

International Journal of Human Capital in Urban Management
(IJHCUM)

Homepage: <http://www.ijhcum.net/>

ORIGINAL RESEARCH PAPER

A spatial multidimensional evaluation of TOD performance around urban rail stations for urban planning

K. Saensomboon, R. Udomsub*

Department of Logistics and Transportation Management, Panyapiwat Institute of Management, Nonthaburi, Thailand

ARTICLE INFO

Article History:

Received 06 September 2025

Revised 08 January 2025

Accepted 30 June 2026

Keywords:

Transit-Oriented Development (TOD); Mass Rapid Transit (MRT); Electric Train; Railway Station; Transit Station.

ABSTRACT

BACKGROUND AND OBJECTIVES: This study analyzes 114 operational electric train stations in Thailand's Bangkok Metropolitan Region, covering seven rail lines: Sukhumvit, Silom, Airport Rail Link, Krung Thonburi, Thani Ratthaya, Nakhonwithi, and Chat Chai. Although substantial investment in rail infrastructure has resulted in a total of 190 stations, a systematic evaluation of the effectiveness of Transit-Oriented Development is still lacking, causing station-area development planning to lack clear direction. This assessment applies the multidimensional "6Ds" framework—Density, Design, Diversity, Connectivity, Destination Accessibility, and Distance to Transit—examined within 500-meter and 1,000-meter station catchment areas. The research has three main objectives: (1) to analyze the strengths and weaknesses of electric train stations in Bangkok and its metropolitan area using Transit-Oriented Development SCORE, (2) to propose future station-area development guidelines to increase public demand for mass transit use, and (3) to develop a web application to support the development of areas around rail transit stations.

METHODS: This study uses the "6Ds" Transit-Oriented Development framework by viewing stations as transportation nodes, urban activity centers, and functional linkages at the same time. The geospatial data used in the study were obtained from the National Statistical Office, the Department of Public Works and Town & Country Planning, and OpenStreetMap. The Transit-Oriented Development indicators consist of population density, household density, and Floor Area Ratio (the ratio of total building floor area to land area) (Density dimension); sidewalk density, number of parking spaces, and road density (Design dimension); land-use diversity (Diversity dimension); number of bus stops and number of railway station entrances/exits (Connectivity dimension); number of Points of Interest (Destination Accessibility dimension); and the distance of Points of Interest to the station and the distance of park-and-ride facilities to the station (Distance to Transit dimension). The researcher used the Information Entropy Weight Method to determine indicator weights based on data variability rather than relying on expert judgment, thereby making the Transit-Oriented Development calculation more consistent with Thailand's context. The IEW method uses the input data to assign Transit-Oriented Development weights to each dimension, enabling calculation of Transit-Oriented Development scores for each dimension. In addition, the researcher developed a prototype web application to display the Transit-Oriented Development values of each station, which allows comparative analysis to identify each station's strengths or weaknesses in each dimension, in order to support stakeholder decision-making for planning the development of areas around electric train stations.

FINDINGS: Based on the research findings, the key factors affecting the choice to use mass transit are "population density" and "the number of Points of Interest" around stations. Therefore, if the goal is to increase the Transit-Oriented Development SCORE, it is necessary to increase population density and increase the number of Points of Interest around the stations where area development is desired. This study shows that Transit-Oriented Development differs from station to station across Bangkok's entire transit network. This research helps fill the gap in objective evaluation by applying the Information Entropy Weight technique to reduce bias in assigning weights to variables. It also complements the literature by providing a large-scale evaluation, assessing as many as 114 electric train stations in Thailand, which is a broader scale than many previous studies.

CONCLUSION: This research develops an approach for evaluating Transit-Oriented Development in Thailand by using the Transit-Oriented Development SCORE. The results indicate differences in Transit-Oriented Development across 114 stations and show that Density and Connectivity have a strong impact on Transit-Oriented Development value. To increase the Transit-Oriented Development value for stations, the first approach that should be implemented is to promote area development in the form of Mixed-use Development by allocating space to support housing, commerce, and public space. This includes creating housing projects such as condominiums, housing estates, and hotels, which increase the number of residents in areas near stations, along with promoting commercial development such as building shopping malls, office buildings, restaurants, and cafés so that the station area becomes lively and has activities throughout the day. Increasing various points of interest, such as schools, hospitals, entertainment venues, parks, or museums, will further encourage more regular trips into and out of the station area and for a wider variety of purposes.

DOI: [10.22034/IJHCUM.2026.04.03](https://doi.org/10.22034/IJHCUM.2026.04.03)



NUMBER OF REFERENCES

57



NUMBER OF FIGURES

3



NUMBER OF TABLES

6

*Corresponding Author:

Email: transportlogisticpim@gmail.com

Phone: +66 982635441

ORCID: [0000-0002-5463-0011](https://orcid.org/0000-0002-5463-0011)

Discussion period for this manuscript open until January 1, 2027 on IJHCUM website at the "Show Article

INTRODUCTION

In Thailand, the Ministry of Transport has developed a strategy to upgrade the country's transportation system, and this strategy is consistent with the 12th National Economic and Social Development Plan (2017–2021), the 20-Year National Strategy (2018–2037), and the Thailand 4.0 vision (Knight Frank Thailand, 2023). The main component of this strategic plan focuses on developing Transport Services. The goal of this plan is to increase mobility by providing transportation options that are accessible, safe, and punctual, in accordance with international standards (Barter, 2013; Institute for Transportation and Development Policy, 2017). The two-decade transportation infrastructure development strategy focuses on improving traffic flow in Bangkok and surrounding provinces through travel demand management, which includes restrictions on private vehicles in commercial zones, limited parking along transit corridors, and road access fees (Belzer & Autler, 2002a). The government has made a large investment in developing rail infrastructure projects. At present, Bangkok and its metropolitan area have a total of 190 electric rail stations in service, namely 60 BTS Skytrain

stations (47 stations on the Sukhumvit Line, 14 stations on the Silom Line), 107 MRT stations on four lines, 8 Airport Rail Link stations, 3 Gold Line stations, and 13 Red Line commuter rail stations. Countries in Asia are facing rapid urban expansion, causing urban planning to shift toward the concept of "neoliberalism," which emphasizes global economic competitiveness, social welfare, environmental quality, and economic development (Kidokoro et al., 2022; Ravindran et al., 2024; Shojaeivand, 2019). Previous studies on urban transport in Chinese cities have also shown that alternative low-emission transport modes, such as electric bikes, can contribute to reducing environmental impacts in rapidly urbanizing areas (Cherry et al., 2007). Therefore, Transit-Oriented Development (TOD) has been designated as an important strategy to enable transportation and urban development to proceed simultaneously (Calthorpe, 1993, 2014; Belzer & Autler, 2002b). From previous research, the term "TOD" refers to an area development approach with high density, leading to mixed land use; this concept emphasizes pedestrians and creates urban activities around public transport centers (Calthorpe, 1993; Liang et al., 2020). For measuring TOD values, the

development started from three dimensions: Density, Diversity, and Design (Cervero & Kockelman, 1997), and additional dimensions have been added in studies because later research included dimensions such as Distance to Transit, Destination Accessibility, Demand Management, and socio-demographic characteristics, resulting in more diverse TOD dimensions (Ewing & Cervero, 2010; Yang et al., 2024). The Node–Place model, which views stations as transportation “nodes” and urban “places” (Bertolini, 1999), has been used to analyze TOD, and it was then developed into the Node–Functionality–Place model, which gives stations a role as links between rail systems and people’s everyday urban life (Su et al., 2021a). As a result, this analysis has become an important foundation used to classify station types and evaluate the alignment of the city with TOD development. A good station is not judged by passenger numbers, but the quality of development in the area around a station depends on the TOD value. Good design of the station area creates more diverse activities, improves accessibility, and enables the station to connect more with society and the economy. TOD promotes multi-modal travel, increases urban vitality, and promotes social and cultural interaction. TOD environments create a vibrant street atmosphere, lead to longer business hours, and create diverse social interactions. Stations with high TOD values carefully arrange land uses for residential, commercial, recreational, and institutional purposes close to transport hubs (Xiao et al., 2021). Recent studies using Points of Interest (PoI) data have analyzed urban changes near stations, then categorized what functions the area emphasizes (food-and-entertainment districts, office districts, residential districts, etc.), and evaluated whether these changes make the area more attractive for tourism or livelier, and how much they make the city appear more vibrant (Ding et al., 2025; Yu et al., 2022). Some studies collected “real evidence” to examine how TOD (urban development around stations/public transport systems) affects the economy, especially housing and condominiums, such as whether prices rise or fall, how rents change, movements of people in and out, and how demand to buy/rent in that area changes. Research in major Chinese cities found that if an area has TOD-type development (convenient travel, near rail stations), it makes house–condo rents increase noticeably, and this is especially clear in areas where travel truly becomes more convenient (easy station

