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# EVALUATING THE TOD POTENTIAL OF LRT STATIONS IN MALAYSIA USING THE TOD INDEX

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## Abstract

The fundamental principle of railway development is that rail stations are not merely nodes where people change from one mode of transport to another but also places where spatial concentrations of high-value activity are recognised as positively impacting cities. This can be a similar definition of transit-oriented development: integrating land uses (mixed-use activities) and transportation systems to improve urban issues, especially traffic congestion. This paper aims to quantitatively assess the current transit nodes using the TOD index by evaluating the standard criteria of the 5Ds that determine TOD levels. The TOD index was calculated for areas of 69 stations on the LRT Ampang/Sri Petaling and LRT Kelana Jaya Lines. Some stations are indicated as having a potential TOD but a poor built environment and accessibility, depending on the TOD index's value. With these results, the recommendations to improve TOD planning and implementation can become effective for each station, depending on its built environment factors and typologies. Therefore, using the TOD index, the study offers insights into the station's potential for TOD implementation at rail station development. It put forward recommendations for enhancing TOD planning and implementation towards a better passenger experience, optimising each station's potential, and achieving the objective of TOD implementation in the first place.

***Keywords**:* Transit-Oriented Development, TOD Index, Transit, Rail Development

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## INTRODUCTION

> *"If TOD design does not work, people will just take the car or choose to live elsewhere"* - (Thomas et al., 2018)

Active mobility and public transportation can be well-promoted integrating transport and land use planning, which is critical for the sustainability of cities and communities (Cervero, 2013; Suzuki et al., 2013). However, urban planning faces challenges in many cities worldwide in terms of effectively planning and improving the built environment to support sustainable transport (Hrelja et al., n.d.). Previous research has demonstrated that land use significantly affects people's travel pattern (Abdullah et al., 2022). It is also apparent that cities that have boosted public transportation ridership increased walking and cycling, decreased land consumption and dependence on cars have done so because land use and transportation planning have been integrated (Van Lierop et al., 2017). Transit-oriented development (TOD) as a planning and development approach for densifying the built environment around public transportation nodes and along transit corridors has resulted in these improvements (Zhang, 2022).

The spread of TOD growth began from the city centre, and the growth of the suburban started due to the urban sprawl that is suffering from bad transport connectivity and new township development in new suburban area (Jamme et al., 2019 & Van Lierop et al., 2017). As noted by Xia & Zhang (2022), land use and transport planning strategies have been significantly influenced and motivated by the widespread car dissemination at the turn of the 20th century, notably in Western countries like the United States and the United Kingdom. The automobile city, driven by concerns about traffic, has replaced the pedestrian and transit-oriented city, leading to urban sprawl, increased energy consumption, and dependence on cars. This scenario has resulted in an underestimation of the impacts of land use decisions and the consequences of relying heavily on cars. The car society model is a way of living that relies heavily on the fast and unchecked exploitation of non-renewable energy sources. In addition, it was supported by uneven industrial, economic, and land use policies because governments heavily subsidised the automotive industry through financial incentives and significant investments in infrastructure and transportation systems (Jamme et al., 2019).

Research on TOD concepts has proliferated in parallel with the growing popularity of planning urban growth around transit nodes. In the TOD literature, European cities, such as the Netherlands, Stockholm, and Copenhagen, are often mentioned as inspirations for the successful development of TOD. These cities are often held in high regard among TOD researchers for their proven competence in achieving a well-integration between land use and rail-based transportation (Pojani & Stead, 2015; Van Lierop et al., 2017).

As a city redevelopment strategy, multiple TODs are planned in tandem with the transport network to form a hierarchical network of TODs with variations in their size, form, and functions depending on the spatial context in which a TOD station is located (Ewing & Cervero, 2010). Thus, this study on TOD aims to provide a deeper understanding of measuring the density, land use mixture (diversity), design, distance, and destination accessibility built to support the passenger experience in the station area and when using the network. This study focuses on measuring an area within an 800-meter radius of transit stations using the TOD index, evaluating the potential for suitable TOD stations, and identifying which area can be improved. The results of the TOD Index are expected to be a comprehensive guideline and reference for establishing the criteria for planning, developing, implementing, and evaluating any current or future transit station.

To promote stations as TOD-compatible stations, this study thus set up two (2) objectives: (i) to compute a TOD index based on the 5D factors, including its station areas; and (ii) to compare the result of the TOD Index level, which generates a TOD score for each station.

## LITERATURE REVIEW

### Unfolding the Transit-oriented Development Concept

Since the 1990s, the number of studies dedicated to the emergence of TOD has been progressively growing, particularly in American and European cities and recently in Asian cities after many Asian cities also faced the challenges of urban issues. They analysed almost 330 articles published on the Web of Science until the end of 2018 by Ibraeva et al. (2020), providing evidence that the vast majority of the research on TOD originated in the USA. In Europe, Dutch universities like the University of Amsterdam and the Delft University of Technology are where most of the TOD research is presented, according to the Scopus database until 2022. In addition to this, the Asia-Pacific region is seeing a growing interest in TOD, particularly at Beijing University and the Universities of Hong Kong, Queensland, and Melbourne. It is clear that despite the unquestionable preponderance of the USA on this matter, TOD-related studies are becoming internationally widespread and have become the agenda of state and local governments, stemming from concerns about the sustainability of urban mobility and environmental responsiveness (Doulet et al., 2017).

The TOD concept is addressed first and foremost as expressed in The Next American Metropolis by Peter Calthorpe (1993), an architect, urban planner, and founder of American TOD. Calthorpe's original portrayal of TOD living envisioned a seamless daily routine. Residents would be able to descend from their apartment building, accessing retail facilities on the ground floor to purchase breakfast. They could then walk or bike to the nearby rail transit station, perhaps enjoying breakfast on a bench along the way or at the station entrance while waiting for the next train. Ultimately, they would disembark the train within walking distance from their office, ensuring a smooth and efficient commute. Calthorpe defined TOD as a mixed-use community within an average 600 m walking distance within more or less 10 minutes of a transit stop and core commercial area (Calthorpe, 1993). He suggests that TOD mixes residential, retail, office, and open space in a walkable environment, making it convenient for people and employees to travel by transit, foot or bicycle, or car. Major commercial and workplaces should be located in close to a station and nearby public spaces to improve neighbourhood configuration and vitality. A residential zone should be developed in the remaining area, with densities decreasing (remaining 25-60 units per hectare). While the secondary zone might appear at a maximum distance of 1.6 km from the core zone, where low-density housing, vast park areas, school, and facilities for the local community could be located. The street network of the outer area should be easily accessible, fast, and direct access to the core area, mainly by foot or bicycle or public transportation (known as the first mile) and provide park-and-ride facilities. With various available routes, users are expected to choose local streets for their short displacements, allowing for higher street connectivity (see Figure 1).

