Transit-Oriented Development Ridership Optimization and Peak Hour Analysis Through TDM-Based Land Use: Tanjung Barat Case Study

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Abstract. Traffic congestion is a critical issue in Jakarta, causing an average of 89 hours of annual travel delay due to high private vehicle dependency. Transit-Oriented Development (TOD) offers a strategic solution by integrating land use and public transport to boost ridership. This study focuses on the Tanjung Barat Station TOD area, aiming to identify an optimal land use configuration that maximizes KRL ridership and analyzes its peak hour implications. Utilizing a comprehensive Travel Demand Modelling (TDM) framework, ridership demand was calculated for existing land use. Initial analysis clearly reveals the existing land use is suboptimal, supporting a daily KRL ridership of 22,666 people. In contrast, the identified optimal configuration dramatically increases daily KRL ridership to 58,313 people. This substantial increase directly results from strategic land use optimization, which also significantly improves the entropy index for both Area A (0-400m) and Area B (400-800m), reflecting enhanced land diversity and mixed-use development. Furthermore, this optimal configuration contributes to a more balanced peak hour demand, with the morning peak percentage slightly decreasing and the noon peak percentage showing a positive increase. These findings offer valuable insights for Tanjung Barat Station's TOD development, supporting an efficient and sustainable transport system, and demonstrate a robust and generalizable methodology for optimizing urban mobility.

Keywords: Transit-Oriented Development, Ridership, Peak Hour, Travel Demand Modelling, Land-use.

1 Introduction

Traffic congestion is a critical issue in megacities like Jakarta, leading to an average of 89 hours of annual travel delay due to high private vehicle dependency [1–3]. This problem is exacerbated by Jakarta's rapid urbanization and immense population, contributing to significant economic losses and environmental degradation within the highly dense urban fabric. Transit-Oriented Development (TOD) offers a strategic solution by integrating diverse land uses and public transport within a 400–800-meter radius of transit hubs, aiming to shift mode choice towards sustainable public transportation and alleviate congestion, thereby promoting more livable and sustainable urban environments [4–8]. The effectiveness of TOD significantly relies on maximizing public transport ridership, primarily influenced by land use characteristics and the "distance decay" effect, where transit use declines sharply with increasing distance from a station. These factors underscore the critical importance of strategic land use

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planning in TOD development to effectively generate and capture travel demand, especially in cities where land scarcity limits infrastructure expansion [9–15].

However, while numerous studies have explored various aspects of Transit-Oriented Development (TOD), land use planning, and their individual relationships with public transport ridership, these analyses often remain fragmented or focus on isolated factors. A persistent challenge therefore lies in integrating these diverse analytical perspectives into a comprehensive and optimizable framework.

This study addresses this gap by introducing a refined TDM framework that, unlike previous models, uniquely integrates a distance-decay function to account for spatial sensitivity. This allows for a more nuanced optimization of land use configurations, a methodological step forward in TOD planning. This study uses Tanjung Barat Station as its case study due to its strategic location and significant potential for intensified mixed-use development [16]. This location serves as a demonstrative case to evaluate and refine a robust, generalizable methodological framework. We identify an optimal land use configuration to maximize KRL ridership and analyze its peak hour implications, thereby evaluating the implications of implementing the TOD concept compared to the existing condition. This comprehensive Travel Demand Modelling (TDM) framework is employed to derive quantitative insights and identify optimal land use configurations for spatial planning. By analyzing the implications of spatial planning on KRL ridership and its peak hour volumes, this framework provides actionable insights for sustainable urban transportation planning in Jakarta and potentially other similar megacities.

2 Materials and Methods

2.1 Materials

The study primarily utilized secondary data. Key datasets included the Regional Spatial Plan (RDTR) Jakarta 2022, which provided information on existing land use, area size, Building Coverage Ratio (KDB), and Floor Area Ratio (KLB) for the Tanjung Barat Station TOD area [17, 18]. Additionally, TOD & Travel Demand Modelling (TDM) Benchmarks were used, consisting of trip generation rates, modal split percentages, entropy index values, distance-decay functions, and ridership peak hour factors [19–26]. For data processing and simulation, ArcGIS and Powersim was used.