access, good connections, convenient transfers) and where land use is well-balanced (housing, shops, workplaces, and amenities are located close together) (Su et al., 2021b; Yang et al., 2024). When a well-connected station becomes well-known, land prices, housing prices, and rents often rise, causing low-income people or vulnerable groups to be unable to stay and to move out, even though that area has more jobs, opportunities, and better services (Lai & Tran, 2025). Although TOD is a concept that most people see as “good,” when it is implemented in practice, the outcomes and methods depend on the conditions of each city. This is especially the case in developing countries, because many cities still lack tools or methods to measure how well TOD has been achieved, and existing tools often do not fit the local context. Importantly, they do not clearly indicate locations on maps regarding which spots are good, which are bad, or where improvements should be made (Ali et al., 2025; Goode, 2023). Many projects that claim to “do TOD” are actually only building something next to a station, which is called Transit-Adjacent Development (TAD) (developing “beside” transit, not developing “for” mobility and daily life). For true TOD, when you get off at the station, it should be easy to walk (good sidewalks, safe crossings), there should be a mix of shops–homes–workplaces–services nearby, and the area design should be connected as a system (walkways, connections, roads, lanes/sois not cut off). For TAD, it only has an area located near a station, but walking is difficult (there are no sidewalks, and you have to cross dangerous roads). The surrounding area has only one type of building (e.g., only condominiums or only malls), and the area is not connected. In the end, users cannot walk and must rely on private cars or taxis (Goode, 2023; Renne, 2009). As for the definition of the boundary of TOD catchment areas, various radius values have been set. Calthorpe (1993) set a radius of 2,000 feet (about 600 meters), but modern ideas suggest a range of 400–800 meters around rail stations, considering differences in people’s walking behavior. In Japan, a distance of 800 meters is considered suitable for walking (Zhuang & Zhao, 2014). Thailand’s 2013 City Planning Act states that if land is within no more than 500 meters of an urban rail station, the state will give “special privileges” to project developers, meaning they can build a larger/more intensive building on the same plot of land (called an FAR bonus). There is also an additional

proposal that for a normal station with a single line, the influence distance should be 500 meters as before, but if it is a large interchange station, the influence distance should be expanded to 800–1,000 meters, because this type of station can attract users from a farther distance, and development around it should be supported more. Research on TOD creates “composite indices” to measure how much the area around a station follows the TOD concept by looking at multiple aspects at the same time, including Density, Diversity, Design, Distance to Transit, Destination Accessibility, and Connectivity (Ogra & Ndebele, 2014; Renne, 2008; Salat & Ollivier, 2017). However, applying TOD in developing countries still has limitations. Those who apply TOD need to adjust the methods to fit local legal frameworks, travel patterns, and data availability (Ali et al., 2025; Goode, 2023). Despite considerable efforts to enhance Bangkok’s urban rail network, the planning process lacks comprehensive, contextually relevant multidimensional criteria for evaluating the spatial advantages and disadvantages of station placements. The researcher achieved notable progress by computing TOD Scores for 53 stations on the Blue and Purple Lines, gathering data on population density, retail mall quantity, road density, land-use diversity, and bus routes per station. A thorough spatial and multidimensional assessment of the entire operational rail network is ongoing (Saensomboon & Thapthimhin, 2023). This study presents a multidimensional assessment of the effectiveness of TOD, in which the researcher calculated the TOD SCORE for 114 operational electric train stations in Bangkok and its metropolitan area in Thailand. For this calculation, the researcher computed TOD in six dimensions: Density, Design, Diversity, Connectivity, Destination Accessibility, and Distance to Transit (Ogra & Ndebele, 2014). The indicators used in this study include several items, such as population density, road density, land-use diversity, POI, and the level of public transportation services, including connections with bus services at each station. For this study, the researcher used the Information Entropy Weight Method (IEW) to determine the weights of the indicators and to calculate the TOD score for each station. This methodology helps reduce bias from assigning weights to each variable and increases the ability to calculate TOD. After calculating the TOD index value of each station, the researcher can rank the TOD score of each station, which makes it possible to identify the

strengths and weaknesses of the station and to plan the development of the environment around the station area in line with changes in the city (Wu & Divigalpitiya, 2023). This research analyzed the TOD value of each station and presented the results on a prototype web application. The displayed TOD value is an accessible decision-support tool for government agencies, private-sector agencies, and stakeholders involved in area development (Xiao et al., 2021). This tool can evaluate station-level performance, compare rail-line routes, and calculate investment opportunities related to transit-oriented development. Research findings will be communicated to key stakeholders, including the Mass Rapid Transit Authority of Thailand (MRTA), State Railway of Thailand (SRT), Bangkok Mass Transit System Public Company Limited (BTS), Bangkok Expressway and Metro Public Company Limited (BEM), and Asia Era One Company Limited, supplying crucial information for the strategic planning of developments near electric train stations efficiently and sustainably.

MATERIALS AND METHODS

Data collection

Data collection for evaluating TOD performance covers 114 rail transit stations across seven main networks in Bangkok and its metropolitan area, using the 6Ds framework to define variables, as detailed below. Catchment Areas: Data were collected within two station-area catchment radii: 500 meters, which aligns with the FAR Bonus incentive criteria under Thailand’s urban planning regulations, and 1,000 meters to assess performance at a broader neighborhood scale in line with walkability and station-access network concepts. Density Variables include population density, household density, and the Floor Area Ratio (FAR). Data were obtained from the National Statistical Office, the Department of Provincial Administration, and online real estate databases (Ogra & Ndebele, 2014; Singh et al., 2017). Design Variables include road density, the number of parking areas, and sidewalk density. Data were collected through field surveys around rail transit stations and geo-spatial data analysis (Cervero, 2004; Chen & Zengras, 2016). Diversity: The variable is land-use diversity, calculated from the diversity of POIs. POIs were categorized into six main types: residential areas, public services, commercial uses, offices, public parks, and other infrastructure, to compute the Mix Index. Data were collected through field surveys around stations

(Renne, 2009; Salat & Ollivier, 2017). Connectivity and Demand Management Variables include the number of bus routes and the number of station entrances/exits. Data were collected through field surveys around stations and from mass transit system databases (Kuby, Barranda, & Upchurch, 2004; Zegras *et al.*, 2016). Destination Accessibility Variables include the number of POI—such as employment locations, schools, and shopping malls—within the study radius, to assess a station’s capacity to function as a center of urban activity. Data were collected through field surveys around stations (Cascetta & Pagliara, 2016; Chen & Zegras, 2016). Distance to Transit Variables include the distance from Park-and-Ride facilities to the station and the average walking distance from POI to the station center, to measure the convenience of access to the transit system at a human scale. Data were collected through field surveys around stations (Fard, 2013; Singh *et al.*, 2017). Data Sources and Processing: All data were obtained from field surveys around rail transit stations, and additional information was received from private companies such as BTS and BEM, as well as government agencies including the National Statistical Office, the Ministry of Transport, MRTA, SRT, and the Bangkok Metropolitan Administration (Knight Frank Thailand, 2023; Ministry of Interior Regulation, 2013). All data will be normalized prior to weighting using the IEW method to construct the TOD Score in the next step. Details of data collection for each dimension are presented in Table 1.

Fig. 1 illustrates the calculation of POI within a 500-meter radius around a mass transit station. The colored dots surrounding the station represent different types of places, such as schools, hospitals, markets, convenience stores, transport services, warehouses, workplaces, and villages. The purpose of collecting this data is to survey what kinds of key facilities are located around the station, how many there are, and how far each one is from the station. This information makes it possible to evaluate the station’s potential to attract people and is also useful for urban development planning—for example, if there are many schools or workplaces near the station, it is likely to increase ridership. Ultimately, all of this data will be used to calculate the TOD Score (Transit-Oriented Development Score), which serves as an indicator of the efficiency and suitability of development in the station area.

Analytical framework

This study employs a multidimensional analytical framework grounded in the Node–Place Model (Bertolini, 1999), which explains the relationship between mass transit stations and the surrounding urban areas. The framework is further extended through the Node–Functionality–Place (NFP) model (Su *et al.*, 2021) to emphasize “functionality” as a linking dimension between the rail transit system and land use. In addition, the Land-use Transport Feedback Cycle concept (Wegener, 1999) is applied to explain how accessibility and station-area activities influence one another. The researcher collected data on six key dimensions of rail transit stations based on the 6Ds principle developed by Cervero and Kockelman (1997) and Ewing and Cervero (2010), in order to calculate the TOD SCORE. Density measures the number of population, households, and FAR around stations to examine how intensively the area is used (Ogra & Ndebele, 2014). Design assesses the quality of the station-area environment—including sidewalks, streets, and parking—in terms of walkability and comfort (Calthorpe, 1993; Cervero & Murakami, 2010). Diversity measures the variety of activities and land uses using a Mix Index derived from the distribution of POI, covering residential uses, retail, and various services (Belzer & Autler, 2002; CTOD, 2009). Connectivity evaluates how well stations connect to other transport systems, based on the number of bus routes and station entrances/exits (Cervero, 2004; Zegras *et al.*, 2016). Destination Accessibility counts key destinations that can be reached from the station, such as schools, workplaces, and shopping malls (Jiang *et al.*, 2017; Singh *et al.*, 2017). Distance to Transit measures the distance from park-and-ride facilities and the average walking distance to destinations to assess how easily the station can be accessed (Kuby *et al.*, 2004; Chen & Zegras, 2016). To ensure neutral weighting that does not depend on subjective judgment, this study applies IEW (Shannon, 1948), a statistical approach that analyzes data variability across 114 stations to identify which indicators contribute most to differences in TOD performance in Bangkok. The weighted indicators are then combined to compute the TOD SCORE for comparing and clustering stations by their level of development (Fard, 2013; Renne, 2016). The resulting scores are used to develop a prototype web application serving as a Spatial Decision Support System (SDSS). This tool