Nevertheless, the importance of TOD on a larger regional scale was emphasized, mixing issues of local neighbourhood configuration with more ambitious public transport strategies. Calthorpe (1993) claims that the growth of regional structure is congruent with the development of public transport, with human scale as the basic element in urban planning and design to reshape and facilitate the multiple functions of surrounding areas of transit stations. In this light, many U.S. cities, such as San Francisco and Atlanta, are the first to adopt the TOD concept in urban planning.

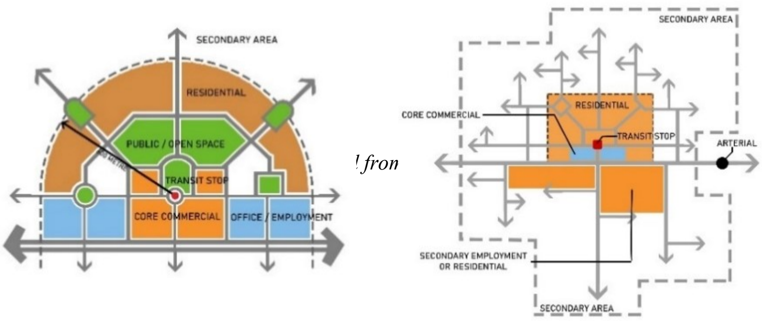



**Figure 1**: Diagrammatic representation of TOD that emphasises land use and train network integration in a city

Transit is one of the many goals of the TOD concept. It is a potential outcome that adds to a strategy with many other benefits for the city and its citizens. Among the benefits of TOD are the frequency of walking, transit use, driving, social capital and local engagement, public health, pedestrian and vehicle fatalities or accidents, property value, and travel time costs (Jamme et al., 2019). The rest of the benefits, as highlighted by Rice (2009) in (Bertolini et al., 2009; 2012), are:

i. Reduce reliance on cars, which has substantial environmental and social benefits.
ii. Improves the viability of public transport and facilitates the provision of better public transport services.
iii. Enables a more compact city, providing housing and development opportunities without adding to city sprawl.
iv. Enable more affordable housing. A basic apartment in an activity centre and should be able to be provided more economically.
v. Creates more activity and community life in a centre by having more people living closer together and interacting with each other much more than if they lived further apart.
vi. Improves the economic viability of businesses in the centre by creating a larger market with easy access to their products.
vii. Revitalize older centres and shopping strips that have struggled to compete with car-based shopping malls.
viii. Brings new development to replace areas perceived as old and rundown.

The TOD concept and principles were progressively adopted in California, Georgia, Massachusetts, Florida, New Jersey, Washington, and New York, later many European cities such as Amsterdam, Copenhagen, Helsinki, Lisbon, Munich, Stockholm, and Zurich followed (Bertolini et al., 2009; Cervero, 2013; Bernick & Cervero, 1997; Dittmar & Ohland, 2004; Vale, 2015). The recent decade has seen TOD applied in Asian cities, such as China, Singapore, South Korea, Japan, Thailand, Indonesia, and Malaysia, to formulate mass transit corridors and reduce traffic congestion due to urbanisation and population growth. Malaysia's TOD policy can be seen as outlined by PLANMalaysia in 2018 through *Garis Panduan Perancangan Pembangunan Berorientasikan Transit* and the Selangor State Transit-Oriented Development Planning Policy in 2016. Although TOD applications followed one basic philosophy in different cities, the main focuses varied greatly with cases. For example, most American planners emphasise the re-concentration of urban developments around transit nodes (Renne, 2009), while European cities highlight the redevelopment of existing transit station areas (Bertolini & Spit, 1998; Papa & Bertolini, 2015).

**TOD Index**

By concentrating development around public transit or transfer stations, bus stops, TOD is commonly defined as an approach to integrating transportation and land use planning that "*...makes walking, cycling, and transit use convenient and desirable and that maximises the efficiency of existing public transit services*" (Thomas et al., 2018). There is a need to define and characterise TOD by measuring the indicators. Many researchers believe that TOD planning needs to use two approaches since TOD emphasises the integration between T (transit) and D (development), as suggested by Singh et al. (2014):

1. Identifying areas where urban development has high transit orientation, but low TOD levels.
2. Identifying potential locations for transit networks characterised by high TOD levels but poor transit connectivity.

A review by Doulet et al. (2017) found that there are several different methods to conceptualise TOD. To illustrate this point, the 3Ds of the concept - density, diversity, and design have received much attention in research. They are among the most frequently applied in quantifying the TOD formulate by Cervero & Kockelman (1997). Density refers to increasing the number of units per hectare; diversity is the need to increase the variety of uses within a development; and design refers to the attractiveness and efficacy of walking, bicycling, and public transportation. The distance to transit and destination accessibility are two more Ds listed by (Ewing & Cervero, 2010). The D-framework can be explained: (1) Density – increased housing and employment near transit; (2) Diversity – a land use mix of housing, retails, services, and public space within walking distance of transit stations; (3) Design – encompasses the tangible and intangible aspects of the built environment, including the arrangement of buildings, streets, and public spaces, the design of individual buildings, landscapes, emotion, experience, and a sense of place or place attachment; (4) Distance to transit – access to transit station including the first and last mile which relates to the walkability; (5) Destination accessibility – the ease of access to trip attractions or destinations (see Table 1).

Singh et al. (2014) argue that a scientific analysis of measuring extant TOD levels is necessary for identifying the extent to which an area is transit-oriented and its potential. Singh et al. (2014, 2017) analyses the TOD network of the City Region Arnhem and Nijmegen by aggregating spatial indicators using a Spatial Multi-Criteria Analysis to determine an overall TOD level value. The TOD index uses quantitative GIS methods and statistical analysis to calculate the actual and potential TOD. Each index is measured at a different scale. For example, the actual TOD index must be measured around an existing transit node, considered the walkable limit from the node which is range between 400 meters to 800 meters of comfortable 10 minutes walking distance. The potential TOD index needs to be measured over an entire region to see how index values vary from one location to another and whether there are areas where levels of TOD are already high.

For quantifying the suitability of TOD stations, Kamruzzaman et al. (2014) employ a similar methodology, taking into account the accessibility of public transportation, net residential and employment densities, land use mix, intersection and cul-de-sac density. According to Kamruzzaman et al. (2014), the TOD concept is applied using sets of indicators to help determine how effective and successful the TOD concept is in supporting the function of the rail station and its network and accommodating a liveable environment. For the same reason, TOD needs to be served by a high-quality transit service because the design and quality of the transit service significantly impact TOD's success potential. The TOD plan and implementation can only succeed if the transit service is good or the station is attractive and convenient (Zhou et al., 2019).