2.2 Methods

As shown in **Figure 1**, this research adopted a two-stage approach incorporating both qualitative and quantitative methods to address its two primary research objectives: (1) to analyze the impact of the Transit-Oriented Development (TOD) concept on KRL daily ridership, specifically identifying the potential for ridership increase; and (2) to examine the implications of the optimized TOD land use configuration on KRL ridership peak hours.

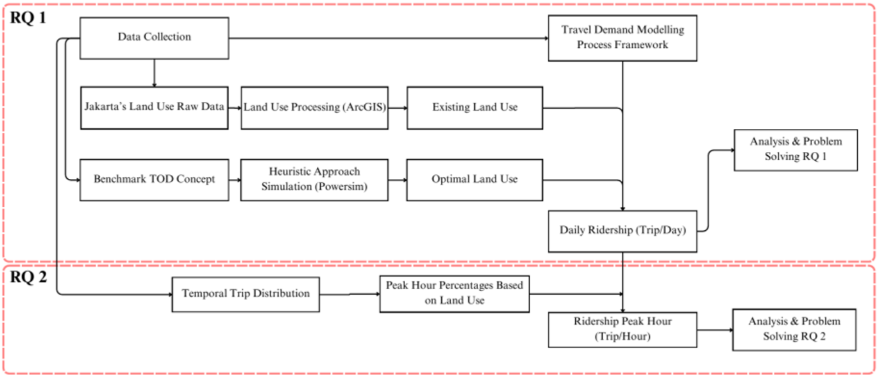

Fig. 1. Methodologies

Analyzing TOD Concept Impact on Daily Ridership. To achieve the first objective, land use configurations for both existing and optimal conditions were established and analyzed. The existing land use in the Tanjung Barat TOD area was processed using ArcGIS, based on RBI shapefiles from 2022, followed by digitization and adjustment to accurately reflect actual conditions. This data was categorized into residential, commercial, office, hotel, and 'others' (including green open spaces, roads, public facilities, terminals, and others).

For the optimal condition, an iterative static simulation was performed using Powersim. This software was selected for its capability to effectively address the complex, ill-defined, and non-linear optimization problem of maximizing ridership due to the entropy index [27]. This simulation aimed to identify the optimal TOD land use configuration by randomizing the proportions of land use types within ranges recommended by ATR/BPN No. 16/2017 and best TOD practices [25, 28], served as guiding benchmarks for the optimization process and are detailed in **Table 1**. A key criterion was ensuring an entropy index (EI) of at least 0.74, indicative of good land use diversity [29]. The entropy index was calculated using the formula [30]:

$$LU_d(i) = \frac{-\Sigma_i Q_{lu_i}\, x \ln(Q_{lu_i})}{\ln(n)} \quad (1)$$

$$Q_{lu_i} = \frac{S_{lu_i}}{S_i}$$

Where:

$LU_d(i)$ = Entropy index value in analysis area-i ; lu_i = A land use type (1, 2, ..., n) in analysis area-i ; Q_{lu_i} = Percentage of a land use type in analysis area-i ; S_{lu_i} = Total area of a land use type in analysis area-i ; S_i = Total overall area in analysis area-i

Table 1. Guiding Benchmarks from TOD Concept Best Practices

TOD Concept Best Practices	
Category	Benchmark

Residential	30% - 60%
Commercial	8% - 34%
Office	6% - 24%
Hotel	4% - 15%
Others	18% - 39%
Entropy Index	≥ 0.74

Source: Residential [28]; Commercial, Office, Hotel, and Others [25]; Entropy Index [29]

Both existing and optimal land use configurations were analyzed within two concentric radii (0–400m and 400–800m) around the station, as shown in **Figure 2**, to understand spatial influence on ridership using a methodology adapted from existing literature [10]. A comprehensive Travel Demand Modelling (TDM) framework, as shown in **Figure 3**, based on land-use based TDM as developed by study literature was then applied to both existing and optimal conditions [25]. A significant novelty of this research lies in its refinement of the TDM framework by integrating a distance-decay function [21]. This integration is crucial as it specifically accounts for the differing influence of land use positions relative to the station on ridership, a critical effect across the two distinct radii defined by distance from the transit hub.

