
TOD_05	First- and last-mile access to the station is easy.	
TOD_06	Directional signage is clear.	
TOD_07	Walking around the station is safe at night.	
B. Transport mode integration (items 8–13)		
TOD_08	Transfers between KAI trains and angkot/ojek are easy.	
TOD_09	Waiting times for feeder services are short.	
TOD_10	Travel information and fares are integrated across modes.	
TOD_11	Bicycle parking and park-and-ride facilities are available.	
TOD_12	Schedules of different modes are coordinated.	
TOD_13	Drop-off areas are well organised.	
C. Land use (items 14–19)		
TOD_14	Land use around the station is mixed.	
TOD_15	Development density around the station is high.	
TOD_16	Commercial activities support transit use.	
TOD_17	There is little vacant land around the station.	
TOD_18	Development intensity is high close to the station.	
TOD_19	Street vendors do not block streets and walkways.	
D. Public facilities (items 20–25)		
TOD_20	Seating, lighting, and shelters are provided.	
TOD_21	Toilets and prayer rooms are available.	
TOD_22	Drainage is clean and functioning.	
TOD_23	Bicycle lanes are available.	
TOD_24	Green open space is available.	
TOD_25	Waste management and security are adequate.	

Table A3. Part III – Integrated Urban Transport System items (Variable Y, 15 items)

Code	Statement	1–5
IUTS_01	Connectivity between transport modes is good.	
IUTS_02	Travel time by public transport is reasonable.	
IUTS_03	Trips can be made without a private vehicle.	
IUTS_04	Transfers between modes are fast.	
IUTS_05	Public transport services run on time.	
IUTS_06	Travel information is easy to obtain.	
IUTS_07	Walking trips of less than 2 km are comfortable.	
IUTS_08	Transport integration reduces motorcycle use.	
IUTS_09	Using public transport is safe.	
IUTS_10	Public transport fares are affordable.	

Code	Statement	1–5
IUTS_11	Transferring between modes is comfortable.	
IUTS_12	Vulnerable groups (elderly, people with disabilities) have adequate access.	
IUTS_13	Transport operators are well coordinated.	
IUTS_14	Integrated transport supports the local economy.	
IUTS_15	Overall, the urban transport system is integrated.	

2.2 Coding and Scoring Scheme (Appendix B)

Responses were entered into IBM SPSS Statistics, one record per respondent (R01–R33), using the scheme in Table B1.

Table B1. Coding and scoring scheme

Variable	Code / formula	Description
Resp_ID	R01–R33	Respondent identifier (n = 33)
Role	1 = planner; 2 = operator; 3 = business/property manager; 4 = regular transit user	Respondent group (Part I)
TOD_01 … TOD_25	1–5 (numeric Likert)	TOD items (Part II)
IUTS_01 … IUTS_15	1–5 (numeric Likert)	IUTS items (Part III)
TOD_SUM (X)	TOD_01 + … + TOD_25 (25–125)	TOD composite score; independent variable
IUTS_SUM (Y)	IUTS_01 + … + IUTS_15 (15–75)	IUTS composite score; dependent variable
TOD_NORM	(TOD_SUM − 25) / 100 × 100	TOD score rescaled to 0–100 (descriptive only)
IUTS_NORM	(IUTS_SUM − 15) / 60 × 100	IUTS score rescaled to 0–100 (descriptive only)

Analysis procedure (SPSS): descriptive statistics (EXAMINE); Kolmogorov–Smirnov (Lilliefors) and Shapiro–Wilk normality tests; reliability, RELIABILITY /VARIABLES = TOD_SUM IUTS_SUM /MODEL = ALPHA; Pearson correlation, CORRELATIONS TOD_SUM IUTS_SUM; simple linear regression, REGRESSION /DEPENDENT IUTS_SUM /METHOD = ENTER TOD_SUM. Significance level $\alpha = 0.05$ (two-tailed).

2.3 GIS Processing Steps (Appendix C)

The spatial workflow summarised above was carried out in the ten steps listed in Table C1.