**Table 1**: TOD Indicators for Calculating the TOD Index

| Indicators | Descriptions | Formula |
|---|---|---|
| Density | Population density (People per $km^2$) | *PD = NP/A*<br>Where *PD* = Population density, *NP* = District population, *A* = District area<br><br>*PA = PD/SA*<br>Where *PA* = buffer area population, *SA* = buffer area coverage ($2.01km^2$)<br><br>*Pd = PR/SA*<br>Where *Pd* = population density of the buffer area, *PA* = population residence area<br>Average household in Malaysia is 3.9 |
| | Commercial density (Number of commercial activities per $km^2$) | *CD = NC/SA*<br>Where *CD* = commercial density, *PA* = number of commercial activities, *SA* = Buffer area coverage |
| Diversity | Land use diversity (mix percentage) | $1 - \sum (a/A)^2$<br>Where *a* is the total area of specific land use (e.g residential, commercial, industry, facilities) within the buffer area<br>*A* = total area of all land use categories within the buffer. |
| Design | Open spaces | Total area in acre |
| | Parking space | Total area in acre |

| Indicators | Descriptions | Formula |
|---|---|---|
| Distance to transit | Pedestrian path | Total length of pedestrian within the buffer area using ArcGIS. |
| | Intersection density | Calculate the number of intersections of the road networks within the buffer area. |
| Destination accessibility | Land use mixedness (Mixedness of residential land use with other land use categories) | MI (i) $= \frac{\sum_j L_0}{\sum_j L_r + L_0}$ <br> $L_0$ = non-residential land uses for each <br> $Lr$ = residential land uses |

*Source: Ewing & Cervero, (2010); Singh et al. (2014); Uddin et al. (2023)*

## INTRODUCTION OF THE SELECTED CASES: LRT LINES

This section briefly introduces LRT lines in the Klang Valley, why this research chose LRT lines as the case study for rail-based transportation, and how this choice relates to the research objectives. Some of these LRT station areas have a significant opportunity to develop and redevelop because of their well-accessible location, economic establishment, and existing attractions. Besides, these lines have been chosen due to their relevance and significance in the context of rail-based transportation in Klang Valley particularly.

The LRT lines are under the operation of RapidKL (Rapid Rail and Rapid Bus), a subsidiary of Prasarana Malaysia Berhad. This research decided to evaluate the TOD index for LRT Ampang/Sri Petaling Line and LRT Kelana Jaya, as both lines are well-established networks since 1996, have the highest ridership among other urban rail services, and are well-developed in the surrounding areas (see Figure 2). Kuala Lumpur Sentral Station is excluded from the case study because both stations are integrated stations that serve not only the LRT network but also KTM Komuter, Express Rail Link (ERL), KLIA Transit, Electric Train Service (ETS) as an intercity train, KL Monorail, and interstate buses.

The process of railway modernization in the Klang Valley region began in 1996 with the introduction of the first urban rail system, the LRT (Light Rail Transit), to link the area between Ampang-Sentul-Kuala Lumpur city centre. This route was known as LRT Ampang/Sri Petaling Line (formerly known as STAR LRT – *Sistem Transit Aliran Ringan*) before it was renamed in April 2005 after it was taken over by Prasarana in 2002. The total stations of the LRT Ampang Line are 47, with a length of 45.1 km. The Ampang Line started its operation with the Ampang-Sultan Ismail route, while the second stretch was Chan Sow Lin-Sri Petaling in 1998. The lines run a total route length of 27 km, of which 17.6 km is at grade and 9.4 km is on the viaduct. There are 25 stations, with 11 stations along

Sentul Timur-Chan Sow Lin and 7 stations along Chan Sow Lin-Ampang and Chan Sow Lin-Sri Petaling. The Sentul Timur-Ampang and Sentul Timur-Sri Petaling converge at the Chan Sow Lin interchange station. The merged line directs to the north and terminates at Sentul Timur. Since its operation, the Ampang Line has been intended to include interchangeability with other rail-based networks. The Bandaraya Station became the first to be designated as an interchange station, connecting to the Bank Negara KTM Komuter Station. After completing the Sri Petaling-Chan Sow Lin Line, the Bandar Tasik Selatan station was opened in 2022 to be integrated with the Ampang Line, KTM Komuter, and ERL.

In the eastern part of the Greater Klang Valley, the second LRT project of LRT2, the LRT Kelana Jaya Line (formerly known as *Projek Usahasama Transit Ringan Automatik* - PUTRA LRT), was operated as the first fully automated and driverless, connecting the urban sprawls of Gombak and Kelana Jaya. The lines were completed in 1998, and the extension was completed in 2016 with 13 new stations over 17 km from Kelana Jaya to Putra Heights, where it meets with the Sri Petaling Line for interchange. Presently, the Kelana Jaya Line consists of 37 stations with a total of 46.1 km track length, with 31 aboveground stations, 5 underground stations, and 1 at-grade station (Sri Rampai Station).

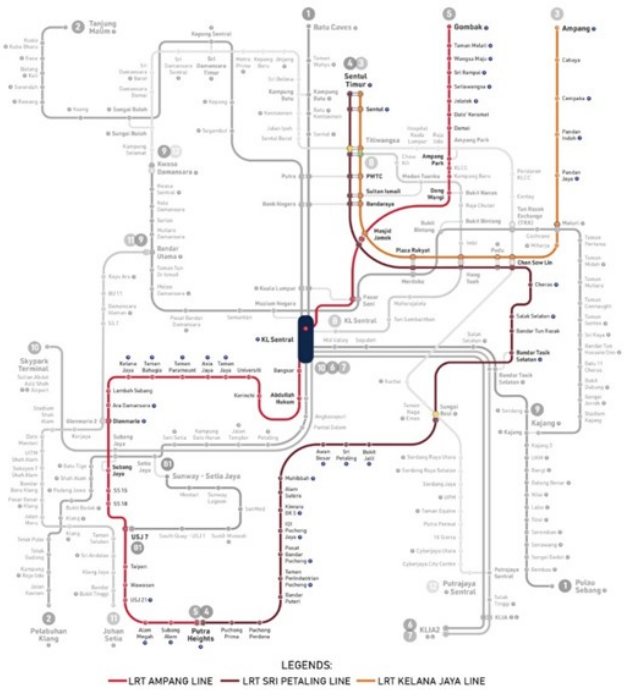



**Figure 2**: Two LRT lines in Klang Valley transit system map
*Source: myrapid.com.my (2023)*

To understand the physical characteristics of each station, Table 3 illustrates five (5) different typologies for each station: terminal building, station, space, function, and settlement hierarchy. For both lines, 13 stations are on-ground (1 – Kelana Jaya Line, 12 – Ampang/Sri Petaling Line), while the rest are elevated, and 5 stations on the Kelana Jaya Line are underground, crossing the main roads, the city centre of Kuala Lumpur, and the central business districts in major commercial areas. Most interchange and connecting stations produce a complex space typology connecting to other modes. However, not all stations with complex space typologies serve multiple functions, serving as transit stations and spaces for economic, service, and social activities as in-transfer areas. The example station that owns this typology is Dang Wangi Station. Each station has also been clustered based on the settlement hierarchy: urban, city centre, sub-city centre, commercial-business park, and neighbourhood centre. Ampang, PWTC, Titiwangsa, Ara Damansara, and KLCC Stations are in urban settlements, connecting to a wide range of destinations and significant activities, especially business, finance, and services.