Fig. 2. Location of Study; Inner circle (Area A: 0 m – 400 m) and Outer circle (Area B: 400 m – 800 m)

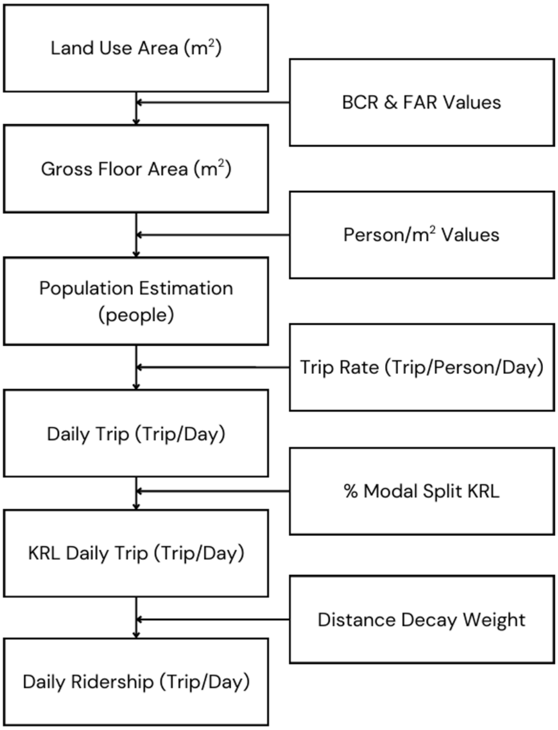

Fig. 3. Travel Demand Modelling Framework

The detailed steps of the TDM framework, including all specific parameters utilized for calculations such as population estimation, trip generation, modal split, and distance decay weighting, are visually represented in **Figure 3** and further detailed in **Table 2**. Notably, while general trip rates were sourced from JUTPI 2 data, their association with specific land use types and Tour Types for various trip purposes involved a dedicated processing step in this study: Residential land use was associated with overall average trip rates; Commercial with Maintenance & Discretionary Tours; Office with Work Tour; and Hotel with Discretionary Tour [19]. Similarly, the normalization process for the distance decay weighting, converting empirical data from various studies (including those in Jakarta, Madrid, and California) into multiplicative factors, was crucial for adapting this concept to the study context [21–23]. The 'Others' land use category was consistently excluded from ridership calculations due to its functions not being primarily associated with KRL transit trips. The daily KRL ridership demand for both existing and optimal conditions, derived from this comprehensive TDM process, directly contributes to answering Research Objective 1.

Table 2. Parameters and Coefficients in Travel Demand Modelling

Land Use	BCR	FAR	Person/m^2	Trip Rate (Trip/Person/Day)	Modal Split	Distance-Decay Weight Area A	Distance-Decay Weight Area B
Residential	0.618	1.445	0.11	2.56	3.20%	1.25	0.75

Commercial	0.55	5.193	0.22	2.64	3.20%	1.40	0.60
Office	0.6	6	0.22	3.05	3.20%	1.40	0.60
Hotel	0.550	4.530	0.20	2.49	3.20%	1.40	0.60

Source: BCR and FAR values adapted from ATR BPN [17]; Person/m^2 values adapted from Berawi et al.[25]; Trip Rates from JUTPI 2 [19]; Modal Split from Atiqah et al.[20]; Distance-Decay Weights adapted from Gutiérrez et al. [21], Kolko [22], and Afkara et al.[23]

Table 3. Ridership Values by Land Use Type

Land Use	Estimation of Train Trip/m^2 Area A	Estimation of Train Trip/m^2 Area B
Residential	0.010	0.006
Commercial	0.073	0.031
Office	0.106	0.045
Hotel	0.056	0.024

Table 3 presents the detailed "Estimation of Train Trip/m^2" values, which are derived from the multiplication of the relevant parameters in **Table 2** and are used for the TDM calculation.

Examining Implications on Ridership Peak Hours. To attain the second objective, the daily KRL ridership calculated from the TDM framework (as detailed in **Figure 3**) was subsequently distributed into peak hour volumes. This was achieved by applying percentage factors based on trip purpose distribution from existing literature [24]. Logical associations were made between land use type and dominant trip purposes (Residential: HBW, HBO; Commercial: HBW, HBO, NHB; Office: HBW, NHB; Hotel: HBO, NHB). Key peak hour percentages for morning, noon, and evening are detailed in **Table 4** [26]. The analysis of these peak hour volumes and their percentages for both existing and optimal scenarios provides the necessary insights to address Research Objective 2.