Table C1. GIS processing steps in QGIS 3.28

Step	Process	QGIS 3.28 tool / parameters	Output
1	Station reference point	Main entrance of Cirebon (Kejaksan) Station, 6.70486°S, 108.55364°E (WGS 84)	Station point
2	Projection	Project CRS set to WGS 84 / UTM zone 49S (EPSG:32749)	Metric layers
3	Study area	Vector › Geoprocessing › Buffer, distance 800 m	800 m buffer (2.01 km²)
4	Base data	OpenStreetMap roads, building footprints, and land use clipped to the buffer (Vector › Geoprocessing › Clip)	Station-area base layers
5	Walking distance	QNEAT3 OD Matrix on the road network, 800 m threshold	Network walking distances
6	Building density	Total building footprint area / buffer area (Field Calculator, $area)	Building coverage ratio
7	Land-use mix	Entropy index $LUM = -\Sigma(p_i \ln p_i) / \ln k$, where p_i is the area share of land-use class i and k the number of classes	Land-use mix (0–1)
8	Feeder stops and facilities	GPS field survey of feeder stops and public facilities, imported as point layers	Point layers

Step	Process	QGIS 3.28 tool / parameters	Output
9	TOD Standard scoring	Indicators from Steps 3–8 assessed against the ITDP TOD Standard	Existing score 52; projected score 66 with pedestrian and cycling improvements (Bronze threshold = 56)
10	Export	All layers saved to a single GeoPackage (Cirebon_TOD_800m.gpkg)	Project dataset

3. Results and Discussion

3.1 Results

3.1.1 Descriptive Analysis

Descriptive analysis is a data analysis technique used to describe, summarize, and present information from collected data, thereby providing a clear picture of the characteristics of the variables being studied.

Table 1. Descriptive Analysis

Descriptives

			Statistic	Std. Error
X	Mean		100.30	2.372
	95% Confidence Interval for Mean	Lower Bound	95.47	
		Upper Bound	105.14	
	5% Trimmed Mean		100.07	
	Median		100.00	
	Variance		185.718	
	Std. Deviation		13.628	
	Minimum		77	
	Maximum		125	
	Range		48	
	Interquartile Range		24	
	Skewness		.420	.409
	Kurtosis		-.951	.798
Y	Mean		62.73	1.144
	95% Confidence Interval for Mean	Lower Bound	60.40	
		Upper Bound	65.06	
	5% Trimmed Mean		62.73	
	Median		62.00	
	Variance		43.205	
	Std. Deviation		6.573	
	Minimum		50	
	Maximum		75	
	Range		25	
	Interquartile Range		10	
	Skewness		.028	.409

Kurtosis	-.546	.798

The descriptive test results show that the Transit-Oriented Development (TOD) score (X) has a mean value of 100.30 with a standard deviation of 13.63 and a data range of 48, where the minimum value is 77 and the maximum is 125. The distribution is relatively symmetrical (skewness = 0.420) and slightly flatter than a normal distribution (kurtosis = −0.951). Meanwhile, the Integrated Urban Transport System score (Y) has a mean value of 62.73 with a standard deviation of 6.57 and a data range of 25, with a minimum value of 50 and a maximum of 75. This variable also displays an almost symmetrical distribution (skewness = 0.028) and a slightly platykurtic form (kurtosis = −0.546). Overall, both variables exhibit relatively even distributions and do not show extreme deviations from normality, indicating that the data are suitable for further associative analysis examining the relationship between the TOD score (X) and the Integrated Urban Transport System score (Y) in the area surrounding Cirebon Station.

3.1.2 Normality Test

Table 2. Normality Test Results

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
X	.128	33	.184	.937	33	.054
Y	.090	33	.200*	.977	33	.686

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

The normality test results in Table 2 show that both variables, Transit-Oriented Development (TOD) and Integrated Urban Transportation System, have significance values in the Kolmogorov-Smirnov and Shapiro-Wilk tests greater than 0.05—namely, 0.184 and 0.054 for TOD, and 0.200 and 0.686 for the Integrated Urban Transportation System. This indicates that the data for both variables are normally distributed, thereby meeting the normality assumption required for parametric statistical analysis.