Table 1: Explain the details of the variables in each dimension

Dimension	Basic Indicator	Impact on TOD	Operational Definition	Data Source
Density	Population Density (people/sq.km)	+	The number of people in a subdistrict per area of the	National Statistical Office / Department of Provincial
	Household Density (households/sq.km)	+	The number of households in a subdistrict per area of the subdistrict (for Bangkok, districts are used instead of subdistricts)	
	FAR	+	Floor Area Ratio	www.feasonline.com
Design	Sidewalk Density	+	Length of sidewalks near the streets around the station	Field surveys / Online maps
	Number of Parking Spaces	-	Number of parking spaces (POI) around the station	
	Road Density	+	Length of roads within the TOD radius around the station	extract.bbbike.org and GIS software analysis
Diversity	Land Use Diversity	+	Calculated based on the number of different types of POI using a Mix Index formula	Field surveys / Online maps and calculation formulas
Connectivity and demand management indicator	Number of Bus Routes	+	Number of bus routes that pass the station (counted by distinct route numbers)	Internet search on “List of train stations in Bangkok and metropolitan area”
	Number of Entrances/ Exits	+	Number of Railway Station Entrances/Exits	Internet search on “List of train stations in Bangkok and metropolitan area”
Destination accessibility indicator	Number of POI	+	Number of POI such as schools, condos, villages, clinics, hospitals, companies, delivery points, department stores, and hotels	Field surveys / Online maps
Distance to transit	Distance Between Park-and-Ride and Station	-	Distance between park-and-ride facilities and the station	Online maps
	Average Distance from POI to Station Center	-	Sum of distances from POI to the station divided by the total number of POI	Online maps

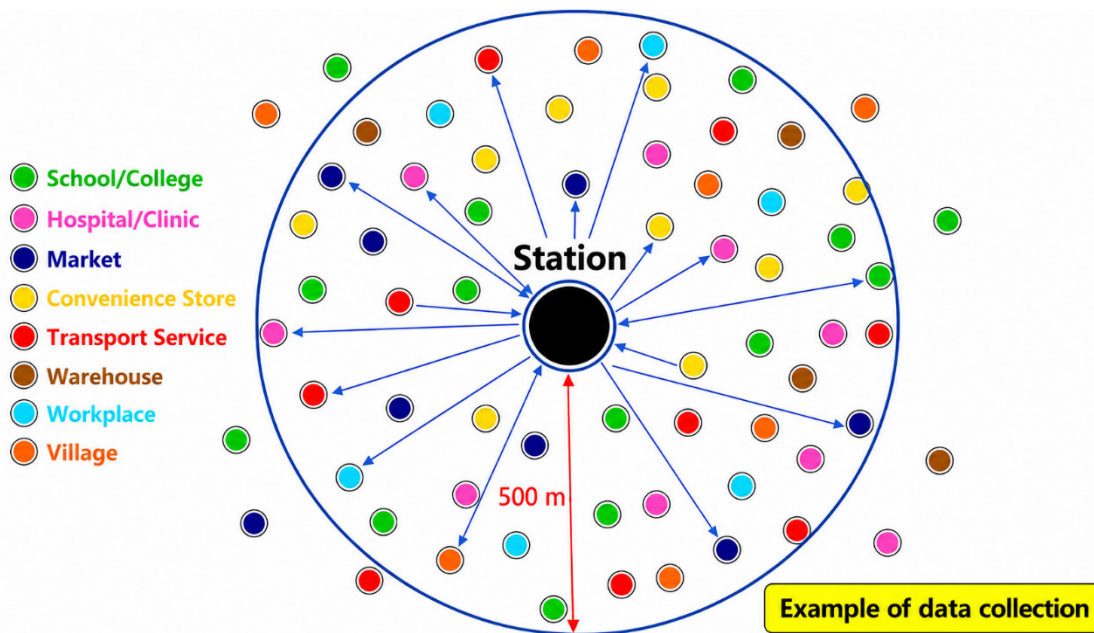


Fig. 1: Calculation of POIs within a 500-meter radius

enables agencies such as MRTA or SRT to analyze the strengths and weaknesses of each station and to formulate policies—for example, promoting mixed-use development or applying tax measures to encourage sustainable land use around stations (CTOD, 2011; Urban Redevelopment Authority, 2024), as shown in Fig. 2.

Fig. 2 shows the several factors that affect the TOD SCORE, as well as the ways the study collected data and the sources of that data. TOD is a concept that aims to make cities better places to live by making it easier to get to and utilize public transportation, which in turn encourages people to use public transportation instead of their own cars. TOD aims to reduce traffic congestion, especially from private cars; improve the development of station areas to get the most out of the land; build infrastructure that makes it easy to get around; mix land uses to make it easier to do important daily tasks like living, going to school, working, shopping, and getting medical care; and cut down on fuel use to protect the environment (Belzer & Autler, 2002; Mehndiratta & Salzberg, 2012; Calthorpe, 2014). More people and families living close together make public transportation more popular. The Floor Area Ratio (FAR) shows that land is being used more efficiently, as seen in high-rise or

high-density constructions (Ogra & Ndebele, 2014; Cervero & Murakami, 2010). The density of sidewalks makes it safe and easy for people to walk (Calthorpe, 1993). But too many parking spaces can make people want to drive more (Belzer & Autler, 2002). Road density means that there are many ways to get to transportation centers (Cascetta & Pagliara, 2016). Mixed land use makes it easier for people to use public transportation for school, work, and living (CTOD, 2011; Singh *et al.*, 2017). More bus lines that stop at a station make it easier to get around (Zegras *et al.*, 2016). The abundance of entrances and exits at the station makes it easier to go to and from the station and eases traffic (Chen & Zegras, 2016). Adding more POIs around the station makes public transportation more appealing and useful (Jiang *et al.*, 2017). On the other hand, increasing the distance between park-and-ride facilities and the station makes it less likely that people will use public transportation. In the same way, ridership goes down when attractions are far away from stations since people have to go a long way to get there (Kuby *et al.*, 2004; Chen & Zegras, 2016). The research utilized both primary and secondary data sources. We used field observations and online mapping tools to collect primary data by surveying POIs within 500-meter and 1000-meter radii

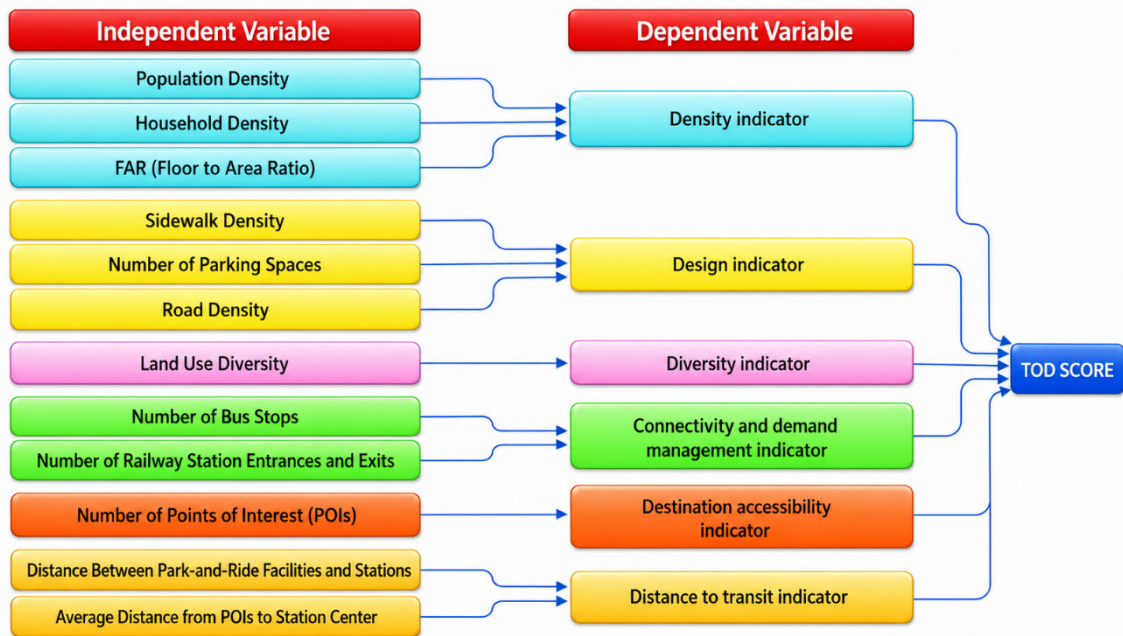


Fig. 2: Conceptual framework of the research

around electric train stations (Fard, 2013). Secondary data were obtained from governmental institutions and online platforms, such as the National Statistical Office, the Department of Provincial Administration, the Ministry of Interior, www.feasyonline.com, and extract-bbbike.org. Table 1 shows the different factors that determine the TOD SCORE, as well as the ways the researchers collected data and the sources of information they used. TOD is «a concept designed to create urban environments that make it easy to get to and use public transportation, which encourages people to use public transportation instead of their own cars» (CTOD, 2009). TOD has several main goals: to reduce traffic congestion, especially that caused by private cars; to make the most of station areas to increase land value; to build infrastructure that makes it easy and convenient to get around; to mix different types of land use so that important daily activities like living, going to school, working, shopping, and getting medical care can happen in the same area; and to use less fuel to protect the environment (Belzer & Autler, 2002; CTOD, 2011; Mehndiratta & Salzberg, 2012).

Density indicator

In this research, density refers to population density, employment density, and development within the area

surrounding a railway station. Higher population and employment density indicate a higher level of TOD (Cervero & Murakami, 2010). The density gradient can be calculated from the ratio of total building floor area to land area (FAR) around the station. A higher FAR value also indicates a higher level of TOD (Fard, 2013).

Design indicator

This refers to smooth and safe access to transit stations, such as the construction of sidewalks, bicycle lanes, and street lighting, as well as the arrangement of facilities like benches, parks, landscaping, and libraries. A well-designed area emphasizes walkability and bikeability, which enhance the convenience of using public transport and increase ridership (Calthorpe, 1993; Ogra & Ndebele, 2014). The design indicator measures urban structure design with a focus on promoting walking and the attractiveness of the built environment. For this research, road density, number of parking spaces, and sidewalk density were used as proxies for the design indicator.