Table 4. Peak Hour Volume (PHV) Coefficients by Land Use Type

Land Use	% Morning Peak Hour (06.00-09.00)	% Noon Peak Hour (09.00-15.00)	% Evening Peak Hour (15.00-18.00)
Residential	13%	7%	9.5%
Commercial	10.3%	8%	9.3%
Office	11%	9%	9.5%
Hotel	7%	10%	9%

Source: All values adapted from Alexander et al. [24]

Generalizability and Methodological Robustness. The effectiveness of the comprehensive TDM framework employed in this study highlights its significant generalizability and practical utility. This framework's robustness stems from its integration of established methodologies. A foundational land-use based TDM approach is combined with a precise analysis of spatial influence based on concentric radii [10, 25]. Furthermore, the framework incorporates a distance-decay function to accurately quantify varying transit use probabilities based on proximity to the station, and a robust peak hour distribution methodology [21, 26, 31]. The application of a heuristic approach for identifying optimal land use configurations within this framework is particularly valuable, enabling the solution of complex, non-linear urban design optimization problems [27]. This integrated approach has enabled a precise identification of optimal land use configurations within specific radii, directly correlating land type distribution with transit ridership outcomes. The ability to quantify the impact of varied land uses at different distances from the station—a critical factor in TOD planning—makes this framework a powerful tool applicable beyond the Tanjung Barat context. It offers urban planners in other megacities facing similar congestion and public transport challenges a robust methodology to strategically allocate land uses and predict their impact on public transport ridership, thereby supporting more efficient and sustainable urban development worldwide.

3 Results

3.1 Land Use Configurations and Entropy Index: Existing vs. Optimal

The analysis of existing land use in the Tanjung Barat TOD area revealed a composition largely dominated by residential functions. The calculated entropy index for Area A (0-400m) was 0.757, and for Area B (400-800m) was 0.510 (See **Equation 1**). Iterative simulations successfully identified an optimal land use configuration designed to maximize KRL ridership while meeting specific entropy index and land use proportion criteria. This optimal configuration yielded entropy index values of 0.760 for Area A (0-400m) and 0.833 for Area B (400-800m) (See **Equation 1**).

A comparative overview of the land use composition in terms of percentages for both existing and optimal conditions, alongside best practices from TOD concepts, is presented in **Table 5**.

Table 5. Comparison of Land Area Percentages: Existing, Optimal, and TOD Best Practices

Land Use Configuration			
Land Use	% Existing Land Area	% Optimal Land Area	% TOD Concept Best Practices
Residential	66.67%	33.59%	30% - 60%
Commercial	8.15%	16.32%	8% - 34%
Office	2.03%	21.02%	6% - 24%
Hotel	1.66%	10.20%	4% - 15%
Others	21.50%	18.87%	18% - 39%
Total	100.00%	100.00%	
Entropy Index			
Location	Existing Entropy Index	Optimal Entropy Index	EI TOD Concept Best Practices

Area A (0 m – 400 m)	0.757	0.76	0.74
Area B (400 m – 800 m)	0.51	0.833	

To further elucidate the impact of distance-decay and land use optimization, a detailed comparison of land use proportions within Area A (0-400m) and Area B (400-800m) for both existing and optimal conditions is presented in **Table 6**. This disaggregation highlights the strategic re-alignment of land uses and its significance, particularly concerning the varying influence of distance from the station. The role of the entropy index as a parameter for land use diversity in both areas is crucial for assessing the effectiveness of the mixed-use development.