3.1.3 Reliability Test

A Reliability Test is a statistical method used to assess the consistency and stability of a research instrument in measuring a variable, ensuring that it produces dependable results when applied under similar conditions. In this study, reliability was measured using Cronbach's Alpha, which evaluates the internal consistency of questionnaire items, with values closer to 1.0 indicating higher reliability. A Cronbach's Alpha score above 0.7 is generally considered good, while a value above 0.6 may be acceptable for exploratory research. This test is essential to confirm that the measurement instrument is free from significant random errors and can accurately reflect the construct being studied, thereby supporting the validity and credibility of the research findings.

Table 3. Reliability Test Results

Reliability Statistics

Cronbach's Alpha	N of Items
.602	2

The reliability test results in Table 3 show that the Cronbach's Alpha value is 0.602 for the two items measured. This indicates a moderate level of internal consistency, suggesting that while the items are sufficiently reliable for preliminary analysis, further refinement or the addition of more items could enhance the reliability of the measurement instrument.

3.1.4 Correlation Test

A Correlation Test is a statistical method used to determine the strength and direction of the relationship between two variables. It produces a correlation coefficient (r) ranging from -1 to +1, where positive values indicate a direct relationship, negative values indicate an inverse relationship, and values near 0 show little or no relationship. The significance level (p-value) indicates whether the correlation is statistically meaningful, with $p < 0.05$ commonly considered significant.

Table 4. Correlations Test Results

Correlations

		X	Y
X	Pearson Correlation	1	.550**
	Sig. (2-tailed)		<.001
	N	33	33
Y	Pearson Correlation	.550**	1
	Sig. (2-tailed)	<.001	
	N	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

The correlation test results in Table 4 indicate a moderate positive association between Transit-Oriented Development (TOD) and the Integrated Urban Transportation System, with a Pearson correlation coefficient of $r = 0.550$ and a significance level of $p < 0.001$. This magnitude suggests that areas with higher TOD scores tend to exhibit better transport system integration; however, the relationship is not strong enough to imply deterministic or comprehensive improvement. Approximately 30% of the variation is shared between the two variables, indicating that other factors beyond TOD also play a substantial role in shaping urban transport system performance.

3.1.5 Regression Test

A Regression Test is a statistical method used to examine the influence of one or more independent variables on a dependent variable and to predict the dependent variable's value based on the independent variable(s). In simple linear regression, the analysis produces a regression coefficient that shows the direction and magnitude of the effect, along with a significance value (p-value) to determine whether the effect is statistically meaningful. This test helps identify how strongly and in what way changes in the independent variable(s) are associated with changes in the dependent variable.

Table 5. Regression Test Results

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	36.133	7.323		4.934	<.001
	X	.265	.072	.550	3.664	<.001

a. Dependent Variable: Y

The regression analysis in Table 5 further shows that TOD is a statistically significant predictor of the Integrated Urban Transportation System score, with an unstandardized coefficient (B) of 0.265 and a standardized coefficient (β) of 0.550. The model explains 30.2% of the variance ($R^2 = 0.302$) in the dependent variable, which represents a moderate explanatory power for a single-predictor model in an urban planning context. Practically, this implies that while incremental improvements in TOD are associated with measurable gains in transport system integration, TOD alone is insufficient to account for the majority of system performance, underscoring the importance of complementary policies such as service quality improvements, fare integration, and network coverage. The unstandardized coefficient indicates that a one-unit increase in the TOD score is associated with a 0.265-unit increase in the Integrated Urban Transportation System score. Although statistically significant, the absolute magnitude of this change is modest, suggesting that TOD interventions are likely to produce gradual rather than transformative impacts on urban transport outcomes in the study area.

