Contents available at: www.repository.unwira.ac.id

ARTEKS

JURNAL TEKNIK ARSITEKTUR

https://journal.unwira.ac.id/index.php/ARTEKS

Research paper

doi: 10.30822/arteks.v9i3.3385

TOD indeks based on factor analysis for rail stations and their surrounding in Jakarta Metropolitan Region

Etty Retnowati Kridarso, Julindiani Iskandar, Agus Budi Purnomo*

Department of Architecture Faculty of Civil Engineering and Planning Universitas Trisakti, Indonesia

ARTICLE INFO

Article history:
Received May 06, 2024
Received in revised form June 16, 2024
Accepted November 05, 2024
Available online Decembert 01, 2024

Keywords:
Factor analysis (FA)
Rail station
Transit Oriented Development (TOD)
TOD index

***Corresponding author**: Agus Budi Purnomo
Department of Architecture Faculty of Civil Engineering and Planning Universitas Trisakti, Indonesia
Email: agusbudi@dnet.net.id

ABSTRACT

In the Jakarta Metropolitan Region (JMR), railroads have existed since 1872, when the city was still known as Batavia and was ruled by the Dutch. When JMR implemented Transit Oriented Development (TOD) at the start of the twenty-first century, train stations and the surrounding area started to be valued as premium real estate. This study created a TOD index to assess the stations' and their surroundings' conditions regarding TOD characteristics. A TOD index based on Factor Analysis (FA) was computed for each of the 122 railway stations and the areas surrounding them in JMR using twenty-six TOD variables, which were based on the eight components of TOD established by IDTP. The results of this study present the TOD index introduced is comparatively similar to the index calculated by other researchers. Furthermore, we may assess train stations and their environs and provide recommendations for how to make them better as TODs by classifying the stations according to the TOD index.

Introduction

Since 1872, railways have been constructed in Batavia or modern-day Jakarta. To move agricultural products like sugar cane from the interior to the shipping port in Batavia, modern-day Jakarta, and other coastal towns, the Dutch Colonials started constructing railroads (Hermawan Iwan 2019). Later, the railways were also developed for transporting people between cities such as Jakarta, Semarang, and Yogyakarta. In other regions of Indonesia, like Aceh, Dutch colonial forces constructed railroads to convey military forces and artillery to quell insurgent activity (Usman dan Rachmatsyah 2017).

Following Indonesia's independence in 1945, trains started carrying people from residences in the hinterland of Jakarta, such as Bekasi and Tangerang, to places of employment in Jakarta, and vice versa (Jumardi et al. 2020; Wijayanto 2019). Jakarta's railways are now used for people's daily commutes rather than for moving cargo. The level of service provided by the railway has not changed significantly, nevertheless (Lingga 2019). The state of the railroads has further deteriorated by then (Setiawan Kartum 2021). As more people relied on the system regularly, the quality of service declined to the point that it was unable to keep up. Eventually, several of the original trains and stations were closed due to the decline in the hinterland's production of horticultural commodities. The railways' service has encountered a severe decline and many accidents have caused lives (Djajasinga Nico et al. 2015; Yanuaris Nurnita 2018; Wikipedia 2022). Only after 2007 were the railways used for commuters and named by the government as commuter lines. The government's initiatives have started to rehabilitate Jakarta's railway system's state (Putranto and Dwi Srie Adhimas 2018). Jakarta implemented a rapid mass transit (MRT) and light transit rail (LRT) system in 2013. Jakarta experienced the emergence of the Transit-Oriented Development (TOD) idea as a result of Indonesia's railway development (Matanasi Petrik 2017). TOD is a development idea that connects Jakarta's trains or transit infrastructure with urban development.

Integrating railways with urban development revitalizes Jakarta's railways (Saputra Dany 2022). The issue is determining how much of Jakarta's railways have been revitalized. This study reports on the creation of a TOD index to gauge the TOD surrounding railway stations in the Jakarta Metropolitan Region (JMR). Like all composite indices, the TOD index works to condense several indicators into an overall indicator for a particular object (Chakrabartty Satyendra Nath 2017). An object can be positioned or distinguished from other objects using the index (Espín Antonio M 2015). A composite index can also be utilized to gauge a case's advancement concerning specific objectives (Singh et al. 2014). Both a temporal and spatial mapping of such an index is possible (H M Taki, Maatouk, and Ahmadi 2019). The map of a composite index can be utilized to predict the spatiotemporal development of objects characterized by the index (Singh et al. 2018). Based on a composite index similar to the TOD index described in this paper, alternative decisions can be made to assist the decision-making process (Singh Y.J. et al. 2015).

Railway stations in Indonesia are formally classified as Large, Class I, Class II, Class III (small station), and Train Stops (Kementrian Perhubungan 2011; Kementrian Perhubungan 2019).