**Table 3**: Typologies of LRT stations

| **Station** | **Typologies** | | | | |
|---|---|---|---|---|---|
| | **Terminal building** | **Station** | **Space** | **Function** | **Settlement hierarchy** |
| **LRT Ampang/Sri Petaling Line** | | | | | |
| Ampang | On-ground | Interchange | Linear | Mono | Urban |
| Cahaya | On-ground | Intermediate | Linear | Mono | Neighbourhood centre |
| Cempaka | On-ground | Intermediate | Linear | Mono | Neighbourhood centre |
| Pandan Indah | On-ground | Intermediate | Linear | Mono | City centre |
| Pandan Jaya | On-ground | Intermediate | Linear | Mono | Neighbourhood centre |
| Maluri | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Miharja | On-ground | Interchange | Complex | Mono | Neighbourhood centre |
| Chan Sow Lin | On-ground | Interchange | Complex | Mono | Neighbourhood centre |
| Pudu | Elevated | Intermediate | Linear | Mono | Commercial-business Park |
| Hang Tuah | On-ground | Interchange | Complex | Mono | Commercial-business Park |
| Plaza Rakyat | Elevated | Interchange | Complex | Mono | Sub city centre |
| Bandaraya | Elevated | Intermediate | Linear space | Mono | Commercial-business Park |
| Sultan Ismail | Elevated | Connecting | Linear | Mono | Sub city centre |

| Station | Typologies | | | | |
|---|---|---|---|---|---|
| | Terminal building | Station | Space | Function | Settlement hierarchy |
| PWTC | Elevated | Intermediate | Linear | Multi | Urban |
| Titiwangsa | Elevated | Interchange | Complex | Mono | Urban |
| Sentul | Elevated | Intermediate | Linear | Mono | Sub urban |
| Sentul Timur | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Cheras | On-ground | Intermediate | Linear | Mono | Neighbourhood centre |
| Salak Selatan | On-ground | Intermediate | Linear | Mono | Sub urban |
| Bandar Tun Razak | On-ground | Intermediate | Linear | Mono | Neighbourhood centre |
| Sungai Besi | Elevated | Intermediate | Linear | Mono | Sub city centre |
| Bukit Jalil | Elevated | Intermediate | Linear | Mono | Sub city centre |
| Sri Petaling | On-ground | Intermediate | Linear | Mono | Neighbourhood centre |
| Awan Besar | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Muhibbah | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Alam Sutera | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Kinrara BK5 | Elevated | Intermediate | Linear | Mono | Commercial-business Park |
| IOI Puchong Jaya | Elevated | Intermediate | Linear | Mono | Sub city centre |
| Pusat Bandar Puchong | Elevated | Intermediate | Linear | Mono | City centre |
| Taman Perindustrian Puchong | Elevated | Intermediate | Linear | Mono | Sub city centre |
| Bandar Puteri | Elevated | Intermediate | Linear | Mono | Commercial-business Park |
| Puchong Perdana | Elevated | Intermediate | Linear | Mono | Sub city centre |
| Puchong Prima | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Putra Heights | Elevated | Interchange | Complex | Mono | Neighbourhood centre |
| **LRT Kelana Jaya Line** | | | | | |
| Subang Alam | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Alam Megah | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| USJ21 | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |

| Station | Typologies | | | | |
|---|---|---|---|---|---|
| | **Terminal building** | **Station** | **Space** | **Functi on** | **Settlement hierarchy** |
| Wawasan | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Taipan | Elevated | Intermediate | Linear | Mono | Commercial-business Park |
| USJ7 | Elevated | Interchange | Complex | Mono | Commercial-business Park |
| SS18 | Elevated | Intermediate | Linear | Mono | Sub city centre |
| SS15 | Elevated | Intermediate | Linear | Mono | City centre |
| Subang Jaya | Elevated | Connecting | Complex | Mono | City centre |
| Glenmarie | Elevated | Intermediate | Complex | Mono | Sub city centre |
| Ara Damansara | Elevated | Intermediate | Linear | Mono | Urban |
| Lembang Subang | Elevated | Intermediate | Linear | Mono | Sub city centre |
| Kelana Jaya | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Taman Bahagia | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Taman Paramount | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Asia Jaya | Elevated | Intermediate | Linear | Mono | City centre |
| Taman Jaya | Elevated | Intermediate | Linear | Mono | City centre |
| Universiti | Elevated | Intermediate | Linear | Mono | Sub city centre |
| Kerinchi | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Abdullah Hukum | Elevated | Intermediate | Linear | Mono | Sub city centre |
| Bangsar | Elevated | Intermediate | Linear | Mono | Commercial-business Park |
| Pasar Seni | Elevated | Interchange | Complex | Mono | City centre |
| Masjid Jamek | Underground | Interchange | Complex | Mono | City centre |
| Dang Wangi | Underground | Connecting | Complex | Multi | Sub city centre |
| Kampung Baru | Underground | Intermediate | Linear | Mono | Sub urban |
| KLCC | Underground | Intermediate | Linear | Multi | Urban |
| Ampang Park | Underground | Intermediate | Linear | Mono | City centre |
| Damai | Elevated | Intermediate | Linear | Mono | Sub city centre |
| Dato' Keramat | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Jelatek | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |

| Station | Typologies | | | | |
|---|---|---|---|---|---|
| | **Terminal building** | **Station** | **Space** | **Function** | **Settlement hierarchy** |
| Setiawangsa | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Sri Rampai | On-ground | Intermediate | Linear | Mono | Neighbourhood centre |
| Wangsa Maju | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Taman Melati | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |
| Gombak | Elevated | Intermediate | Linear | Mono | Neighbourhood centre |

*Source: Author*

## RESEARCH METHODOLOGY

As given in Table 4, five (5) indicators - density, diversity, design, distance, and destination accessibility (Ewing & Cervero, 2010) were calculated in ArcGIS to measure the TOD index for 69 stations on the LRT 1 and 2 Lines. Each of the indicators can be measured using different performance variables. Some performance variables are excluded from this research due to a lack of data availability, such as employment density under the density indicators.