Diversity indicator

This study utilized POIs as a surrogate for mixed land use (Xie, 2017). The POIs were categorized into six classifications: 1) Residential zones, 2) Public services

(e.g., governmental institutions, educational facilities, healthcare services), 3) Commercial establishments (e.g., retail outlets, entertainment venues), 4) Corporations, 5) Parks, and 6) Miscellaneous (e.g., transportation-related infrastructures, storage facilities). The extent of mixed land use was subsequently determined using a specified formula.

$$Mix = -\frac{1}{\ln n} \sum_{i=1}^n p_i \ln p_i \quad (1)$$

Where Mix = degree of mixing (Level of Mixed-Use Integration), p_i = percentage share of each type of POI, i = type of POI, n = number of POI categories

Destination accessibility indicator

This indicator demonstrates the various types of locations accessible via public transportation, including your workplace, service centers, parks, and other destinations. It examines factors such as travel duration, service frequency, and the number of required transfers to assess the accessibility of these vital locations (Verduzco Torres, 2024). Destination accessibility is crucial as it exemplifies the fundamental purpose of transportation: to facilitate individuals' access to desired activities and essential services (Victoria Transport Policy Institute, 2024). Accessible locations foster a sense of welcome, generate employment opportunities, and enhance urban living by facilitating mobility and connecting individuals with essential destinations.

Distance to transit indicator

The distance to transit denotes the physical space an individual must traverse to reach a transit station or stop. The shorter the distance to transit, the more it enhances the efficiency and appeal of public transportation, as reduced distances promote walking as the primary means of access. Acceptable walking distances vary among cities due to variations in urban design, climate, and socio-cultural influences. For example, although a walking distance of 400 to 800 meters (approximately a 5 -10-minute walk) is frequently referenced in numerous studies, recent research indicates that individuals may be inclined to walk significantly greater distances based on the quality of the walking environment and personal attributes (Ewing & Cervero, 2010; Naess, 2015; Smith et al., 2015). A study of transit users revealed that those located two miles from a transit stop had

approximately a 50% likelihood of walking instead of utilizing motorized transport to access the station, indicating significant variability in walking behaviors (Durand et al., 2015).

Composite TOD index

Calculation of TOD Score. The researcher applied IEW to determine the weight of each variable, following the approaches of Jiang et al., (2016) and Y. Xie et al., (2017), which were originally developed by Shannon and Weaver (1948). The calculation steps are as follows:

1) Decision matrix construction. A data matrix is constructed as: $X = (X_{ij})_{m \times n}$, where m = number of stations, n = number of TOD indicators, X_{ij} = the value of indicator j for station i . 2) Normalization of the decision matrix. This step eliminates the effect of different measurement units of each variable to obtain standardized quantitative index values for comparison. These standardized values are denoted as X'_{ij} . For variables that have a positive effect on TOD, the normalized value can be calculated using Eqs. 2-4 as follows:

$$X'_{ij} = \frac{X_{ij} - X_{j \min}}{X_{j \max} - X_{j \min}} \quad (2)$$

For variables that hurt TOD

$$X'_{ij} = \frac{X_{j \max} - X_{ij}}{X_{j \max} - X_{j \min}} \quad (3)$$

X'_{ij} = the standardized quantitative index value of indicator j at station i , after normalization. X_{ij} = the original value of indicator j at station i . $X_{j \min}$ = the minimum value of indicator j among all stations considered. $X_{j \max}$ = the maximum value of indicator j among all stations considered.

Entropy calculation for each indicator

The entropy of indicator j is:

$$H_j = -\frac{1}{\ln m} \sum_{i=1}^m p_{ij} \ln p_{ij} \quad (4)$$

H_j = the entropy value of each indicator j . m = the number of stations. p_{ij} = the proportion of the standardized quantitative value of indicator j at station i to the sum across all stations.

$$p_{ij} = \frac{X'_{ij}}{\sum_{k=1}^m X'_{kj}} \quad (5)$$

$i=1,2,3,\dots,m$ and $j=1,2,3,\dots,n \rightarrow$ where m is the number of stations and n is the number of indicators, respectively. If $p_{ij} = 0$, assume $\ln p_{ij} = 0$. In general, if the

Table 2: TOD indicators and weight calculation using the IEW method

Dimension	Basic Indicator	Impact on TOD	Weight	
			500 m	1000 m
Density	Population Density (people/sq.km)	+	0.12	0.08
	Household Density (households/sq km)	+	0.14	0.12
	FAR (the ratio of total building floor area to land area)	+	0.06	0.07
Design	Sidewalk Density	+	0.13	0.14
	Number of Parking Spaces	-	0.15	0.08
	Road Density	+	0.03	0.05
Diversity	Land Use Diversity	+	0.03	0
Connectivity and demand management	Number of Bus Routes	+	0.1	0.11
	Number of Railway Station Entrances/Exits	+	0.07	0.08
Destination accessibility	Number of POIs	+	0.11	0.19
Distance to transit	Distance Between Park-and-Ride and Station	-	0.01	0.01
	Average Distance from POI to Station Center	-	0.04	0.08

entropy value is low, it indicates a higher degree of variation and greater information content. This leads to a larger weight being assigned to that indicator in the TOD calculation. Calculate the imbalance coefficient of each indicator.

$$G_j = 1 - H_j \quad (6)$$

G_j = the degree of divergence (or information utility) of indicator j . H_j = the entropy value of each indicator.

Weight calculation of each indicator

$$W_j = \frac{G_j}{\sum_{j=1}^n G_j} \quad (7)$$

W_j = the weight of indicator j . G_j = the degree of divergence of indicator j .

Compute the TOD SCORE for each station

$$V_i = \sum_{j=1}^n W_j X'_{ij} \times 100 \quad (8)$$

V_i is the TOD score of the station; n is the number of indicators that affect TOD. W_j is the weight of indicator j . X'_{ij} is the standardized quantitative index value of indicator j affecting TOD at station i .

RESULTS AND DISCUSSION

For the calculation of the weights of each factor influencing the TOD SCORE using the IEW method, the results are as follows:

From Table 2, the researcher calculated the weights of 12 indicators, divided into six dimensions: 1) density, 2) diversity, 3) design, 4) diversity, 5) connectivity and demand management, and 6) distance to public transit. The weights were calculated in two forms: 1) within a 500-meter radius of the station and 2) within a 1,000-meter radius of the station. The results of the weight calculation are as follows. In the density dimension, the weights of population density and household density within a 500-meter radius are higher than within a 1,000-meter radius, while the FAR weights are similar in both radii. In the design dimension, sidewalk density weights are similar in both 500 and 1,000 meters, parking facility weights are higher within 500 meters than 1,000 meters, and road density weights are lower at 500 meters compared to 1,000 meters. In the diversity dimension, the weight of land-use diversity within a 500-meter radius is higher than within a 1,000-meter radius, because the number of POIs at 500 and 1,000 meters varies significantly, leading to different results when calculating diversity. In the

connectivity and demand management dimension, the weights of bus routes and the number of station entrances and exits are similar in both 500 and 1,000 meters. In the destination accessibility dimension, the weight of POI at 500 meters is lower than at 1,000 meters, because the number of POI within 1,000 meters is considerably greater than within 500 meters. In the distance to transit dimension, the weight of park-and-ride distance is similar in both 500 and 1,000 meters, while the average distance of POIs to the station center is lower at 500 meters compared to 1,000 meters.

From Table 3, it is found that within a 500-meter radius, each transit line has the following average TOD scores: Sukhumvit Line (Light Green) – Average TOD Score: 34.94, Silom Line Dark Green) – Average TOD Score: 45.48 Airport Rail Link – Average TOD Score: 36.92 Krung Thonburi Line (Gold) – Average TOD Score: 43.23 Thani Ratthaya Line (Dark Red) – Average TOD Score: 26.55 Nakhon Withi Line (Light Red) – Average TOD Score: 23.73 Chat Chai Line (Pink) – Average TOD Score: 29.93. From these values, it can be explained that lines with stations located within densely populated areas of Bangkok tend to have higher TOD scores than those with stations outside Bangkok. For the density dimension, the Krung Thonburi and Silom Lines have higher average TOD scores than other lines, while the Thani Ratthaya and Nakhon Withi Lines have lower averages. For the design dimension, the Thani Ratthaya and Silom Lines score higher than others, while the Krung Thonburi and Nakhon Withi Lines score lower. For the diversity dimension, the Chat Chai and Krung Thonburi Lines score higher, while the Nakhon Withi and Thani Ratthaya Lines score lower. For the connectivity and demand management dimension, the Sukhumvit and Silom Lines score higher, while the Nakhon Withi and Thani Ratthaya Lines score lower. For the destination accessibility dimension, the Krung Thonburi Line, Airport Rail Link, and Silom Line score higher, while the Thani Ratthaya and Chat Chai Lines score lower. For the distance to transit dimension, the Nakhon Withi and Thani Ratthaya Lines score higher than other lines, while the Krung Thonburi and Silom Lines score lower.