Railways passing through a station can be divided into commuter and intercity lines based on the services they provide (Kementrian Perhubungan 2011). The land on and around the station is owned by PT KAI (Indonesia Railways Ltd.). The space around a station has not been adequately exploited since the first railways were established in 1872. For instance, the Indonesia Land Bureau (BTN) has only certified 40% of the land owned by PT KAI. As a result, since 1872, individuals or other parties have unlawfully taken possession of the land surrounding a station in Indonesia (Nurjanah Siti et al. 2019). Furthermore, as the owner of most of the land in the vicinity of a station and railways, PT KAI had leased it to other parties unrelated to any railway's functions. In Indonesia, the land surrounding a train station became unmanaged slums and other areas unrelated to the railway station's primary operations (Evasentia 2022).

With the increasing need to develop a station and its *surroundings* as a TOD at the beginning of the 21st century in Jakarta, there is an increasing consciousness about the values of the land around a train station (Syabri Ibnu 2011; VOI 2022). In Indonesia, there is a growing demand to improve the surroundings of rail stations, particularly in major cities like JMR. To assess the value of the vicinity of a station in JMR, this research introduced the TOD index. We can determine when the area surrounding a station has achieved a particular level of TOD using the TOD index.

There are three parts to TOD. The transit station (T), development area (D), and connection (C) between the two components are the first, second, and third components, respectively (Qiang et al., 2022). In its TOD-Standards 3.0 (ITDP 2017), ITDP outlined those three characteristics as eight parts of TOD. The eight components of ITDP were also used in this work as TOD features, following the majority of TOD literature (Legowo and Sumadio 2021; Siburian et al. 2020; Taki et al. 2019). A composite indicator known as the TOD index was computed in the majority of those investigations using the TOD characteristics.

A composite index is the TOD index. A composite index can be determined in several methods using a set of variables (Greco et al. 2019a). The first approach involves a weightless average of all standardized variables. According to Greco et al. (2019b), every variable is seen as an entity with a single variance. Consequently, using this approach, the following equation can be used to determine the TOD index (CI):

$$\mathrm{CI} = {\sum_1^n \mathrm{V_i}}/{\mathrm{n}} \qquad \text{Equation 1}$$

Where n is the number of variables, and Vi is the value of variable i.

The second method considered the composite index as a weighted average of variables. Equation 2 presents how the composite index is calculated with certain weighting factors.

$$CI = \frac{\sum_1^n (W_i \, x \, V_i)}{\sum_1^n W_i} \qquad \text{Equation 2}$$

Where Wi is the weight of Vi. This second method can be divided into two sub-methods. The first sub-method employs a panel of experts to determine the weightings. Multi-criterion analysis (MCA) and the Analytic Hierarchy Process (AHP) employ panel experts to determine the weighting of each variable (Greco et al. 2019b).

The second sub-method establishes the weightings based on the correlation between the variables. The weighting and variables for determining the composite index are derived from Factor Analysis (FA) data, such as the variance of factors and Factor Scores (Fs). Based on FA, several composite indices were computed, including the bibliometric index (Aprilliant Audhi 2021; Fernando et al. 2012; Valderrama Pilar et al. 2021).

A panel of specialists evaluates pairwise comparisons in AHP. The weighting assignments become too complex and demand a great deal of work from the panel as the number of levels rises (Kurek et al. 2022; Oguztimur 2011). It appears that there is no standard in AHP for deciding how to weight variables (Poledníková Eva and Melecký Lukáš 2017). In the case of FA, weighing is rather straightforward and uncomplicated. The eigenvalues of every factor are employed in FA as the weighting. It is a typical Factor Analysis outcome (Verma 2013). Consequently, balancing the variables in FA is simpler than having panel experts weigh them in AHP. A construct or composite index is each factor's Factor Score (Fs) (Bolaños et al. 2008). Another typical FA output is Fs. Every Fs in the analysis indicates a collection of traits or variable values for every case.

AHP depends on the expert panel's weightings and is primarily employed in planning and design (Yeh and Shi 1999). Consequently, the expert panel's weighting may introduce a cognitive bias into the planning and design review process (Bay J.H. n.d.; Dror 2020; Langfeldt Liv 2002). We believed that because the FA process is more objective, there would be less cognitive bias in the planning and design process, resulting in a more reproducible evaluation with a TOD score based on FA (Bohne et al. 2015; Quijano et al. 2022). We will demonstrate in this study how the planning and design process can also benefit from the findings of FA. We may observe the relationship between the TOD index and the grouped qualities represented by a factor by mapping the index into factors space. The planning and design for a better TOD can be guided by this relationship.

An automatically generated TOD index does not include human specialists; instead, it is based on the correlation of factors from inside the data. As a result, the FA-based index may be deemed appropriate for incorporation into contemporary IT advancements like machine learning, artificial intelligence, and the Internet of Things. Convergence to the index derived from expert panelists remains an issue even with autonomous composite index production. We speculate that there is a substantial correlation between the FA-based TOD index suggested in this paper and an index of a similar nature produced by panelists with expertise.