3.1.6 Coefficient of Determination

The Coefficient of Determination (R Square) is a statistical measure that indicates the proportion of variance in the dependent variable that can be explained by the independent variable(s) in a regression model. Its value ranges from 0 to 1, where a higher value means the model explains a greater proportion of the variance. For example, an R Square of 0.30 means that 30% of the variation in the dependent variable is explained by the independent variable(s), while the remaining 70% is influenced by other factors not included in the model.

Table 6. Coefficient of Determination Results

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.550[a]	.302	.280	5.579

a. Predictors: (Constant), X

The coefficient of determination results in Table 6 show that Transit Oriented Development (TOD) has an R Square value of 0.302, meaning that 30.2% of the variance in the Integrated Urban Transportation System can be explained by TOD, while the remaining 69.8% is influenced by other factors not examined in this study. The correlation coefficient (R) of 0.550 indicates a moderate positive relationship between TOD and the Integrated Urban Transportation System, with a standard error of estimate of 5.579 reflecting the average deviation of the predicted values from the actual data.

3.2 Discussion

The results of this study indicate a moderate, statistically significant association between Transit-Oriented Development (TOD) conditions around Cirebon Station and the performance of the integrated urban transportation system. While the findings support the premise that TOD-related attributes such as accessibility, modal integration, and mixed land use are linked to improved urban mobility, the observed effects are incremental rather than transformative, consistent with the model's explanatory power ($R^2 = 0.302$). This suggests that TOD contributes meaningfully but does not operate in isolation from other determinants of transport system performance.

From an engineering and infrastructure perspective, the results imply that specific TOD interventions are more likely to yield measurable transport benefits than broad TOD designation alone. Improvements in pedestrian connectivity, first–last mile access, and feeder service integration are the most plausible mechanisms through which TOD influences transport system integration, aligning with prior findings that accessibility and transfer efficiency are key drivers of transit performance [9,10]. In practical terms, this points to prioritizing sidewalk continuity, safe crossings, bicycle access, and clearly organized

feeder interfaces within the station catchment area as near-term investments with observable mobility outcomes.

The empirical findings align with previous quantitative studies showing that employment density, land-use mix, and station-area design positively influence transit ridership and network efficiency. Studies in the United States and Asia report correlation coefficients and explanatory powers comparable to those observed here, typically explaining between 25–40% of ridership or integration outcomes through TOD-related variables [12,13]. However, unlike larger multi-city analyses, the present study focuses on a single station area, which limits cross-context comparability and may partially explain the moderate effect size.

At the same time, alternative explanations must be acknowledged. Approximately 69.8% of the variance remains unexplained, suggesting the influence of unobserved factors such as service frequency, fare integration, socio-demographic characteristics, informal transport dynamics, and broader network structure. Spatial spillover effects may also be present, whereby improvements around Cirebon Station affect nearby corridors or stations, as observed in other TOD studies [12], but these effects were not explicitly modeled. Additionally, the reliance on perception-based survey data introduces potential sample and response bias, which may overrepresent frequent transit users or residents already favorably disposed toward TOD principles.

Comparatively, studies in cities such as Cleveland, Nagpur, and Indore demonstrate that stronger transport and economic impacts tend to occur where TOD is coupled with large-scale capital investment, regulatory reform, and long-term implementation frameworks [14]. In contrast, the TOD conditions around Cirebon Station currently fall below the ITDP TOD Standard "Bronze" threshold (56 of 100 points), reflecting an early stage of TOD maturity. The reported score of approximately 52, and the projected increase to 66 through pedestrian and cycling improvements, are derived from ITDP's TOD Standard indicators, which assess dimensions such as walkability, connectivity, land-use mix, and transit access [10]. Practically, moving from a score of 52 to 66 would require measurable upgrades, including reduced block lengths, improved sidewalk quality, safer intersections, and enhanced bicycle infrastructure, rather than symbolic or policy-only interventions.