Table 6. Comparative Land Use Proportions by Radius: Existing vs. Optimal

Land Use	Area A (0-400m) % Existing	Area A (0-400m) % Optimal	Area B (400-800m) % Existing	Area B (400-800m) % Optimal
Residential	53.90%	3.06%	70.92%	43.77%
Commercial	18.81%	51.44%	4.60%	4.61%
Office	4.95%	17.40%	1.05%	22.23%
Hotel	2.97%	24.16%	1.22%	5.55%
Others	19.37%	3.94%	22.21%	23.84%
Total	100.00%	100.00%	100.00%	100.00%

3.2 KRL Ridership and Peak Hour Volumes: Existing vs. Optimal

Based on the comprehensive Travel Demand Modelling (TDM) framework, the total daily KRL ridership demand for the existing Tanjung Barat TOD area was 22,666 passengers. In contrast, the projected total daily KRL ridership demand for the optimal configuration increased to 58,313 passengers. This represents a potential ridership growth of 35,647 people. A direct comparison of total ridership and peak hour percentages between existing and optimal conditions is provided in **Table 7**.

Table 7. Ridership Comparison: Existing vs Optimal

Existing Condition				Optimal Condition			
Time	**Ridership Peak Hour**	**Ridership Total**	***% Ridership Peak Hour***	**Time**	**Ridership Peak Hour**	**Ridership Total**	***% Ridership Peak Hour***
Morning	2555	22666	11.27%	Morning	5961	58313	10.22%
Noon	1790		7.90%	Noon	4948		8.49%
Evening	2132		9.41%	Evening	5461		9.36%

4 Discussion

The analysis of the Tanjung Barat Station TOD area reveals a significant potential for increased KRL ridership and enhanced urban functionality through strategic land use optimization. This study quantitatively demonstrates the effectiveness of the TOD concept in improving public transport utilization, providing valuable insights for urban planning.

4.1 Interpretation of Land Use and Ridership Results

The study projects a substantial increase in total daily KRL ridership from 22,666 to 58,313 passengers, a growth of 35,647 people. This compelling increase is a direct outcome of the strategic land use re-alignment, particularly when examined across the two distinct radii from the station (Area A: 0-400m and Area B: 400-800m).

Strategic Land Use Re-alignment and Distance-Decay Impact. As detailed in **Table 6**, the optimal configuration shifts high-intensity non-residential functions significantly closer to the station in Area A. Commercial land use, for instance, dramatically increases from 18.81% to 51.44%, office from 4.95% to 17.40%, and hotel from 2.97% to 24.16% in Area A. This deliberate concentration of trip-generating activities within the immediate walkable vicinity (0-400m) directly leverages the concept of distance-decay, a fundamental principle where transit use declines sharply with increasing distance from a station. By placing major employment, retail, and hospitality functions in Area A, the optimized configuration maximizes the number of trips originating from and destined for the most accessible zone, effectively mitigating the negative impact of distance on transit ridership for these high-frequency trip purposes. This strategic alignment brings the land use proportions in Area A closer to established TOD best practices (**Table 6**), reinforcing the area's potential for optimal transit integration. This ideal zoning concept is illustrated in **Figure 4**, adapted from existing literature [8].

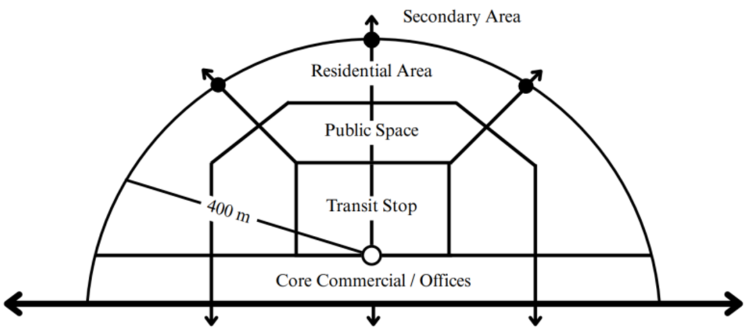

Fig. 4. Conceptual TOD Land Use Zoning

Supporting this strategic shift, the analysis reveals that non-residential land uses are inherently more sensitive to distance from the station compared to residential ones. Specifically, the distance-decay weights indicate that non-residential functions experience a more significant drop in transit usage probability (from 1.40 in Area A to 0.60 in Area B) compared to residential functions (from 1.25 in Area A to 0.75 in Area

B). This higher sensitivity of non-residential trips underscores the importance of their proximity to the transit hub for maximizing ridership.