Methods

ITDP unveiled TOD Standard 3.0 in 2017. There are eight TOD components in the standard. Each component is accompanied by multiple TOD metrics in the standard. We utilized secondary data from a variety of sources, including the official PT KAI website, Google Maps, and numerous other websites on the Internet, due to the limited time and resources supporting our study. Consequently, we do not employ primary data for ITDP measures. However, the eight elements of the ITDP TOD standard serve as the foundation for this investigation. The operational definitions of the measures or variables utilized in this study to generate the TOD index are displayed in table 1. Table 1 demonstrates the operational definition of each case's variables within the 0.5 km radius around a railway station. The cases included in this study are the 122 railway stations in the Jakarta Metropolitan Region (JMR) and the areas surrounding them. A circle having a radius of 0.5 km around a train station is employed to define the station's surroundings. We gathered all of the TOD variables for this investigation within 0.5 kilometers of a train station.

The TOD index of stations and their surrounds was determined by most research using AHP. In those investigations, the weighting of each measure or variable that would be included in the TOD index was decided by a panel of experts. The subjectivity of the expert will likely become more of an issue as there are more variables, making weighting more difficult to determine (Whitaker 2007). In other areas of research, such as the creation of a bibliographic index, factor analysis (FA) was utilized in place of AHP while calculating the index. In factor analysis (FA), the number of variables gathered into a factor determines the weightings. Therefore, using professional judgment regarding the weightings is not necessary.

The fact that FA divides the variables into factors is another benefit. Based on their TOD index, each factor can be used to describe a station and its surroundings. Planning can be enhanced by this categorization of a station and its surroundings based on the factors and TOD index since the variables and TOD index size indicate the extent to which a station has met all of the TOD variables.

We compare the TOD index presented in this study to one that was similarly generated for the station and its surroundings in JMR by other researchers (Legowo and Sumadio 2021; Siburian et al. 2020; Taki et al. 2017). This allows us to verify our theory regarding the TOD index. AHP was employed in all of the other researchers' TOD index computations for JMR stations. This study's TOD index was also verified by contrasting it with other criteria, like the station's amenities, quality, and class. The station factors used to validate the TOD index from this investigation are displayed in table 2.

Table 1. The TOD index variables were calculated for an area of 0.5 km from a station

	Operational definitions	Sources
V1	Average FAR.	Jakarta Satu
V2	The number of apartment buildings.	Google Maps
V3	The number of office buildings.	Google Maps
V4	Land use entropy $= -\left(\sum_1^k \left(P_i \times \ln(p_i)\right)/\ln(k)\right)$, where k is the number of land use types, P_i is the probability of land use type i.	(Zagorskas Jurgis, 2016)
V5	Length of pedestrian ways.	Jakarta Satu
V6	The number of Bus Rapid Transit (BART) lines.	Google Maps, Jakarta Satu
V7	The number of paratransit stops.	Google Maps
V8	The number of road intersection points.	Google Maps
V9	The length of roads.	Google Maps
V10	The average road section length.	Google Maps
V11	The number of housing complexes	Google Maps
V12	The average BCR.	Jakarta Satu
V13	The number of recreational facilities (museums, theatres, amusement centers).	Google Maps
V14	The number of parks and public open spaces.	Google Maps
V15	The average shortest bus time to/from stations from/to various land use functions.	Google Maps
V16	The average shortest walking distance to/from stations from/to various land use functions.	Google Maps
V17	The average shortest bike path to/from stations from/to various land use functions.	Google Maps
V18	The number of Google Reviews about the pedestrian system.	Google Maps
V19	The number of Google Reviews about walkability.	Google Maps
V20	A number of good Google Reviews about walkability.	Google Maps
V21	The population density (peoples/km^2)	Central Bureau of Statistics
V22	The number of boarding houses.	Google Maps
V23	The average monthly peak size of the passenger.	Google Maps, PT KAI
V24	The number of parking provided by a station.	Google Maps, PT KAI
V25	The number of amenities and accesses	Google Maps, PT KAI
V26	The number of parking facilities	Google Maps, PT KAI

Table 2. Railway station variables

Station's Variables	Sources
Station Class	PT KAI
Number of lines that pass a station	PT KAI

Station's Variables	Sources
Number of inter-city lines that pass a station	PT KAI
Google stars	Google Maps
Google reviews	Google Maps
Google bad reviews	Google Maps
TOD index	Taki et al. (2017)
TOD index	Siburian et al. 2020
TOD index	Legowo et al. 2021
Distance to the nearest urban center from a station	Google Maps and (Rustiadi et al., 2021)
Distance to nearest regional center from a station	Google Maps and (Rustiadi et al., 2021)
The urban zone where a station is located	Google Maps and (Rustiadi et al., 2021)

In this study, we employed FA to reduce the data. The FA administered the Principal Component method and Varimax rotation. Only factors with eigenvalues (ʎ) equal to or larger than one is extracted. Factor Scores (Fs) are saved as composite variables. The TOD index is calculated using the formula,

$$TOD\ index = \frac{\sum_1^n (\lambda_i \times Fs_i)}{\sum_1^n \lambda_i} \qquad \text{Equation 3}$$

Fsi = factor scores, ʎi= eigenvalue of Factor i, and n is the number of factors extracted by FA.