Policy trade-offs and potential negative externalities also warrant careful consideration. While TOD has been widely promoted as a sustainable planning model [13], evidence indicates that poorly managed TOD can contribute to land price escalation and displacement, particularly in areas experiencing new investment [15]. Equity outcomes depend heavily on implementation quality, housing policy alignment, and safeguards for lower-income residents. Therefore, TOD around Cirebon Station should be accompanied by affordable housing strategies, inclusive public space design, and fare accessibility measures to ensure that mobility gains do not come at the expense of social equity.

4. Conclusion

The findings suggest that the application of selected Transit-Oriented Development (TOD) principles around Cirebon Station is associated with improvements in local transport integration and accessibility, particularly in terms of pedestrian access, modal connectivity, and land-use intensity within the station area. Respondents indicated better connectivity between modes and reduced dependence on private vehicles for short-distance trips; however, these effects are context-specific and limited to the immediate station catchment area. Given the small sample size and limitations in survey instrument robustness, the results should be interpreted as indicative rather than conclusive. The study does not demonstrate system-wide behavioral change or long-term modal shift, nor does it capture broader socio-economic impacts beyond the study area. Therefore, claims regarding city-scale sustainability or economic growth are not asserted. Within these constraints, the study provides localized, evidence-based insights into how TOD elements at Cirebon Station may contribute to incremental improvements in urban mobility when supported by appropriate design, coordination, and management.

Declaration of AI and AI assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT (OpenAI) in order to improve the language, grammar, and readability of the manuscript. The tool was not used to generate research data, perform the statistical or spatial analyses, or draw scientific conclusions. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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Appendix

Appendix A. Research Questionnaire

The questionnaire was administered in Bahasa Indonesia; the English version is reproduced below. Part I records the respondent group, Part II contains 25 Transit-Oriented Development (TOD) items (variable X), and Part III contains 15 Integrated Urban Transport System (IUTS) items (variable Y). All items in Parts II and III are positively worded statements rated on a five-point Likert scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree.

Table A1. Part I – Respondent group

Question	Response options
Which group best describes your involvement with the Cirebon Station area?	Urban/transport planner; transport operator; business or property manager; regular transit user

Table A2. Part II – Transit-Oriented Development items (Variable X, 25 items)

Code	Statement	1–5
A. Accessibility (items 1–7)		
TOD_01	Walking up to 800 m to the station is comfortable.	
TOD_02	Sidewalks around the station are continuous.	
TOD_03	Zebra crossings near the station are safe.	
TOD_04	Access for people with disabilities is available.	
TOD_05	First- and last-mile access to the station is easy.	
TOD_06	Directional signage is clear.	
TOD_07	Walking around the station is safe at night.	
B. Transport mode integration (items 8–13)		
TOD_08	Transfers between KAI trains and angkot/ojek are easy.	
TOD_09	Waiting times for feeder services are short.	
TOD_10	Travel information and fares are integrated across modes.	
TOD_11	Bicycle parking and park-and-ride facilities are available.	
TOD_12	Schedules of different modes are coordinated.	
TOD_13	Drop-off areas are well organised.	
C. Land use (items 14–19)		
TOD_14	Land use around the station is mixed.	
TOD_15	Development density around the station is high.	
TOD_16	Commercial activities support transit use.	
TOD_17	There is little vacant land around the station.	
TOD_18	Development intensity is high close to the station.	
TOD_19	Street vendors do not block streets and walkways.	
D. Public facilities (items 20–25)		
TOD_20	Seating, lighting, and shelters are provided.	
TOD_21	Toilets and prayer rooms are available.	
TOD_22	Drainage is clean and functioning.	
TOD_23	Bicycle lanes are available.	
TOD_24	Green open space is available.	
TOD_25	Waste management and security are adequate.	