**Table 4**: Criteria for Calculating TOD Index and The Data Sources

| Indicators | Measurement variables | Data source |
|---|---|---|
| Density | Population density<br>(Number of persons per $km^2$)<br><br>Commercial density<br>(Number of commercial per $km^2$) | www.dosm.gov.my/mycendash<br>open.dosm.gov.my/kawasanku<br><br>Land use of commercial<br>Floor area ration (FAR) |
| Diversity | Land use diversity | ArcGIS and OSM |
| Design | Acreage of fully utilised of public space<br>Number of parking space | Land use of public space<br><br>ArcGIS and OSM |
| Distance | Density of intersection per square kilometre<br>(Number of intersections per $km^2$)<br><br>Length of pedestrian networks<br>(Total length of walkable/cyclable paths in km) | ArcGIS and OSM<br><br><br><br>www.pedcatch.com |
| Destination accessibility | Mixed-ness of land uses | ArcGIS and OSM |

*Open Street Map (OSM)

The indicators were calculated and aggregated using ArcGIS 10.8 and Quantum GIS (QGIS) 3.28. Using both vector and raster data formats to generate the index made it easier and faster to calculate the TOD index, especially for a large number of stations. On the note, all indicators have been standardised using the maximum standardisation technique, which applied a 0-1 gradient to all values and aggregated them into the TOD index with an equal-weighted technique.

## ANALYSIS AND DISCUSSION

The TOD area is pedestrian-friendly, with an 800-metre radius around transit stations. Within this buffer area, the 5D indicators directly affect ridership and act as an activity node. Based on the studies by Huang et al. (2018) and Niu et al. (2021), this study employs an 800-metre buffer around the transit station as the pertinent unit analysis for TOD planning in Malaysia. The size of the buffer encourages people to walk to or from the station along the pedestrian connectivity within 10 minutes or less. Figure 3 illustrates the buffers around the train stations for three (3) lines, i.e., LRT Ampang, LRT Sri Petaling, and LRT Kelana Jaya. The 800-metre buffers represent the land uses around the station areas, which have been analysed using GIS software. Once the TOD buffer areas are demarcated, the variables for the TOD index are identified. Thus, when such an index is computed for each station area, recommendations can be made to improve the TOD around stations.

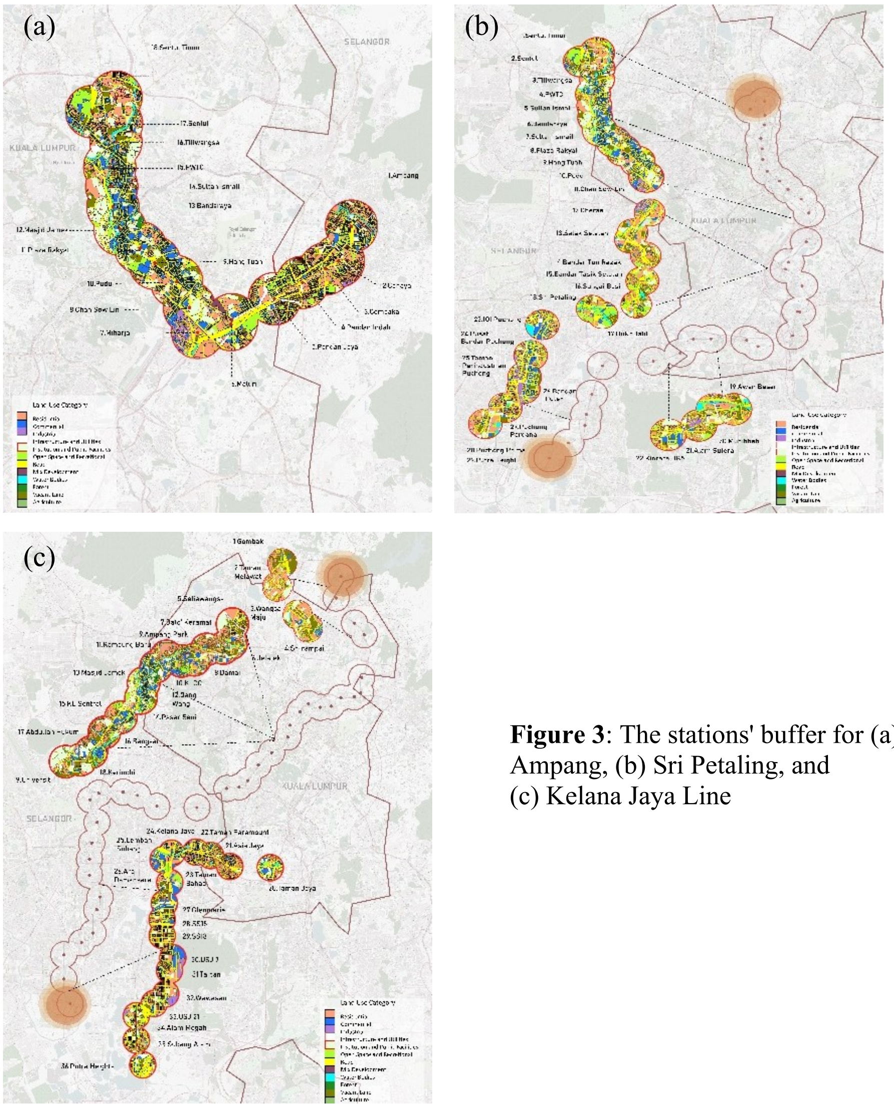



**Figure 3**: The stations' buffer for (a) LRT Ampang, (b) Sri Petaling, and (c) Kelana Jaya Line

**TOD Measurement**
This research has comprehensively analysed the TOD level for 69 LRT stations. The findings, tabulated in Table 5, offer valuable insights into the five (5) indicators of TOD and their potential for implementation in the station areas. Using these results, the station can be ranked based on the high and low scores of the TOD index value. According to the total scale of 0.00 to 1.00, the score can be classified into three (3) categories: 0.00 to 0.50 is the lowest score, 0.51 to 0.70 is the median score, and 0.71 to 1.00 is the highest. The range of TOD index values for the 69 LRT stations is from 0.39 to 0.97, with the briefs as follows:

1. The highest score is 0.97, which is dedicated to Glenmarie Station.
2. The lowest score is 0.39, which is dedicated to Universiti Station.

Among the 69 stations analysed, 49 scored above 0.70, thus indicating a good overall level of TOD in the city. The high-scoring stations are primarily located in the sub-city and neighbourhood centres, highlighting the significance of population and employment density in the station areas. Examples of sub-city centres with promising development opportunities include Glenmarie, Bukit Jalil, IOI Puchong, and Sungai Besi. However, these stations scored less in the diversity and density aspects. This suggests that although these stations have the potential for development, there is an area for improvement in the high intensity of development, which focuses on the mix and intensity of land uses.

On the other hand, the station with the lowest TOD score of 0.39 is Universiti Station. This low score is attributed to limited land use diversity, suboptimal design, and inadequate pedestrian infrastructure. Similarly, Kerinchi Station scored 0.40 and shares similar challenges with Universiti Station. These two stations are close by and exhibit higher diversity due to the presence of public facilities, institutions, and affordable residential developments. In addition, these stations are located beside the Federal Highway (railroad ROW), which limits people from other sides access to the station and discourages people from walking to the station as the pedestrian infrastructure needs better conditions and well-connected.