We divide the stations according to the TOD index into four categories of stations and their surrounds to enhance the condition of the stations and their surroundings. This is based on the TOD index standard deviation (SD= 0.40). Stations of Group 1 have TOD index ⩽- SD. Stations of Group 2 have -SD < TOD index ⩽ 0, stations of Group 3 have 0< TOD index ⩽ SD, and Group 4 has TOD index> SD. The groups are mapped into factor spaces. The features of every group are visible based on the factor scores (Fs) values. We can identify a group's strengths and weaknesses based on its features, and we can then suggest necessary actions to raise each group of stations' TOD index.

Results and discussion

Seven factors having an eigenvalue of one or more were retrieved using FA. The overall variance from the FA is demonstrated in table 3. The factor structures are displayed in table 4. We determine each case's TOD index by using Equation 3 and table 3's variance. An index map for TOD is presented in figure 1. We identify each of the seven factors by the meaning of variables in table 1 based on the factor structure in table 4 and the TOD variables with high loading on a factor:

1. Factor 1 contains variables of average FAR or floor area ratio (V1), number of apartments (V2), number of businesses (V3), land-use entropy (V4), number of housings (V22), parking facilities (V26), the length of pedestrian system (V5), number of BART lines (V6), and number of paratransit stops (V7) on the vicinity (500m radius) of a railway station. The majority of the factors point to the presence of mixed-use development. Therefore, we have designated factor 1 as the mix-use factor.
2. Factor 2 consists of variables the number of roads or street intersection points (V8), total road length (V9), negative loading of mean road length (V10), and the number of housings (V11) in the area 0.5 km around a station. As a result, we designated factor 2 as the road and housing density factor.
3. The variables in factor 3 include the entropy of land use (V4), the number of parks and open spaces (V14), the number of recreational facilities (V13), and the BCR (V12) with negative loading. We designated the low-density development factor as factor 3.
4. A group of variables designated as Factor 4 include the average time it requires to travel by bus from a train station to a specific facility or business (V15), the average walking distance from a train station to facilities or places (V16), the average shortest distances to the closest paratransit stops from/to stations (V17), and the variable number of amenities and access points belonging to a train station

(V25) with the loading removed. The more the Fs of factor 4, the greater the distance between locations close to a train station. We identify factor 4 as the closeness factor as a result.

5. Factor 5 is the group of variables about the reviews on pedestrian existence collected from the Google Maps Reviews (V18), the number of Google Maps reviews associated with walkability (V19), the percentage of good Google Maps reviews about walkability (V20), and the total length of the pedestrian system (V5) around a train station. We designated factor 5 the walkability factor.
6. Factor 6 encompasses variables population density (V21), number of boarding houses (V22), number of paratransit stops with negative loading (V7) on the area 500-meter radius from a train station, and the average peak passenger per month of a station (V23). For that reason, we identified Factor 5 as the housing and passenger factor.
7. The variables included in factor 7 are as follows: the number of parking spaces (V24), the number of amenities and access points (V25) to a railroad station, the number of parking spaces within 500 meters of a station (V26), and the average monthly peak passenger count of the stations (V22). The station's amenities and parking facilities factor is denoted by the number 7.

Figure 1 illustrates how a station's TOD index tends to increase in proximity to regional hubs and decrease in distance from them. Table 5 demonstrates that nearly all station characteristics have a substantial correlation with the TOD index. The spatial distribution of the TOD index in figure 1 is consistent with the considerable association discovered between the TOD index and the spatial factors (distance from JMR centers and other regional centers).

Table 3. The total variance of extracted factors

Factor	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cum. %	Total	% of variance	Cum. %	Total	% of variance	Cum. %
1	5.55	21.33	21.33	5.55	21.33	21.33	4.27	16.41	16.41
2	2.96	11.40	32.73	2.96	11.40	32.73	3.10	11.91	28.32
3	2.72	10.48	43.21	2.72	10.48	43.21	2.66	10.24	38.57
4	2.22	8.56	51.76	2.22	8.56	51.76	2.63	10.11	48.68
5	1.86	7.17	58.93	1.86	7.17	58.93	2.27	8.73	57.41
6	1.40	5.37	64.29	1.40	5.37	64.29	1.74	6.69	64.10
7	1.32	5.09	69.38	1.32	5.09	69.38	1.37	5.28	69.38