Table 4 shows that each transit route has the following average TOD scores within a 1,000-meter radius: The average TOD score for the Light Green Sukhumvit Line is 36.36. The Silom Line (Dark Green) has an

average TOD score of 40.00. Airport Rail Connection: Average TOD Score: 36.40. The average TOD score for the Gold Krung Thonburi Line is 45.09. The average TOD score for the Thani Ratthaya Line (Dark Red) is 29.52. There is an average TOD score of 25.01 for the Nakhon Withi Line (Light Red). Chat Chai Line (Pink) - Average TOD Score: 30.54. These numbers show that transit lines that serve Bangkok's most densely populated neighborhoods have higher TOD scores than those that serve areas outside the city, where the population density is lower. The Krung Thonburi and Silom Lines have higher average TOD scores for the density dimension, whereas the Thani Ratthaya and Chat Chai Lines have lower scores. The Thani Ratthaya and Sukhumvit Lines get higher design scores than the Nakhon Withi Line and Airport Rail Link, which get lower scores. In terms of diversity, all lines have almost the same average TOD scores. The Sukhumvit and Silom Lines are better at connecting and managing demand than the Nakhon Withi and Thani Ratthaya Lines. The Krung Thonburi Line and Airport Rail Link are better than the Silom and Chat Chai Lines at getting you to your destination. The Krung Thonburi Line and Airport Rail Link are rated higher for how far away they are from transportation, whereas the Nakhon Withi and Thani Ratthaya Lines are rated lower. Tables 4 and 5 support the same idea: the TOD score goes up when a transit route has stops in Bangkok, especially in areas with a lot of people. The number of people living in a square kilometer (persons/km²), the number of dwelling units in a square kilometer (households/km²), and the Floor Area Ratio (FAR) all affect the density dimension. When you do the maths for distances of 500 m and 1,000 m, you always get the same answer. The only differences are due to the different weights used. The number of pathways, parking spots, and highways affects the design dimensions. Calculating distances of 500 m and 1,000 m gives answers that are partly the same, but changes in the length of the pavements, parking spaces, and roads between the two radii cause problems. Land-use diversity determines the variety dimension. This is measured by the number of different sorts of POI, such as schools, condominiums, housing estates, clinics, hospitals, businesses, logistics centers, shopping malls, restaurants, and hotels. The 500 m and 1,000 m radii yield disparate outcomes owing to substantial variations in point of interest counts within categories. The connection and demand management

Table 3: The TOD scores of each studied urban rail transit line, calculated based on POIs within a 500-meter radius

Line	Statistical Value	Density	Design	Diversity	Connectivity and demand management	Destination accessibility	Distance to transit	TOD Score
Sukhumvit Line (Light Green Line)	Average	9.3	10.4	1.7	8.2	2.6	2.8	34.9
	Standard Deviation	3.5	3.5	0.6	3.3	1.4	0.8	8.2
	Minimum	2.1	4.3	0.1	1.3	0.7	1.4	19.1
	Maximum	19.1	16.3	2.6	14.5	6.0	5.5	49.6
Silom Line (Dark Green Line)	Average	19.6	10.7	1.8	6.7	4.1	2.5	45.5
	Standard Deviation	7.0	4.9	0.3	2.4	2.2	0.5	7.7
	Minimum	6.7	4.1	1.3	1.6	0.2	1.8	37.0
	Maximum	27.3	18.7	2.2	11.0	7.0	3.5	63.4
Airport Rail Link	Average	13.4	10.4	1.5	4.8	4.2	2.7	36.9
	Standard Deviation	9.0	3.2	0.6	2.9	3.9	0.9	12.3
	Minimum	0.4	6.6	0.6	1.2	0.5	1.4	22.5
	Maximum	28.2	16.0	2.1	8.7	11.2	4.0	57.5
Krung Thonburi Line (Gold Line)	Average	23.2	5.9	1.9	5.4	4.6	2.3	43.2
	Standard Deviation	0.1	2.9	0.1	1.9	0.3	0.5	5.1
	Minimum	23.0	2.1	1.7	3.0	4.3	1.6	40.0
	Maximum	23.3	9.1	2.1	7.7	5.0	2.9	49.1
Thani Ratthaya Line (Dark Red Line)	Average	6.6	10.8	1.5	3.2	1.6	2.9	26.6
	Standard Deviation	3.5	8.7	0.7	1.3	0.7	1.0	10.4
	Minimum	2.2	1.4	0.0	1.6	0.4	1.6	13.1
	Maximum	11.0	23.9	2.5	6.1	3.0	4.8	41.0
Nakhon Withi Line (Light Red Line)	Average	7.5	6.4	0.9	2.9	2.2	3.8	23.7
	Standard Deviation	5.5	2.7	0.3	0.8	1.4	0.7	6.3
	Minimum	4.0	4.7	0.6	2.2	0.7	3.0	16.9
	Maximum	13.9	9.6	1.3	3.7	3.2	4.5	29.2
Chatuchai Line (Pink Line)	Average	9.1	7.9	1.9	6.3	1.9	2.8	29.9
	Standard Deviation	4.3	3.6	0.4	2.2	1.6	0.7	6.4
	Minimum	4.0	3.0	1.0	1.2	0.0	0.9	18.2
	Maximum	18.4	18.7	2.5	11.1	5.3	4.5	44.8

Table 4: TOD scores of each studied urban rail transit line, calculated based on POI within a 1,000-meter radius

Line	Statistical Value	Density	Design	Diversity	Connectivity and demand management	Destination accessibility	Distance to transit	TOD Score
Sukhumvit Line (Light Green Line)	Average	10.7	11.4	0.2	8.8	2.3	2.9	36.4
	Standard Deviation	5.6	2.8	0.0	3.5	1.8	1.0	10.2
	Minimum	1.4	5.9	0.1	1.4	0.0	1.0	18.7
	Maximum	25.9	16.6	0.2	15.6	6.5	5.6	59.4
Silom Line (Dark Green Line)	Average	16.6	10.9	0.2	7.2	1.8	3.3	40.0
	Standard Deviation	4.0	2.3	0.0	2.6	1.1	1.1	5.2
	Minimum	7.9	6.8	0.2	1.7	0.5	1.9	30.0
	Maximum	21.1	14.6	0.2	11.9	4.8	5.6	49.0
Airport Rail Link	Average	10.6	9.5	0.2	5.2	7.5	3.4	36.4
	Standard Deviation	7.1	2.3	0.0	3.1	6.4	2.0	16.3
	Minimum	0.5	6.1	0.1	1.3	1.0	1.2	18.0
	Maximum	22.1	12.3	0.2	9.4	18.6	7.6	63.5
Krung Thonburi Line (Gold Line)	Average	16.9	9.7	0.2	5.9	9.0	3.5	45.1
	Standard Deviation	0.2	1.6	0.0	2.1	0.5	0.3	3.2
	Minimum	16.6	7.5	0.2	3.3	8.3	3.2	43.0
	Maximum	17.1	11.1	0.2	8.3	9.6	3.8	48.7
Thani Ratthaya Line (Dark Red Line)	Average	6.3	12.8	0.2	3.4	4.2	2.7	29.5
	Standard Deviation	1.4	7.8	0.0	1.4	0.9	0.7	8.9
	Minimum	3.6	4.7	0.2	1.7	2.9	2.0	16.8
	Maximum	8.0	24.4	0.2	6.6	5.3	4.1	42.1
Nakhon Withi Line (Light Red Line)	Average	8.4	7.2	0.2	3.1	3.8	2.3	25.0
	Standard Deviation	2.3	1.9	0.0	0.8	1.7	0.2	6.3
	Minimum	6.0	5.1	0.2	2.4	1.9	2.1	17.8
	Maximum	10.6	8.6	0.2	4.0	4.8	2.5	28.9
Chatuchai Line (Pink Line)	Average	7.9	9.5	0.2	6.8	2.7	3.4	30.5
	Standard Deviation	3.4	3.4	0.0	2.4	2.5	1.4	5.4
	Minimum	4.0	5.0	0.2	1.3	0.0	0.9	18.3
	Maximum	17.5	19.5	0.2	12.0	6.9	6.9	41.6

elements are based on how many bus lines there are and how many entrances and exits there are at each station. Because there are the same number of bus routes and entrances/exits for both distances, the calculations for lengths of 500 m and 1,000 m give the same results. The number of POIs affects how easy it is to go to the place. The computations for 500 m and 1,000 m are mostly the same, although there are some differences because there are more POI inside the 1,000 m radius. The distance of the transit distance is based on how close the station is to park-and-ride facilities and how far away attractions of interest are from the station center on average. The estimates for 500 m and 1,000 m are different because the distances between the park-and-ride and POI are very different for the two radii.

TOD score in each dimension of the station

The researcher calculated the TOD Score of each station using POIs within 500 meters and 1,000 meters around the transit stations. For the average TOD Score across all dimensions:

A TOD Score below 25.3 indicates that the level of development around the station area is very low.

A TOD Score between 25.3 and 31.0 indicates that the level of development around the station area is low.

A TOD Score between 31.0 and 37.0 indicates that the level of development around the station area is moderate. A TOD Score between 37.0 and 41.8

indicates that the level of development around the station area is high. A TOD Score above 41.8 indicates that the level of development around the station area is very high.

Table 5 shows an example of the TOD Scores of Each Station, calculated based on POIs within a 500-Meter Radius, which presents the TOD assessment of selected stations. The TOD Score is derived from six key dimensions: Density, Design, Diversity, Connectivity and Demand Management, Destination Accessibility, and Distance to Transit. The combination of these dimensions provides an overall score that reflects the development potential of each station area. High-scoring stations include Saint Louis (63.44) and Phaya Thai (57.53). These stations demonstrate high density, strong accessibility, and favorable design characteristics, indicating very high TOD potential. Moderately scoring stations such as Bang Wa (36.98), Charoen Nakhon Iconsiam (40.03), Lak Si (40.95), Chaeng Watthana–Pak Kret 28 (44.84), and Wat Phra

Sri Mahathat (43.33) fall within the medium-to-high development range. These stations exhibit balanced performance across the TOD dimensions. Low-scoring stations such as Srinagarindra (19.10), Taling Chan (16.91), and Chatuchak (13.12) show weak performance in most dimensions, particularly in density, connectivity, and accessibility, indicating low TOD potential. Suvarnabhumi (22.49) and Bang Son (29.21) are categorized as relatively low to moderate in TOD potential due to weak land-use diversity and accessibility, despite moderate design or connectivity scores. Overall, the table highlights that stations located in central urban areas (e.g., Saint Louis, Phaya Thai, Ha Yaek Lat Phrao) tend to achieve higher TOD Scores due to higher density and better accessibility, while peripheral or less-connected stations (e.g., Chatuchak, Taling Chan, Srinagarindra) score lower due to limited development intensity and connectivity challenges.