Amplified Ridership through Non-Residential Characteristics. The overall increase in daily KRL ridership is further amplified by the inherent characteristics of non-residential land uses. Non-residential categories (Commercial, Office, Hotel) generally exhibit higher trip rates per person compared to residential uses, meaning they inherently generate more trips for a given population. Moreover, the person/m² coefficients for non-residential uses are typically higher than for residential. This reflects the efficient use of space in commercial and office buildings, where a smaller land area can accommodate more people due to multi-story structures. This efficiency is also reflected in their generally higher Building Coverage Ratio (BCR) and Floor Area Ratio (FAR) values, allowing for greater Gross Floor Area (GFA) on a smaller land footprint, thus maximizing activity density near the station. The increase in daily KRL ridership is thus primarily driven by the creation of a dense, diverse, and transit-proximate demand source, where a larger number of people are living, working, or visiting within an easily walkable distance to the station, making KRL their preferred mode of travel.

Balanced Residential Distribution and Urban Vitality. Conversely, while residential land use remains dominant overall, its proportion shifts from 53.90% to 3.06% in Area A, and from 70.92% to 43.77% in Area B. This indicates a more balanced distribution, with residential functions still sufficiently concentrated in Area B to provide a critical mass of population, yet allowing higher-intensity non-residential uses to flourish closer to the station. This supports ridership from a broader catchment area, while also accommodating potential first mile/last mile integration for residents further away. The strategic reduction of residential area in Area A (near the station) in favor of commercial, office, and hotel developments aligns with the TOD principle of maximizing economic activity and pedestrian-oriented environments directly adjacent to transit hubs.

It is crucial to understand that while maximizing non-residential uses appears to be a straightforward solution for increasing ridership and reducing private vehicle dependency, a TOD is not designed to be exclusively non-residential. An area dominated solely by non-residential functions, particularly office-centric commercial activities, would lack a consistent resident population to sustain activity during evenings and weekends. Consequently, its urban vitality would significantly decline outside of typical working hours and weekdays. This undesirable outcome, where vibrant daytime activity gives way to reduced night-time and weekend activity, is precisely why TOD best practices advocate for maintaining a balanced mixed-use development, which includes a significant proportion of residential land use (30% - 60% as per **Table 1**). This ensures a continuous presence of people and activities throughout various times of the day and week, fostering a truly vibrant and resilient urban environment that is always alive, while still prioritizing increased ridership through the strategic allocation of non-residential functions.

Enhanced Mixed-Use Development and Entropy Index. The improvement in entropy index values further confirms the success of this land use optimization. Area A's entropy index slightly increases from 0.757 to 0.760, while Area B shows a more substantial increase from 0.510 to 0.833 (See **Equation 1**). These values consistently meet or exceed the TOD concept best practices (EI of 0.74), signifying a more diverse and balanced mixed-use development. An increased entropy index fosters a vibrant, transit-supportive environment by offering a variety of destinations and services within walkable distances, thereby reducing the need for private vehicle use and encouraging KRL patronage. This enhanced land diversity not only supports the observed ridership growth but also contributes to the resilience and vibrancy of the TOD area.

4.2 Interpretation of Peak Hour Ridership Patterns

The analysis of peak hour ridership patterns reveals important shifts despite the overall increase in daily ridership. KRL ridership peak hour volumes increased across all periods in absolute terms: morning (from 2,555 to 5,961), noon (from 1,790 to 4,948), and evening (from 2,132 to 5,461). This absolute increase directly reflects the overall growth in daily ridership driven by land use optimization. The underlying patterns of trip purpose distribution throughout the day, which influence these peak hour dynamics, are conceptually illustrated in **Figure 5**.

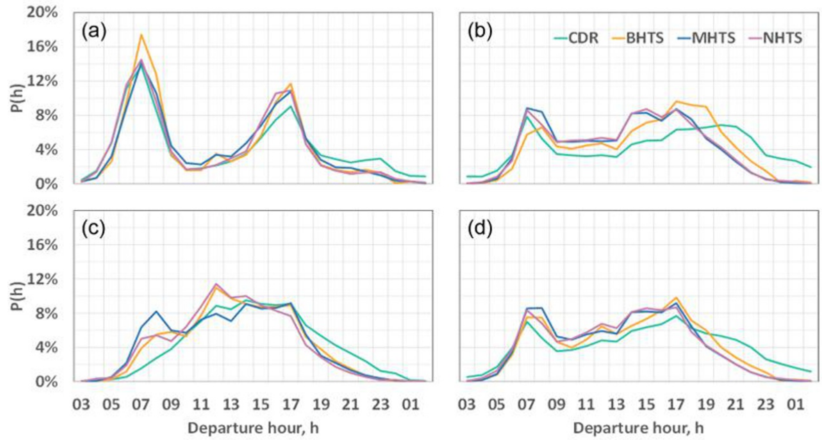

Fig. 5. Trip Purpose Distribution by Time of Day; (a) home-based work trips; (b) home-based other trips; (c) non-home-based trips; (d) all trips. Source: Alexander et al. [24]