Table 4. The varimax rotated factor loadings

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
V1	0.88						
V2	0.78						
V3	0.69						
V4	0.69		0.38				
V5	0.66				0.34		
V6	0.57						
V7	0.39					-0.33	
V8		0.93					
V9		0.91					
V10		-0.84					
V11		0.59					
V12			-0.90				
V13			0.89				
V14	0.37		0.82				
V15				0.91			

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
V16				0.88			
V17				0.73			
V18					0.86		
V19					0.84		
V20					0.73		
V21						0.71	
V22	0.39					0.71	
V23						0.52	0.36
V24							0.67
V25				-0.38			0.64
V26	0.44						0.54

We calculate the correlation coefficients between the TOD index established in this study and the comparable index determined by other researchers for comparable stations, including (Legowo and Sumadio 2021; Siburian et al. 2020; Taki et al. 2017), to validate the TOD index. Furthermore, table 5 demonstrates a substantial correlation between the TOD index of this study and similar indices from other researchers.

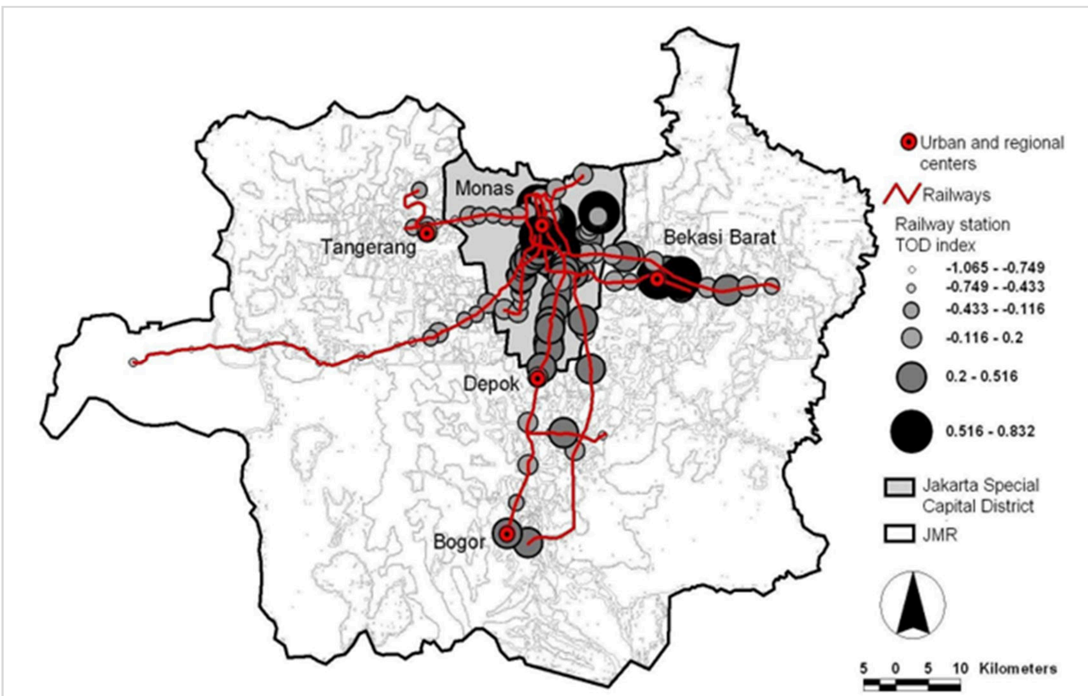

Figure 1. Map of the TOD index of all stations in this study

The maps of the groups of stations into factors space show the following characteristics:

1. Group 1 (TOD index ≤ -SD) encompasses stations and their surroundings with relatively low Fs for all factors.
2. Group 2 (-SD < TOD index ≤ 0) is a group of stations and their surroundings with relatively small Fs of factor 4 and factor 5, while Fs for other factors vary.
3. Group 3 (0< TOD index ≤ SD) is a group of stations that possess large Fs for factor 1 and factor 2, with the values for Fs for other factors varying. Figure 2 illustrates the distribution of cases in group 3.
4. Group 4 (TOD index > SD) contains the stations and surroundings with high Fs for all factors. Figure 3 demonstrates an example of

the distribution of cases of group 4 in Fs 1 and Fs 2 factors space.

Table 6 incorporates the resume of the characteristics of each group of stations and their surroundings mentioned above.