Table 6 shows how several transit stops performed on the TOD test: This shows the TOD scores for each station, which were based on sites of interest (POI) that were within 1,000 meters of the station. The six sections of the TOD Score—Density, Design, Diversity, Connectivity and Demand Management, Destination Accessibility, and Distance to Transit—are identical to the 500-meter research. The stations with the best TOD scores are Ratchathewi (59.38) and Phaya Thai (63.45). They may have done so well because they are densely populated and easy to get to, which means they are close to city activities and have a lot of connections. Sala Daeng (49.00) and Krung Thon Buri (48.73) are both in the midst of a huge city and have good connections to other places, which is why they are ranked so high. Wat Phra Sri Mahathat (41.62), Lak Si (42.06), and Charoen Nakhon Iconsiam (42.99) are all stations that get medium to high scores. These stations aren't as crowded as the ones in the Central Business District (CBD), but they have unique architecture and do well in all areas. Bang Son (28.94) and Bang Wa (30.02) are at the bottom of the moderate range, with scores that are not very high. They have good design and density, but they can't create transit-oriented neighborhoods since they don't have enough land-use diversity and are hard to get to. The stations with the lowest scores are Bearing (23.45), Ban Thap Chang (17.98), Taling Chan (17.75), Si Rat (18.34), and Lak Hok Rangsit University (16.76). These are largely peripheral stations that aren't ex-

Table 5: Example of the TOD scores of each Station, calculated based on POIs within a 500-meter radius

Station	Density	Design	Diversity	Connectivity and demand management	Destination accessibility	Distance to transit	TOD SCORE
Ha Yaek Lat Phrao	9.03	14.81	2.56	14.48	5.49	3.2	49.56
Srinagarindra	6.19	6.38	1.8	1.26	1.61	1.85	19.1
Saint Louis	27.19	18.74	1.75	6.69	7.03	2.05	63.44
Bang Wa	15.99	9.54	1.99	4.23	2.93	2.31	36.98
Suvarnabhumi	0.43	12.17	0.95	4.03	0.88	4.04	22.49
Phaya Thai	28.18	9.77	0.6	5.59	11.2	2.19	57.53
Krung Thon Buri	23.28	9.1	1.71	7.68	4.98	2.34	49.09
Charoen Nak-hon Iconsiam	23.28	2.11	1.93	5.54	4.25	2.92	40.03
Lak Si	9.51	22.68	1.9	3.71	1.46	1.68	40.95
Chatuchak	3.05	1.37	1.25	3.08	1.68	2.68	13.12
Taling Chan	3.98	4.99	0.63	2.2	0.66	4.46	16.91
Bang Son	13.87	4.66	0.84	2.77	3.22	3.85	29.21
Chaeng Watthana–Pak Kret 28	18.42	8.64	2.4	6.74	5.04	3.6	44.84
Wat Phra Sri Mahathat	11.5	16	1.58	8	2.86	3.39	43.33

cellent for TOD since they don't have a lot of diverse forms of land use, aren't well-connected, and have lower urban density.

Fig. 3 illustrates the web application interface displaying the TOD Score of an individual station in relation to the average score of the entire transit line. It employs a table and a radar image to substantiate its argument. The green line represents the score of the selected station, while the blue line indicates the average score. The evaluation comprises six components: Density, Design, Diversity, Connectivity and Demand Management, Destination Accessibility, and Distance to Transit. The station performs above average in nearly all categories, particularly in Densi-

ty, Design, Destination Accessibility, and Distance to Transit. However, it performs somewhat below average in diversity. This indicates that, despite the station's limited array of adjacent activities, it possesses significant potential for density, architectural development, and accessibility. The primary objective of enhancement should be to augment the diversity of interests surrounding the station.

Discussion

In this study, the researcher calculated the TOD SCORE of electric train stations in Bangkok by building on the previous study by Xie (2017), which analyzed Beijing and Singapore using IEW. The key strength

Table 6: Example of the TOD scores of each station, calculated based on POIs within a 1,000-meter radius

Station	Density	Design	Diversity	Connectivity and demand management	Destination accessibility	Distance to transit	TOD SCORE
Ratchathewi	25.78	14.3	0.18	9.31	6.46	3.34	59.38
Bearing	7.2	10.26	0.23	4.57	0.2	1	23.45
Sala Daeng	21.08	11.63	0.18	9.25	2.79	4.08	49
Bang Wa	12.37	10.18	0.23	4.57	0.54	2.14	30.02
Ban Thap Chang	3.09	10.06	0.24	1.3	2.11	1.18	17.98
Phaya Thai	22.06	12.3	0.14	6.04	18.56	4.35	63.45
Krung Thon Buri	17.06	11.07	0.21	8.29	8.29	3.81	48.73
Charoen Nak-hon Iconsiam	17.06	7.46	0.21	5.98	9.04	3.24	42.99
Lak Hok Rangsit University	3.63	4.65	0.22	1.69	3.81	2.77	16.76
Lak Si	7.3	23.31	0.22	4	4.89	2.33	42.06
Taling Chan	5.97	5.12	0.19	2.37	1.9	2.2	17.75
Bang Son	10.58	8	0.2	2.99	4.69	2.48	28.94
Si Rat	3.97	5.09	0.21	1.3	3.32	4.45	18.34
Wat Phra Sri Mahathat	9.35	18.76	0.22	8.63	2.65	2.02	41.62

of this study that fills the literature is expanding the scope from four dimensions (Density, Diversity, Design, Connectivity) to six dimensions by adding Destination Accessibility and Distance to Transit, which is consistent with the expansion of TOD indicators from the “3Ds” to the “6Ds,” and this fits the context of countries with rapid urban development such as China (Liang et al., 2020). In addition, the six-dimensional framework is linked to the Node-Functionality-Place Model, which emphasizes “Functionality,” also called connectivity that facilitates walking and access, and this is considered the key to success in TOD projects (Su et al., 2021a; Su et al., 2022). Findings consistent with previous studies are that Population Density, the number of POIs, and the number of bus routes have high weights on the TOD SCORE. This is confirmed by research in Shenzhen showing that bus density and mixed-use land use are the main factors driving urban vibrancy around electric train stations (Xiao et al., 2021), while road density and the number of station

entrances/exits have lower impacts. However, this study found that parking facilities have increased importance weight compared with Xie (2017), reflecting Thailand’s travel context, which still relies on private cars to access the rail system (feeder system), unlike Singapore or Beijing, which have denser feeder transport systems. In addition, the results also show clear spatial differences, where stations in the core area such as Saint Louis and Phaya Thai have higher performance than peripheral stations such as Lak Hok. This is consistent with phenomena in Tokyo and Chinese megacities showing that TOD sustainability decreases with distance from the city center (Su et al., 2021a; Yang et al., 2024). This issue reflects the problem of spatial inequality in Bangkok under neoliberal policies that emphasize commercial development in key economic areas, which may lead to “gentrification,” or rising housing prices in areas with high TOD scores, making it difficult for low-income people to access (Kidokoro et al., 2022; Su et al., 2021b). There-

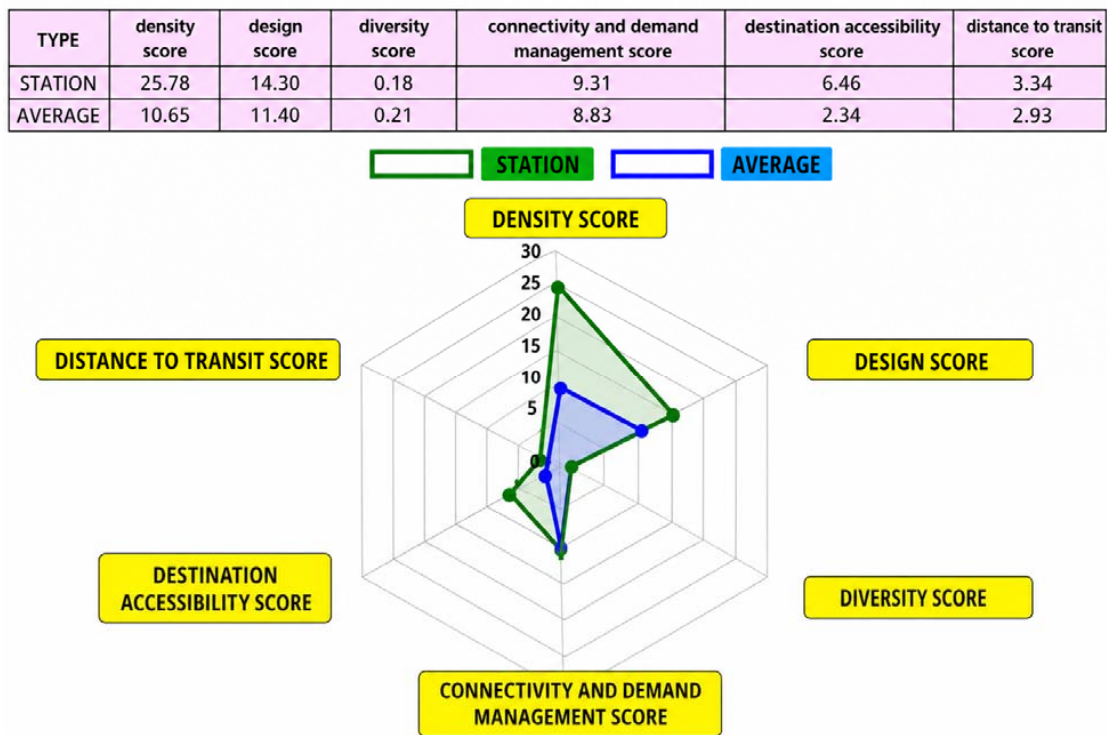


Fig. 3: Visualization of TOD score on the web application

fore, the development of the Web Application tool in this study is considered an innovation that helps policymakers evaluate station-level performance (micro-scale evaluation) and define area-specific strategies (typology-based strategy) to reduce development gaps and promote equity in sustainable access to mass transit (Li & Gu, 2025; Su et al., 2022).