Morning Peak-Shaving Effect. However, a closer look at the percentages of total daily ridership indicates a partial morning peak-shaving effect. Despite the increased absolute morning ridership, its percentage of total daily ridership slightly decreased from 11.27% to 10.22%. This beneficial spread of demand can be attributed to the diversified nature of trips generated by the optimized mixed-use development. The significant increase in non-residential land uses (commercial, office, hotel) in Area A attracts a broader range of trip purposes beyond the traditional home-to-work commute. These include non-home-based (NHB) trips like business meetings and discretionary tours (shopping, leisure), which are less time-sensitive and more distributed throughout the day. The presence of such diverse functions encourages trips during off-peak hours, thereby smoothing the overall demand curve for KRL services. This suggests a more efficient utilization of the KRL system's capacity beyond conventional peak periods.

Improved Noon Utilization. Conversely, the noon peak hour percentage shows a positive increase from 7.90% to 8.49%. This notable improvement in midday utilization signifies that the TOD's enhanced mixed-use character is successfully fostering diverse non-commute trips. With more commercial, office, and hotel activities near the station, KRL becomes a viable option for midday errands, lunch breaks, or inter-office meetings, leading to increased activity and transit use during traditionally less busy periods. This indicates a more efficient and balanced use of the KRL system's capacity throughout the day, beyond the traditional morning and evening commutes.

Stable Evening Peak. The evening peak hour percentage remained largely stable, showing a minor decrease from 9.41% to 9.36%. This indicates that despite the increased absolute ridership, the inherent return-commute pattern is less flexible to land use changes, maintaining a relatively consistent proportion of daily trips during the evening peak. Unlike the morning peak which can be partially diffused by varied arrival times for non-work trips, the evening peak is predominantly driven by the synchronous departure of commuters returning home. This highlights the robust nature of home-based commute trips and their lesser susceptibility to spatial land use adjustments alone.

5 Conclusion

This study definitively demonstrates the transformative potential of Transit-Oriented Development (TOD) in optimizing public transport utilization, particularly for KRL ridership in the Tanjung Barat Station area. Our comprehensive quantitative analysis reveals that the existing land use configuration is notably suboptimal, currently supporting a daily KRL ridership of 22,666 people with an imbalanced peak hour distribution. However, through the application of an adaptable iterative simulation methodology, we successfully identified an optimal TOD land use configuration that is projected to dramatically increase daily KRL ridership to 58,313 people.

This strategic optimization not only achieves a substantial increase in ridership but also significantly enhances land use diversity, as evidenced by improved entropy index values, fostering a more vibrant and mixed-use urban environment. Crucially, this optimized configuration leads to a more balanced ridership peak hour demand: the morning peak percentage subtly decreases, indicating a beneficial peak-shaving effect, while the noon peak percentage shows a positive increase, signifying a more efficient midday utilization of the KRL system.

While these findings are robust, it is important to acknowledge the inherent limitations of the methodology and their implications. The TDM framework relies on aggregated, generalized benchmarks, and the use of a static simulation means the model does not capture the dynamic feedback loops where development influences transit demand over time. A key area for future research is the incorporation of statistical uncertainty measures to enhance the policy applicability of the findings. The current deterministic model produces a single point estimate for ridership; however, conducting sensitivity analyses by varying key parameters (e.g., trip rates or modal split percentages) or performing scenario testing would provide policymakers with a range of likely outcomes rather than a single point estimate. As a potential mitigation strategy for the current constraints, future work could also employ dynamic simulation models and integrate more localized socio-economic data to build upon our current framework and provide a more granular, temporally aware forecast of TOD impacts.

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