Table 4 indicates that the development factor of the area around the station can be attributed to factors 1, 2, and 3. The mix-use development surrounding a train station is indicated by factor 1. For instance, the factor 1 enormous Fs of MRT Blok M and LRT Rasuna Said stations. The factors in Factor 2 indicate the comparatively high physical density in the vicinity of a rail station. Two stations that have high Fs for factor 2 are Pasar Minggu and Klender Baru. Relatively wide-open public areas associated with sport and recreation are evident from the factors classified under factor 3. Stations with high Fs of factor 3 include MRT Senayan and LRT Velodrome. Factor 4 and factor 7 show the degree of connection between the surrounding areas and the train stations. Factor 4 contains the proximity variables from the surrounding area and the train stations. Large Fs of factor 4 means the average proximity to a train station is larger. For instance, MRT Blok A and Kramat stations have smaller Factor 4 Fs than others, indicating a greater connection between the train station and the surrounding functions. The variables that demonstrate how accessible the region is surrounding a rail station are found in Factor 5. Another indicator of the degree of connectivity between a rail station's surroundings is factor 5. For instance, compared to Tanjung Priok and LRT Boulevard Utara, stations Gambir and MRT Senayan have higher Fs of Factor 5 and are considered more accessible. Housing density-related variables constitute Factor 6. There is a comparatively intensive urban development in the vicinity of the train stations that factor 6 describes. Tanjung Priok and LRT Boulevard Utara are two stations with high Fs of factor 6.

Table 5. The correlation between the TOD index and with locational variables of the stations

Correlations between TOD index with railway station variables						
Statistics/variables	**Station class**	**Number of lines**	**Number of intercity lines**	**% of Bad Reviews**	**Google Star**	**Google Reviews**
Pearson Correlation	.202*	.258**	.254**	-.251**	.296**	.307**
Sig. (2-tailed)	0.026	0.004	0.005	0.005	0.001	0.001
Correlations between the TOD index of this study to other studies						
Statistics/sources	**Siburian et al. 2020**	**Taki et al. 2017**	**Legowo_et al. 2021**			
Pearson Correlation	.682*	.329**	0.423			
Sig. (2-tailed)	0.021	0.007	0.081			
Correlations between the TOD index with spatial variables of railway stations						
Statistics/variables	**Nearest distance to the urban center**	**Nearest distance to the regional center**	**Urban zone (Rustiadi et al. (2020)**			
Pearson Correlation	-.555**	-.578**	.299**			
Sig. (2-tailed)	0.000	0.000	0.001			

Table 6. Characteristics of groups of stations and their surroundings

Group of Stations	**TOD index**	**The factor with high Fs**	**The factor with low Fs**	**The factor with variable Fs**
Group 1	TOD index≤ -SD	-	All factors	-
Group 2	(SD< TOD index≤ 0	-	Factor 1, 2, 4 and 5	All other factors
Group 3	0< TOD index≤ SD	Factor 1 and 2	Factor 5	All other factors
Group 4	TOD index> SD.	all factors	-	-

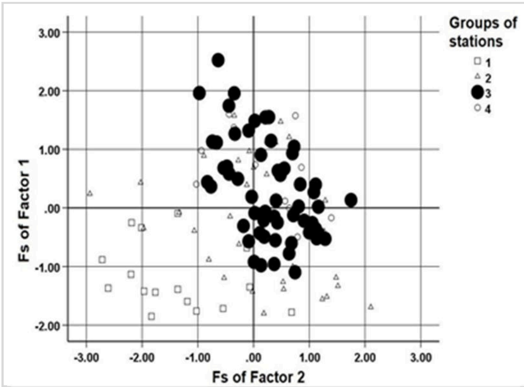

Figure 2. Map of station group 3 on Fs 1 and Fs 2 space

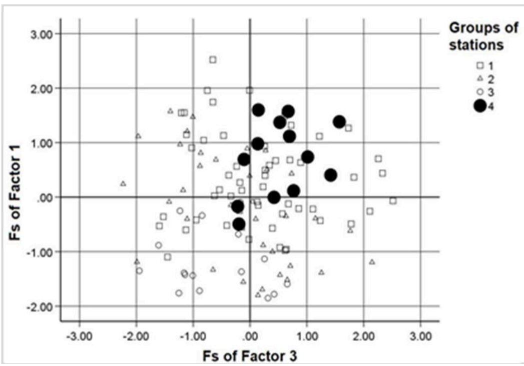

Figure 3. Map of station group 4 on Fs 1 and Fs 3 space

A set of criteria identified as factor 7 assesses the standard of a station's amenities, including the availability of parking for buses and cars. Stations with high Fs of factor 7 are Depok Baru and Soekarno Hatta International Airport. This element defines the notion of a TOD since it represents an alternative growth path. The usage of personal vehicles and motorcycles should be restricted by TOD. One method for achieving that goal was to reduce the number of parking spaces accessible for automobiles and motorcycles. Larger-scale park-and-ride schemes are, however, compatible with parking. There is an attempt to reduce the amount of time that people spend driving private cars within cities (Fatimah 2021).