Table A3. Part III – Integrated Urban Transport System items (Variable Y, 15 items)

Code	Statement	1–5
IUTS_01	Connectivity between transport modes is good.	
IUTS_02	Travel time by public transport is reasonable.	
IUTS_03	Trips can be made without a private vehicle.	
IUTS_04	Transfers between modes are fast.	
IUTS_05	Public transport services run on time.	
IUTS_06	Travel information is easy to obtain.	
IUTS_07	Walking trips of less than 2 km are comfortable.	
IUTS_08	Transport integration reduces motorcycle use.	
IUTS_09	Using public transport is safe.	
IUTS_10	Public transport fares are affordable.	
IUTS_11	Transferring between modes is comfortable.	
IUTS_12	Vulnerable groups (elderly, people with disabilities) have adequate access.	
IUTS_13	Transport operators are well coordinated.	
IUTS_14	Integrated transport supports the local economy.	
IUTS_15	Overall, the urban transport system is integrated.	

Appendix B. Coding and Scoring Scheme

Responses were entered into IBM SPSS Statistics, one record per respondent (R01–R33), using the scheme in Table B1.

Table B1. Coding and scoring scheme

Variable	Code / formula	Description
Resp_ID	R01–R33	Respondent identifier (n = 33)
Role	1 = planner; 2 = operator; 3 = business/property manager; 4 = regular transit user	Respondent group (Part I)
TOD_01 … TOD_25	1–5 (numeric Likert)	TOD items (Part II)
IUTS_01 … IUTS_15	1–5 (numeric Likert)	IUTS items (Part III)
TOD_SUM (X)	TOD_01 + … + TOD_25 (25–125)	TOD composite score; independent variable
IUTS_SUM (Y)	IUTS_01 + … + IUTS_15 (15–75)	IUTS composite score; dependent variable
TOD_NORM	(TOD_SUM − 25) / 100 × 100	TOD score rescaled to 0–100 (descriptive only)
IUTS_NORM	(IUTS_SUM − 15) / 60 × 100	IUTS score rescaled to 0–100 (descriptive only)

Analysis procedure (SPSS): descriptive statistics (EXAMINE); Kolmogorov–Smirnov (Lilliefors) and Shapiro–Wilk normality tests; reliability, RELIABILITY /VARIABLES = TOD_SUM IUTS_SUM /MODEL = ALPHA; Pearson correlation, CORRELATIONS TOD_SUM IUTS_SUM; simple linear regression, REGRESSION /DEPENDENT IUTS_SUM /METHOD = ENTER TOD_SUM. Significance level $\alpha = 0.05$ (two-tailed).

Appendix C. GIS Processing Steps

The spatial workflow described in Section 2 was carried out in the ten steps listed in Table C1.

Table C1. GIS processing steps in QGIS 3.28

Step	Process	QGIS 3.28 tool / parameters	Output
1	Station reference point	Main entrance of Cirebon (Kejaksan) Station, 6.70486°S, 108.55364°E (WGS 84)	Station point

Step	Process	QGIS 3.28 tool / parameters	Output
2	Projection	Project CRS set to WGS 84 / UTM zone 49S (EPSG:32749)	Metric layers
3	Study area	Vector › Geoprocessing › Buffer, distance 800 m	800 m buffer (2.01 km²)
4	Base data	OpenStreetMap roads, building footprints, and land use clipped to the buffer (Vector › Geoprocessing › Clip)	Station-area base layers
5	Walking distance	QNEAT3 OD Matrix on the road network, 800 m threshold	Network walking distances
6	Building density	Total building footprint area / buffer area (Field Calculator, $area)	Building coverage ratio
7	Land-use mix	Entropy index LUM = $-\Sigma(p_i \ln p_i) / \ln k$, where p_i is the area share of land-use class i and k the number of classes	Land-use mix (0–1)
8	Feeder stops and facilities	GPS field survey of feeder stops and public facilities, imported as point layers	Point layers
9	TOD Standard scoring	Indicators from Steps 3–8 assessed against the ITDP TOD Standard	Existing score 52; projected score 66 with pedestrian and cycling improvements (Bronze threshold = 56)
10	Export	All layers saved to a single GeoPackage (Cirebon_TOD_800m.gpkg)	Project dataset