The study's findings indicate that a significant number of stations have scored low in design, density, and distance to transit. Specifically, stations such as Ampang, Cahaya, and Cempaka on the Ampang/Sri Petaling Line, as well as Gombak, Taman Melati, and Wangsa Maju on the Kelana Jaya Line, exhibit poor design and limited provision of public space in their surrounding areas. TOD patterns of public spaces are urban spaces enclosed by commercial storefronts and public buildings such as libraries, healthcare facilities, post offices, mosques, and police stations. The loading platforms are on the sidewalks, and the street works are public spaces. The public space around the station areas is an important component in the station context as it reflects the nature of activities and the presence of people (environmental psychology). When there are no activities and fewer people, the area may create a negative user experience. The reasons for the negative experience are mainly the unwanted behaviour of other people, abandonment, darkness, poor visibility, and, in short, making the station unattractive.

Meanwhile, in the distance aspect, especially the distance and the provision of pedestrian infrastructure, many stations have scored low, such as Cahaya, Bukit Jalil, Puchong Prima, and Gombak Station. Implicitly incorporated in the TOD definition, walkability environments are crucial for the convenience of the users to walk from their origin to the station or from the station to any destination. Fostering walkability is essential to ensuring seamless first- and last-mile connectivity between the train systems and the users' origins and destinations because walking depends on the design of the streets, walkway infrastructure, and commercial activity. Understandably, the station uniquely connects to the pedestrian walkways, hence, integrating with cities without any barriers to create a good walkable condition. However, the walkable conditions of the TOD stations have revealed that the built environment, such as public space and commercial activities, influences the size of the walking distance because some stations have shorter and poorer continuity of pedestrian networks. It is noted that pedestrian activity triggers commercialization by creating public spaces and attracting pedestrians as potential transit users. Commercialization around the stations is closely associated with pedestrian movement when the arriving and departing passengers converge on and disperse from the station area. The examples of commercial activities around station areas can be observed in Putra Heights and USJ7 Station.

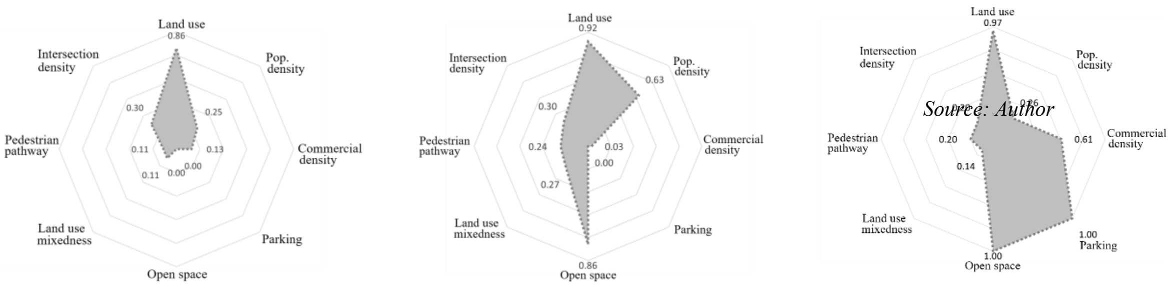
From the above discussion on the impacts of active pedestrians on commercial activity, this can be further discussed in terms of commercial density, as it has a strong association. The stations with the highest scores in density (commercial density) are Subang Jaya, Plaza Rakyat, and Dang Wangi Station. These three stations, however, have scored the lowest in pedestrian distance. This finding reveals that due to poor pedestrian connectivity and unsafe walkable conditions, the users prefer to travel by car to the station, as the stations have also provided a Park N’ Ride, such as in Subang Jaya Station, and a limited parking space in Dang Wangi Station. Due to the high number of drivers, this scenario will contribute to the absence of commercial activity, either formal or informal activity, around the station areas, and the station will ultimately continue to serve only as a transit hub rather than being multifunctional as intended by TOD.

**Table 5**: The TOD Index Values of All 69 LRT Station Areas

| Station | Density | | Diversity | Design | | Distance to transit | | Destination accessibility | TOD Index |
|---|---|---|---|---|---|---|---|---|---|
| | Pop. density | Commercial density | Land use diversity | Parking | Public space | Pedestrian (km) | Intersection density | Land use mixedness | |
| Glenmarie | 0.26 | 0.61 | 0.97 | 1.00 | 1.00 | 0.20 | 0.20 | 0.14 | 0.97 |
| Taman Bahagia | 0.94 | 0.09 | 0.78 | 1.00 | 0.43 | 0.18 | 0.50 | 0.45 | 0.97 |
| Bukit Jalil | 0.48 | 0.33 | 0.85 | 1.00 | 0.65 | 0.06 | 0.60 | 0.17 | 0.92 |
| Awan Besar | 0.70 | 0.03 | 0.92 | 0.30 | 1.00 | 0.39 | 0.50 | 0.28 | 0.92 |
| Taman Paramount | 1.00 | 0.07 | 0.71 | 0.88 | 0.30 | 0.16 | 0.40 | 0.53 | 0.90 |
| Ampang | 0.81 | 0.30 | 0.96 | 1.00 | 0.00 | 0.15 | 0.50 | 0.35 | 0.90 |
| Taman Jaya | 0.60 | 0.60 | 0.94 | 1.00 | 0.31 | 0.20 | 0.20 | 0.21 | 0.90 |
| IOI Puchong Jaya | 0.50 | 0.46 | 0.96 | 1.00 | 0.00 | 0.32 | 0.60 | 0.18 | 0.89 |
| Sungai Besi | 0.57 | 0.05 | 0.96 | 0.28 | 1.00 | 0.31 | 0.60 | 0.20 | 0.88 |
| Putra Heights | 0.24 | 0.10 | 0.92 | 1.00 | 1.00 | 0.29 | 0.30 | 0.13 | 0.88 |
| Ara Damansara | 0.50 | 0.62 | 0.97 | 1.00 | 0.00 | 0.42 | 0.30 | 0.17 | 0.88 |
| Kelana Jaya | 0.88 | 0.05 | 0.95 | 0.94 | 0.00 | 0.15 | 0.50 | 0.38 | 0.86 |
| Asia Jaya | 0.60 | 0.60 | 0.94 | 1.00 | 0.00 | 0.15 | 0.30 | 0.23 | 0.85 |
| Pusat Bandar Puchong | 0.64 | 0.38 | 0.94 | 0.66 | 0.00 | 0.31 | 0.60 | 0.23 | 0.84 |
| Kinrara BK5 | 0.61 | 0.41 | 0.94 | 0.75 | 0.00 | 0.28 | 0.50 | 0.24 | 0.83 |
| Maluri | 0.56 | 0.22 | 0.96 | 0.10 | 1.00 | 0.15 | 0.50 | 0.19 | 0.82 |
| Sentul | 0.64 | 0.23 | 0.92 | 0.46 | 0.44 | 0.17 | 0.60 | 0.24 | 0.82 |
| Sentul Timur | 0.78 | 0.08 | 0.90 | 0.67 | 0.00 | 0.36 | 0.60 | 0.30 | 0.82 |
| Sri Petaling | 0.58 | 0.07 | 0.87 | 0.14 | 1.00 | 0.34 | 0.50 | 0.21 | 0.82 |
| Alam Megah | 0.57 | 0.02 | 0.95 | 0.37 | 1.00 | 0.37 | 0.20 | 0.19 | 0.82 |
| KLCC | 0.60 | 0.61 | 0.85 | 0.00 | 0.88 | 0.24 | 0.30 | 0.21 | 0.82 |
| Cempaka | 0.86 | 0.11 | 0.94 | 0.53 | 0.00 | 0.20 | 0.50 | 0.39 | 0.78 |
| Pudu | 0.21 | 0.59 | 0.88 | 0.92 | 0.00 | 0.24 | 0.50 | 0.11 | 0.77 |
| Pandan Indah | 0.81 | 0.13 | 0.88 | 0.40 | 0.15 | 0.21 | 0.50 | 0.34 | 0.76 |
| USJ7 | 0.63 | 0.60 | 0.93 | 0.00 | 0.32 | 0.18 | 0.50 | 0.26 | 0.76 |
| Wangsa Maju | 0.90 | 0.08 | 0.85 | 0.58 | 0.00 | 0.21 | 0.40 | 0.38 | 0.76 |
| SS15 | 0.70 | 0.58 | 0.87 | 0.00 | 0.30 | 0.20 | 0.40 | 0.32 | 0.75 |
| Abdullah Hukum | 0.27 | 0.60 | 0.97 | 0.00 | 0.67 | 0.52 | 0.20 | 0.14 | 0.75 |
| Pasar Seni | 0.05 | 0.52 | 0.81 | 0.00 | 1.00 | 0.54 | 0.40 | 0.04 | 0.75 |
| Cahaya | 0.90 | 0.10 | 0.93 | 0.45 | 0.00 | 0.03 | 0.50 | 0.41 | 0.74 |
| Masjid Jamek | 0.08 | 0.64 | 0.88 | 0.00 | 0.45 | 0.65 | 0.60 | 0.01 | 0.74 |
| Sultan Ismail | 0.54 | 0.56 | 0.87 | 0.00 | 0.00 | 0.60 | 0.60 | 0.17 | 0.74 |
| Jelatek | 0.71 | 0.08 | 0.89 | 0.21 | 0.56 | 0.15 | 0.40 | 0.33 | 0.74 |