The TOD index introduced in this paper correlates with the train station's distance to the urban and regional centers (table 5). The correlations indicated that the TOD-ness of the area surrounding a train station decreases as their location moves further from the centers. This fact corroborates the results of studies stating that a station can be categorized as urban, suburban, or local in terms of the TOD index (Huang et al. 2018; Taki et al. 2017). The spatial distribution of the railway stations and the areas around them according to their TOD index is displayed in figure 1 and table 5. The typology of TOD described by Li et al. (2019); Taki et al. (2019) is supported by the correlation between the TOD index and the distances of the rail stations to the closest regional or urban center. Thus, it supports the TOD index that was presented in this research. The results of this investigation were further verified by the substantial correlations discovered between the TOD index and similar indexes in previous studies (Legowo and Sumadio 2021; Siburian et al. 2020; Taki et al. 2017). On the other hand, if the variables utilized in calculating the index have the same definition and computation techniques, the correlation may be substantially stronger. Some researchers (Legowo and Sumadio 2021; Siburian et al. 2020; Taki et al. 2017) employed similar variables in their calculations of the TOD index. Those researchers used AHP but did not use FA to analyze their data.

The train stations and the surrounding areas TOD preparedness is also indicated by the factor scores (Fs) from FA. Developments with a mix of applications are the situations with high Fs of Factor 1. On the other hand, compared to the situations with high Fs of factor 4 and 5, the stations with such surroundings, as factor 1 demonstrates, have considerably closer proximity but poor walkability. On the other hand, unlike stations with high factor 7 values, those with high Fs of factor 1 have low parking areas despite having substantial mix-use growth.

In terms of TOD variables, FA should ideally extract a single factor. The cases with high Fs and TOD index will exhibit all the traits of a TOD if there is only one factor. Concerning table 4's factor loading, stations with high Fs of factor 1 are deemed more prepared as TODs than those with high Fs of factor 2. When comparing stations with minor factor variance to others, those with bigger variances are more prepared as TOD, as indicated by table 3's listing of variances for each factor.

In this study, the TOD index (table 5) has a substantial correlation with all station factors (table 2). The TOD index of the stations is highly correlated with their size and quality (Li et al. 2019; Taki et al. 2019). Table 5 demonstrates a substantial correlation between the stations' locational factors and their TOD index. Stated differently, the TOD index in this study diminishes when stations are located closer to JMR's boundary. The spatiality of the TOD index, as noted by Li et al. (2019); Taki et al. (2019), is supported by these results.

The station categories discovered in table 6 appear to correspond with the groups that (Yang and Song 2021) described. From table 6, we can propose some improvements to each group of train stations and their surroundings (Singh et al. 2017). Group 1 can be considered to have minor TOD characteristics. Except for factor 4 (proximity factor), where small Fs indicate closer proximity to a train station, all of the factors have very low Fs for example in group 1. The values of all TOD variables in table 1 for each station in group 1 should be raised if the railway stations and the areas around them are to be developed into a TOD. Factors 1, 2, and 5 are the vulnerabilities of group 2. For instance, to convert group 2 into a TOD, new functions should be added to the land use around one of the group's stations, allowing it to become a mixed-use development. Regarding factor 2, the intensity of businesses and other functions at a train station should be increased, and the proximity to the train station could be made nearer.

In group 3, the surroundings around railway stations have moderately strong Fs for factors 1 and 2. The stations of group 3 can be regarded as TOD when combined with lesser Fs of factor 4 (proximity). Nonetheless, group 3 stations' walkability requires to be increased due to low factor 5 (walkability), for the stations and the area around them to qualify as a TOD. All of the group 4 railway station factors are significant (high Fs), except for factor 4 (proximity). It can be concluded that the cases in Group 4 have become completely pledged TOD if the proximity problem of the factor is fixed.

There are limitations to our study. First, the ITDP TOD metrics were not adequately utilized by us. It would have been simpler to validate the TOD index from this study using the same index introduced by other researchers who also employed ITDP TOD measures if we had used the ITDP TOD metrics. Secondly, the sensitivity of the TOD index was not examined in this investigation. Sensitivity analysis is a rigorous process; therefore, it might be preferable to undertake it in future research. Thirdly, because this research is not diachronic, we are unable to monitor changes in the TOD index over time. On the other hand, the method used in this research for determining the TOD index appears to be simple. Thus, a periodic diachronic study of the index's evolution would not encounter any issues in the future.

Conclusions

This study employed JMR FA to assess 26 TOD characteristics of 122 railway stations and the areas around them. Seven parameters were derived from the analysis. The Fs and factor variances were utilized to calculate the TOD index for 122 railway stations. By contrasting it with a comparable index from other academics, the index was verified. The TOD index for this study was confirmed by the strong correlation it had with the TOD index of other researchers. The TOD index of the surrounding railway stations is declining as they are further removed from the JMR's regional and core centers. These data further substantiate the TOD index in this study and support findings from earlier investigations.

The mapping of the TOD index into factor scores space demonstrates the TOD characteristics of the railway stations and their surroundings as TOD. There are four categories of railroad stations and the areas around them based on the TOD features that are represented by the Fs of each of the seven factors. Group 4 railway stations have large Fs for all criteria, except for factor 4 (closeness to stations). We only suggest shortening the average distances between different activities and functions and the railway stations to enhance group 4's stations.