Recommendations

This study reveals substantial spatial differences in the efficiency of TOD across Bangkok's train network, necessitating tailored strategies for each station rather than uniform standards applicable to the entire system. Planning agencies should adopt typology-based strategies that prioritize investments according to station classifications: «Undersupplied TODs,» marked by considerable urban activity but inadequate connectivity, require immediate infrastructure improvements, while «Underdeveloped TODs» in suburban areas such as Lak Hok necessitate mixed-use zoning reforms and density incentives to enhance urban vitality (Su et al., 2021a; Wu & Divigalpitiya, 2023; Li & Gu, 2025; Ding et al., 2025). Secondly, con-

sidering that high-performing TOD areas generally incur rental premiums of 10-20% (Su et al., 2021b; Yang et al., 2024), governments must establish social equity measures, such as mandates for affordable housing and provisions for student accommodations, within the primary 500-meter catchments to avert economic displacement and spatial inequality (Kidokoro et al., 2022; Lai & Tran, 2025; Yang et al., 2024). Third, planners should adopt a Node-Place-Ecology (NPE) model that integrates environmental aspects, including the provision of green spaces and clean energy technologies, while also enhancing sidewalk density and human-scale design to diminish automobile reliance and bolster sustainable tourism vitality (Yang et al., 2024; Ding et al., 2025; Xiao et al., 2021). The web application must be improved by incorporating big data analytics that integrates social media and mobile positioning data for real-time assessments of urban vibrancy, supplemented by sophisticated spatial statistical models like Multiscale Geographically Weighted Regression (MGWR) to accurately analyze the spatial impact of TOD factors on property values (Xiao et al., 2021; Yu et al., 2022; Yang et al., 2024). Future

research should focus on cross-city comparative analyses in developing countries with emerging transit systems (Ali et al., 2025) and examine Land Value Capture (LVC) mechanisms and Rail+Property (R+P) models to generate sustainable financing streams for long-term transit infrastructure development (Wu & Divigalpitiya, 2023; Ravindran et al., 2024).

CONCLUSION

The main factors affecting TOD performance in Bangkok are density, design, and connectivity, which is consistent with the concept of “Functionality” that links transit accessibility together with urban place-making (Su et al., 2021a; Xiao et al., 2021). High TOD scores in this study reflect high population density and a high number of POIs around stations. The results of this study are consistent with the phenomenon of the “monopolization of central stations” observed in Tokyo and the “integrated” typology in Shanghai. In this study, Saint Louis and Phaya Thai stations ranked highest because they have strong urban amenities. In contrast, peripheral stations such as Chatuchak and Lak Hok have lower TOD SCORE, reflecting the “unsustained node” typology commonly found in Asian megacities under neoliberal urban planning, where infrastructure development often happens faster than land development. This study contributes to the literature by validating the multidimensional “6Ds” evaluation framework, which extends traditional models by adding destination accessibility and distance to transit, as a planning tool for the Global South (Liang et al., 2020; Ali et al., 2025). In practice, the findings suggest that policymakers should move beyond “one-size-fits-all” approaches and adopt typology-based interventions. Future development should not only promote mixed-use projects but should also implement Land Value Capture (LVC) or “Rail+Property (R+P)” strategies to secure funding for affordable social housing and student housing, reduce the risk of displacement caused by gentrification, and improve urban social welfare (Kidokoro et al., 2022; Lai & Tran, 2025; Wu & Divigalpitiya, 2023). In addition, the developed prototype web application is an innovative spatial planning support system that enables real-time benchmarking. To advance the field further, other researchers should integrate ecological indicators into this framework to transition toward a holistic Node-Place-Ecology (NPE) model and to ensure urban sustainability amid demographic changes and urban shrinkage (Yang et al., 2024; Ding et al., 2025).

AUTHOR CONTRIBUTIONS

Krisada Saensomboon, First Author, as the project leader, was responsible for securing research funding, conducting the literature review, collecting related documents, designing the experiment, carrying out field data collection, analyzing and interpreting the data, developing the Web Application, preparing the manuscript, and revising the manuscript. Rapee Udomsub, Corresponding Author, as the project researcher, was responsible for designing the experiment, conducting field data collection, sourcing the software used in the research, analyzing and interpreting the data, providing consultation to the project leader, and revising the manuscript.

ACKNOWLEDGEMENT

The researcher expresses deep gratitude to the Panyapiwat Institute of Management for providing research funding through the Research Development for Industry Project for the year 2024. The study acknowledges the Mass Rapid Transit Authority of Thailand (MRTA) for providing the necessary data. The researcher extends gratitude to CP ALL Public Company Limited, the affiliated organisation, for granting permission and offering staff support for this research. The researcher extends appreciation to the Assistant Prof. Dr. Salilatip Tipyaikraisorn, Dean of the Faculty of Logistics and Transportation Management, and Asst. Prof. Dr. Anupong Thuenginatham, Associate Dean of the Faculty of Logistics and Transportation Management, for their steadfast support in the execution of this study.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the research, authorship, or publication of this article. All ethical principles in research, including informed consent, data integrity, and originality of the work, have been strictly adhered to.

OPEN ACCESS

©2026 The author(s). This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution, and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third-party material in this article are included in the article's Creative

Commons license unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit: <http://creativecommons.org/licenses/by/4.0/>

PUBLISHER NOTE

Tehran Urban Research & Planning Centre (TURPC) takes a neutral position on claims on disputed territories, place names, international boundaries, jurisdiction in published maps, and institutional affiliations. TURPC is committed to retracting a paper after its publication if it becomes apparent that there are serious problems in its content, in terms of research and publication ethics (<https://www.ijhcum.net/journal/process?ethics>).

ABBREVIATIONS (NOMENCLATURE)

<i>BEM</i>	Bangkok Expressway and Metro Public Company Limited
<i>BTS</i>	Bangkok Mass Transit System Public Company Limited
<i>eq.</i>	Equation
<i>FAR</i>	Floor Area Ratio
<i>Fig.</i>	Figure
G_j	The degree of divergence (or information utility) of indicator j
H_{ij}	The entropy value of each indicator j
<i>IEW</i>	Information Entropy Weight Method
<i>LVC</i>	Land Value Capture
m	Number of stations
<i>MGWR</i>	Multiscale Geographically Weighted Regression
<i>MRTA</i>	Mass Rapid Transit Authority of Thailand
n	Number of TOD indicators
p_{ij}	The proportion of the standardized quantitative value of indicator j at station i to the sum across all stations.
<i>POI</i>	Points of Interest
<i>SRT</i>	State Railway of Thailand

<i>TOD</i>	Transit-Oriented Development
V_i	TOD score of the station
W_j	Weight of indicator j
X_{ij}	The original value of indicator j at station i
X'_{ij}	The standardized quantitative index value of indicator j at station i , after normalization
$X_{j\max}$	The maximum value of indicator j among all stations considered
$X_{j\min}$	The minimum value of indicator j among all stations considered

REFERENCES

- Ali, M. M.; Alssadah, G. M.; Yu, Y.; Altahir, M. M.; Damos, M. A.; Zhou, R.; Abdrhman, H., (2025). Evaluating transit-oriented development (TOD) in Khartoum: A spatial analysis of bus terminals. *J. Urban Manage.*, 14: 717–734 (18 pages).
- Barter, P.A., (2013). Singapore's mobility model: Time for an update?. In: Canzler, W.; Kaufmann, V.; Kesselring, S. (Eds.), *Megacity mobility culture: How cities move on in a diverse world*, Springer, Heidelberg, pp. 225–242 (18 pages).
- Belzer, D.; Autler, G., (2002). Countering sprawl with transit-oriented development. *Issues Sci. Technol.*, 19(1): 51–58 (8 pages).
- Belzer, D.; Autler, G., (2002). Transit-oriented development: Moving from rhetoric to reality. *Brookings Inst. Center on Urban and Metropolitan Policy*, Washington, DC, USA.
- Bertolini, L., (1999). Spatial development patterns and public transport: The application of an analytical model in the Netherlands. *Plann. Pract. Res.*, 14(2): 199–210 (12 pages).
- Calthorpe, P., (1993). *The next American metropolis: Ecology, community, and the American dream*. Princeton Architectural Press, New York, USA.
- Calthorpe, P.; Yang, B.; Zhang, Q., (2014). *Transit oriented development in China: A manual of land-use and transportation for low carbon cities* (1st ed.). China Architecture & Building Press.
- Cascetta, E.; Pagliara, F., (2016). Rail friendly transport and land-use policies: The case of the regional metro system of Naples and Campania. In *Transit oriented development*, pp. 49–63 (15 pages).
- Cervero, R., (2004). *Transit-oriented development in the United States: Experiences, challenges, and prospects*. Transportation Research Board, Washington, DC, USA.
- Cervero, R.; Ferrell, C.; Murphy, S., (2002). Transit-oriented development and joint development in the United States: A literature review. *TCRP Res. Results Digest*, 52: 1–144 (144 pages).
- Cervero, R.; Kockelman, K., (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transp. Res. Part D*, 2(3): 199–219 (21 pages).
- Cervero, R.; Murakami, J., (2010). Effects of built environments on vehicle miles traveled: Evidence from 370 US urbanized areas. *Environ. Plann. A*, 42(2): 400–418 (19 pages).
- Chen, S.H.; Zegras, C., (2016). Rail transit ridership: Station-area analysis of Boston's Massachusetts Bay transportation authority. *Transp. Res. Rec.*, 2544(1): 110–122 (13 pages).
- Cherry, C.; Weinert, J.; Ma, C., (2007). The environmental impacts of