| Station | Density | | Diversity | Design | | Distance to transit | | Destination accessibility | TOD Index |
|---|---|---|---|---|---|---|---|---|---|
| | Pop. density | Commercial density | Land use diversity | Parking | Public space | Pedestrian (km) | Intersection density | Land use mixedness | |
| Wawasan | 0.70 | 0.05 | 0.90 | 0.00 | 0.64 | 0.26 | 0.40 | 0.32 | 0.73 |
| Pandan Jaya | 0.63 | 0.20 | 0.93 | 0.52 | 0.00 | 0.22 | 0.50 | 0.25 | 0.72 |
| Bandar Puteri | 0.24 | 0.36 | 0.93 | 0.00 | 0.63 | 0.46 | 0.50 | 0.13 | 0.72 |
| USJ21 | 0.63 | 0.03 | 0.92 | 0.00 | 0.86 | 0.24 | 0.30 | 0.27 | 0.72 |
| Bandaraya | 0.13 | 0.53 | 0.87 | 0.18 | 0.00 | 0.82 | 0.60 | 0.05 | 0.71 |
| Lembah Subang | 0.62 | 0.60 | 0.93 | 0.12 | 0.00 | 0.38 | 0.30 | 0.26 | 0.71 |
| Bangsar | 0.70 | 0.24 | 0.90 | 0.00 | 0.40 | 0.33 | 0.30 | 0.32 | 0.71 |
| Titiwangsa | 0.26 | 0.43 | 0.88 | 0.00 | 0.55 | 0.37 | 0.50 | 0.14 | 0.70 |
| PWTC | 0.24 | 0.57 | 0.87 | 0.25 | 0.00 | 0.46 | 0.60 | 0.12 | 0.69 |
| Cheras | 0.64 | 0.13 | 0.94 | 0.38 | 0.00 | 0.30 | 0.50 | 0.23 | 0.69 |
| Muhibbah | 0.60 | 0.03 | 0.94 | 0.66 | 0.00 | 0.23 | 0.40 | 0.24 | 0.69 |
| SS18 | 0.94 | 0.04 | 0.86 | 0.00 | 0.24 | 0.20 | 0.40 | 0.41 | 0.69 |
| Kampung Baru | 0.71 | 0.52 | 0.89 | 0.00 | 0.00 | 0.26 | 0.40 | 0.33 | 0.69 |
| Miharja | 0.58 | 0.13 | 0.95 | 0.38 | 0.00 | 0.33 | 0.50 | 0.21 | 0.68 |
| Gombak | 0.69 | 0.03 | 0.91 | 1.00 | 0.00 | 0.05 | 0.10 | 0.30 | 0.68 |
| Bandar Tun Razak | 0.87 | 0.04 | 0.97 | 0.00 | 0.00 | 0.29 | 0.50 | 0.35 | 0.67 |
| Taipan | 0.70 | 0.23 | 0.89 | 0.00 | 0.00 | 0.38 | 0.50 | 0.33 | 0.67 |
| Masjid Jamek | 0.08 | 0.62 | 0.81 | 0.00 | 0.45 | 0.65 | 0.40 | 0.01 | 0.67 |
| Setiawangsa | 0.86 | 0.06 | 0.87 | 0.43 | 0.00 | 0.14 | 0.30 | 0.35 | 0.67 |
| Taman Melati | 1.00 | 0.01 | 0.72 | 0.00 | 0.00 | 0.33 | 0.40 | 0.52 | 0.66 |
| Subang Jaya | 0.60 | 0.71 | 0.90 | 1.00 | 0.00 | 0.36 | 0.20 | 0.16 | 0.65 |
| Puchong Perdana | 0.78 | 0.07 | 0.91 | 0.00 | 0.00 | 0.19 | 0.60 | 0.31 | 0.64 |
| Puchong Prima | 0.88 | 0.06 | 0.86 | 0.00 | 0.00 | 0.06 | 0.60 | 0.43 | 0.64 |
| Dang Wangi | 0.26 | 0.64 | 0.84 | 0.20 | 0.46 | 0.23 | 0.30 | 0.13 | 0.64 |
| Ampang Park | 0.62 | 0.56 | 0.91 | 0.00 | 0.00 | 0.23 | 0.30 | 0.28 | 0.64 |
| Subang Alam | 0.86 | 0.05 | 0.88 | 0.12 | 0.00 | 0.31 | 0.20 | 0.35 | 0.62 |
| Damai | 0.85 | 0.17 | 0.82 | 0.00 | 0.00 | 0.17 | 0.30 | 0.41 | 0.60 |
| Dato' Keramat | 0.87 | 0.17 | 0.87 | 0.00 | 0.00 | 0.14 | 0.30 | 0.37 | 0.60 |
| Taman Perindustrian Puchong | 0.12 | 0.31 | 0.95 | 0.24 | 0.00 | 0.40 | 0.60 | 0.05 | 0.59 |
| Sri Rampai | 0.60 | 0.23 | 0.86 | 0.12 | 0.00 | 0.30 | 0.30 | 0.25 | 0.59 |
| Alam Sutera | 0.58 | 0.02 | 0.95 | 0.00 | 0.18 | 0.27 | 0.40 | 0.21 | 0.58 |

| Station | Density | | Diversity | Design | | Distance to transit | | Destination accessibility | TOD Index |
|---|---|---|---|---|---|---|---|---|---|
| | **Pop. density** | **Commercial density** | **Land use diversity** | **Parking** | **Public space** | **Pedestrian (km)** | **Intersection density** | **Land use mixedness** | |
| Salak Selatan | 0.12 | 0.42 | 0.86 | 0.20 | 0.00 | 0.42 | 0.50 | 0.04 | 0.57 |
| Hang Tuah | 0.22 | 0.61 | 0.88 | 0.00 | 0.00 | 0.27 | 0.40 | 0.12 | 0.56 |
| Chan Sow Lin | 0.20 | 0.46 | 0.97 | 0.00 | 0.00 | 0.13 | 0.50 | 0.11 | 0.53 |
| Plaza Rakyat | 0.16 | 0.67 | 0.83 | 0.00 | 0.00 | 0.22 | 0.30 | 0.12 | 0.51 |
| Kerinchi | 0.25 | 0.21 | 0.88 | 0.00 | 0.00 | 0.16 | 0.20 | 0.12 | 0.40 |
| Universiti | 0.25 | 0.13 | 0.86 | 0.00 | 0.00 | 0.11 | 0.30 | 0.11 | 0.39 |




Universiti Station USJ21 Station Glenmarie Station

**Figure 4**: Hexagonal Diagram for the Lowest, Median, and Highest Scores of the TOD Index

Figure 4 illustrates the hexagonal diagrams of the characteristics of the three stations as an example case, which has scored the TOD index's lowest, median, and highest values. Each diagonal corner represents the score for eight (8) station indicators scaled from 0 to 1 in the same standardised technique - Universiti Station scores 0.39, with 0.00 for parking and open space in the design aspect. Located in the major redevelopment area of Kampung Kerinchi into high-rise residential, office towers, and shopping malls, the main land use within the buffer is public facilities and institutions, with a total of 74 hectares. Surrounded by low-cost apartments in a compact area, this station has no provision for parking or urban space as both are components of the built environment, which leads people to walk to the station conveniently. The poor connectivity of the pedestrian walkways to the station contributes to the lowest value for the design aspect.

The median score of the TOD index was 0.72 at USJ21 Station. The same score was also recorded for Bandar Puteri Station and Pandan Jaya Station. The highest indicators were land use (diversity) with 0.92 and open space (design) with 0.86. This station is surrounded by a mix of uses – mosque, shop lots, school, and a neighbourhood mall, all within walking distance. The major land use development in the buffer area of the station is a medium-density residential type of landed house. While the open spaces are well-designed due to the neighbourhood unit concept, which has been applied in Subang Jaya, which is an old city in Selangor, since the 1970s. The street-grid pattern in USJ is particularly able to disperse traffic and allow for a tremendous variety of route options, which means that the roads are smaller and therefore walkable. This street system concentrates both traffic and destinations such as shop lots, schools, mosques, and parks on large secondary roads.

The highest TOD index score goes to Glenmarie Station. In the future, this station will integrate with Glenmarie 2 as an interchange station for the Shah Alam Line, which is also known as LRT3. The LRT3 project is expected to be fully completed in early 2025. Glenmarie Station has scored the highest for commercial density, land use diversity, parking, and open space provision. It can be said that this station's location is strategically located in between the airport (Subang Airport), adjacent to Kelana Jaya, Subang Jaya, and Shah Alam, and is connected to the Federal Highway. Surrounded by the industrial zone area, services, and commercials, this station has scored the lowest for land use mixedness as the residential land use is only 29.9 hectares, or 14.8%, of the total development area. The distance to the transit aspect of the station also scored the lowest value. From the OSM data, the pedestrian distance within the buffer area was only recorded at approximately 2.8 km from the farthest pedestrian walkway to the station. As the station is located beside the primary road of Jalan Lapangan Terbang Subang and the ongoing construction of the LRT3 line along Persiaran Kerjaya, thus, access by pedestrian walkways is impossible.

## CONCLUSION

In conclusion, this study has explored an important key point to highlight the potential benefits of using the TOD index to facilitate TOD planning and implementation in Malaysia, aligning with the ambition to encourage more transit use instead of private vehicles in urban areas. The methodology adopted to calculate the TOD index is relevant, straightforward, and practical, especially in the Malaysian context. The study's findings provide valuable insights into the TOD potential of these LRT stations in Malaysia. Malaysia needs to align its policies and investment opportunities with TOD principles to capitalise on the benefits of TOD. This includes implementing appropriate land use zoning, promoting mixed-use developments with the right density and intensity of development near transit stations, improving pedestrian and cycling infrastructure, and enhancing connectivity between transit modes. Besides, Malaysian cities can implement the TOD concept, as their location is more robust. In recent years, this country has strived for a better public transportation system to face crucial urban challenges.

Since this study on the TOD index has been completed to measure 69 station areas for the first instance in Malaysia, there are no references available in the literature. Yet, the ridership statistic data must be corroborated in future research of the case stations with their TOD index to better understand the station's potential. The analysis of the 69 LRT stations revealed that the overall TOD level in the city is good, with 49 stations scoring above 0.71 on the TOD Index. The high-scoring stations were predominantly located in the sub-city and neighbourhood centres, indicating the significance of population density and employment opportunities in shaping the TOD level. Some stations, such as Glenmarie, Bukit Jalil, IOI Puchong, and Sungai Besi Station, exhibited potential for further development and redevelopment.

At the same time, it is envisaged that more data, such as employment density and investment or business value, will be collected and made accessible for TOD index calculations. Statistical data at a more in-depth level would also lead to higher accuracy in results. One can use this TOD index approach to plan for higher transit connectivity at the high-potential stations and lines and higher TOD levels around the extant transit nodes. The availability of passenger counts per station has also helped to highlight stations that would benefit from better access and a better-built environment for high-quality transit.

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