- electric bikes in Chinese cities (UCB-ITS-VWP-2007-2). UC Berkeley Center for Future Urban Transport: A Volvo Center of Excellence.
- CTOD, (2009). Why transit-oriented development and why now? Reconnecting America, Washington, DC, USA.
- CTOD, (2011). Transit-oriented development strategic plan / Metro TOD program. Reconnecting America, Washington, DC, USA.
- De Almeida, E.S.; Haddad, E.A.; Hewings, G.J., (2010). Transport–regional equity issue revisited. *Reg. Stud.*, 44(10): 1387–1400 **(14 pages)**.
- Ding, J.; Xia, T.; Zhang, Y.; Ma, S., (2025). How does the TOD pattern affect urban tourism vitality? Insights from Nanjing based on land use and urban form. *Front. Archit. Res.* (23). **(23 pages)**.
- Durand, Casey P.; Tang Xiaohui; Gabriel, Kelley P.; Sener, Ipek N.; Oluyomi, Abiodun O.; Knell, Gregory; Porter, Anna K.; Hoelscher, Deanna M.; Kohl, Harold W., (2016). The association of trip distance with walking to reach public transit: Data from the California Household Travel Survey. *J. Transp. Health*, 3(2): 154–160 **(7 pages)**.
- Ewing, R.; Cervero, R., (2010). Travel and the built environment. *J. Am. Plann. Assoc.*, 76(3): 265–294 **(30 pages)**.
- Fard, P.E.D.R.A.M., (2013). Measuring transit oriented development: Implementing a GIS based analytical tool for measuring existing TOD levels. Master's thesis, Univ. Twente, Netherlands.
- Florida Department of Transportation, (2009). Encouraging transit oriented development: Case studies of tools that work. Florida DOT, Tallahassee, FL, USA.
- Goode, C. E., (2023). TOD in regional urban growth boundaries (UGBs): A case of transit adjacent development or a strategic housing solution? *J. Transp. Geogr.*, 113: 103714–103723 **(10 pages)**.
- Institute for Transportation and Development Policy, (2017). TOD Standard (3.0). ITDP, New York, USA.
- Jiang, Y.; Gu, P.; Chen, F.; Chen, Y.; Zegras, P.C., (2017). Measuring transit-oriented development in quantity and quality: A case of 24 cities with urban rail systems in China. Paper No. 17-05885, Transportation Research Board, Washington, DC, USA.
- Kidokoro, T.; Matsuyuki, M.; Shima, N., (2022). Neoliberalization of urban planning and spatial inequalities in Asian megacities: Focus on Tokyo, Bangkok, Jakarta, and Mumbai. *Cities*, 130: 103914 **(16 pages)**.
- Knight Frank Thailand, (2023). Thailand real estate market overview report 2023. Knight Frank Thailand Co., Ltd., Bangkok.
- Kuby, M.; Barranda, A.; Upchurch, C., (2004). Factors influencing light-rail station boardings in the United States. *Transp. Res. Part A Policy Pract.*, 38(3): 223–247 **(25 pages)**.
- Lai, N. V.; Tran, P. T., (2025). Integrating sustainable urban development and student housing to enhance urban social welfare (case study: Ho Chi Minh City). *Int. J. Hum. Capital Urban Manage.*, 10(2): 329–344 **(16 pages)**.
- Li, L., (2015). The built environment impact on travel behavior in the context of China: Evidence from transit-oriented development areas in Shenzhen. Doctoral thesis, Univ. Hong Kong.
- Liang, Y.; Du, M.; Wang, X.; Xu, X., (2020). Planning for urban life: A new approach of sustainable land use plan based on transit-oriented development. *Eval. Program Plann.*, 80: 101811–101821 **(11 pages)**.
- Lopez-Garcia, P.; Onieva, E.; Osaba, E.; Masegosa, A.D.; Perallos, A., (2016). GACE: A meta-heuristic based in the hybridization of genetic algorithms and cross entropy methods for continuous optimization. *Expert Syst. Appl.*, 55: 508–519 **(12 pages)**.
- Mehndiratta, S.; Salzberg, A., (2012). Improving public transport in Chinese cities: Elements of an action plan. In *Sustainable low-carbon city development in China*, pp. 269–298 **(30 pages)**. World Bank, Washington, DC.
- Ogra, A.; Ndebele, R., (2014). The role of 6Ds: Density, diversity, design, destination, distance, and demand management in transit oriented development (TOD).
- Ravindran, K.; Chandan, A. C.; Sivakumar, D.; Inayath Ahamed, S. B.; Dhanabalan, T.; Kumaresan, V., (2024). Urban management and sustainable business by entrepreneurs. *Int. J. Hum. Capital Urban Manage.*, 9(3): 413–428 **(16 pages)**.
- Renne, J. L., (2008). From transit-adjacent to transit-oriented development. *Local Environ.*, 14(1): 1–15 **(15 pages)**.
- Renne, J.L., (2009). Measuring the success of transit oriented development. In *Transit oriented development*, pp. 241–255 **(15 pages)**.
- Renne, J. L., (2016). Measuring the success of transit-oriented development. In: Curtis, C.; Bertolini, L.; Renne, J. L. (Eds.), *Transit oriented development: Making it happen*, Routledge, Abingdon, UK, pp. 241–255 **(15 pages)**.
- Saensomboon, K.; Thapthimhin, T., (2023). The analysis of transit oriented development (TOD) of electric train stations in Bangkok and metropolitan region: The case study of Chaleom Ratchamongkon Line and Chalong Ratchadham Line. *Eng. Technol. Horiz.*, 40(3): 400310 **(19 pages)**.
- Salat, S.; Ollivier, G., (2017). Transforming the urban space through transit-oriented development: The 3V approach.
- Shannon, C.E., (1948). A mathematical theory of communication. *Bell Syst. Tech. J.*, 27(3): 379–423 **(45 pages)**.
- Shojaeivand, B., (2019). Urban landscape and quality of urban environment by means of geographic information system. *Int. J. Hum. Capital Urban Manage.*, 4(3): 239–246 **(8 pages)**.
- Singh, Y.J.; Lukman, A.; Flacke, J.; Zuidgeest, M.; Van Maarseveen, M.F.A.M., (2017). Measuring TOD around transit nodes: Towards TOD policy. *Transp. Policy*, 56: 96–111 **(16 pages)**.
- Su, S.; Zhang, H.; Wang, M.; Weng, M.; Kang, M., (2021a). Transit-oriented development (TOD) typologies around metro station areas in urban China: A comparative analysis of five typical megacities for planning implications. *J. Transp. Geogr.*, 90: 102939 **(18 pages)**.
- Su, S.; Zhang, J.; He, S.; Zhang, H.; Hu, L.; Kang, M., (2021b). Unraveling the impact of TOD on housing rental prices: A comparative analysis of five Chinese megacities. *Habitat Int.*, 107: 102309–102321 **(13 pages)**.
- Urban Redevelopment Authority, (2024). Jurong Lake District: A model of integrated transport and urban development.
- Verduzco Torres, J.R., (2024). Public transport accessibility indicators to urban and regional services in Great Britain. *Sci. Data*, 11(53).
- Victoria Transport Policy Institute, (2024). Evaluating accessibility for transport planning. Victoria Transport Policy Institute.
- World Bank, (2013). East Asia's changing urban landscape. The World Bank.
- Wu, W.; Divigalpitiya, P., (2023). Evaluating the dynamic performance of TODs and determining the priority TODs in Hefei city. *Multimodal Transp.*, 2(4): 100104–100114 **(11 pages)**.
- Xiao, L.; Lo, S.; Liu, J.; Zhou, J.; Li, Q., (2021). Nonlinear and synergistic effects of TOD on urban vibrancy: Applying local explanations for gradient boosting decision tree. *Sustain. Cities Soc.*, 72: 103063 **(16 pages)**.
- Xie, Y., (2017). Measuring the performance of metro-based transit oriented development (TOD): A comparative study between

- Beijing and Singapore. Doctoral dissertation, Massachusetts Institute of Technology.
- Yang, W.; Xu, Q.; Zhai, M.; Chen, C.; Yi, S., (2024). Are different TOD circles oriented towards sustainability amidst urban shrinkage? Evidence from urban areas to suburbs in the Tokyo metropolitan area. *J. Environ. Manage.*, 372: 123274-123289 (16 pages).
- Yu, Z.; Zhu, X.; Liu, X., (2022). Characterizing metro stations via urban function: Thematic evidence from transit-oriented development (TOD) in Hong Kong. *J. Transp. Geogr.*, 99: 103299-103309 (11 pages).
- Zegras, C.; Stewart, A.; Forray, R.; Hidalgo, R.; Figueroa, C.; Duarte, F.; Wampler, J., (2016). Designing BRT-oriented development. In *Restructuring public transport through bus rapid transit*, pp. 181–208 (28 pages).
- Zhang, M.; Sussman, J.M., (2019). Public transit-oriented development in rapidly growing regions: Case study analysis in Asia. *J. Urban Plann. Dev.*, 145(1): 1–13 (13 pages).
- Zhuang, X.; Zhao, S., (2014). Effects of land and building usage on population, land price and passengers in station areas: A case study in Fukuoka, Japan. *Front. Archit. Res.*, 3(2): 199–212 (14 pages).

COPYRIGHTS

©2026 The author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, as long as the original authors and source are cited. No permission is required from the authors or the publishers.



HOW TO CITE THIS ARTICLE

Saensomboon, K.; Udomsub, R., (2026). A spatial multidimensional evaluation of TOD performance around urban rail stations for urban planning. *Int. J. Hum. Capital. Urban Manage.*, 11(4): 671-691

DOI: 10.22034/IJHCUM.2026.04.03

URL: https://www.ijhcum.net/article_737246.html