While the stations in group 3 have lower Fs for Factor 4, they have strong Fs for factors 1 and 2, indicating compact land use and proximity between activities and functions and the stations. These three variables indicate that Group 3 stations have turned into TODs, which is encouraging. However, group 3 stations have small Fs of factor 5 (walkability), factor 6 (housing and population density), and factor 7 (number of station facilities). To enhance the stations' preparedness to become TODs, we can increase the walkability, housing number (factor 6), population, and facilities (factor 7) of the group 3 railway stations. Small Fs for factor 1, factor 2, and factor 5 are present in group 2 stations. Building density, walkability (factor 5), and land use types (factor 1) may be improved to increase the TOD-ness of group 2 stations. For all parameters, the Fs of group 1 stations are comparatively small. Group 1 stations are still a long way from being TOD.

References

Aprilliant Audhi. 2021. "The Factor Analysis for Constructing a Composite Index."

Bay J.H. n.d. "Cognitive Biases in Design." 2001.

Bohne, Rolf André, Ole Jonny Klakegg, and Ola Lædre. 2015. "Evaluating Sustainability of Building Projects in Urban Planning." *Procedia Economics and Finance* 21:306–12. https://doi.org/10.1016/S2212-5671(15)00181-1.

Bolaños, Rocío Loría, Timo Partanen, Milena Berrocal, Benjamín Alvárez, and Leonel Córdoba. 2008. "Determinants of Health in Seasonal Migrants: Coffee Harvesters in Los Santos, Costa Rica." *International Journal of Occupational and Environmental Health* 14 (2): 129–37. https://doi.org/10.1179/oeh.2008.14.2.129.

Chakrabartty Satyendra Nath. 2017. "Composite Index: Methods and Properties."

Djajasinga Nico, Septanto Djoko, Tarli Tarli, and Rasyid Ubaini. 2015. "Pemetaan Jalur Kereta Api Rawan Kecelakaan Lintas Jati Negara – Jakarta Kota (Survai Di Jakarta, Kota)."

Dror, Itiel E. 2020. "Cognitive and Human Factors in Expert Decision Making: Six Fallacies and the Eight Sources of Bias." *Analytical Chemistry* 92 (12): 7998–8004. https://doi.org/10.1021/acs.analchem.0c00704.

Espín Antonio M. 2015. "Relative Positioning."

Evasentia, Yosefina. 2022. "Diduga Praktek Prostitusi Dan Judi, Daop 1 Jakarta Tertibkan Bangunan Liar."

Fatimah, Siti. 2021. "Tipologi Potensi Transit-Oriented Development (TOD) Di Sekitar Stasiun Light Rail Transit (LRT) Sumatera Selatan." *Warta Penelitian Perhubungan* 33 (1). https://doi.org/10.25104/warlit.v33i1.1778.

Fernando, MACSS, S Samita, and R Abeynayake. 2012. "Modified Factor Analysis to Construct Composite Indices: Illustration on Urbanization Index." *Tropical Agricultural Research* 23 (4): 327. https://doi.org/10.4038/tar.v23i4.4868.

Greco, Salvatore, Alessio Ishizaka, Menelaos Tasiou, and Gianpiero Torrisi. 2019a. "On the Methodological Framework of Composite Indices: A Review of the Issues of Weighting, Aggregation, and Robustness." *Social Indicators Research* 141 (1): 61–94. https://doi.org/10.1007/s11205-017-1832-9.

———. 2019b. "On the Methodological Framework of Composite Indices: A Review of the Issues of Weighting, Aggregation, and Robustness." *Social Indicators Research* 141 (1): 61–94. https://doi.org/10.1007/s11205-017-1832-9.

Hermawan Iwan. 2019. "Kereta Api: Kuasa Ekonomi Masa Kolonial Belanda Railway: Economic Power of the Dutch Colonial Era."

Huang, Runjie, Anna Grigolon, Mafalda Madureira, and Mark Brussel. 2018. "Measuring Transit-Oriented Development (TOD) Network Complementarity Based on TOD Node Typology." *Journal of Transport and Land Use* 11 (1). https://doi.org/10.5198/jtlu.2018.1110.

ITDP. 2017. "TOD Standard 3.0," 2017.

Jumardi, Ruly R, Abdulhadi, Atika Siska, Viki A, and Zaqi AZ. 2020. "Perkembangan Transportasi Kereta Api di Jakarta."

Kementrian Perhubungan. 2011. *Jenis, Kelas Dan Kegiatan Di Stasiun Kereta Api*.

———. 2019. *Standar Pelayanan Minimum Angkutan Orang Dengan Kereta Api*.

Kurek, Katarzyna A., Wim Heijman, Johan van Ophem, Stanisław Gędek, and Jacek Strojny. 2022. "Measuring Local Competitiveness: Comparing and Integrating Two Methods PCA and AHP." *Quality & Quantity* 56 (3): 1371–89. https://doi.org/10.1007/s11135-021-01181-z.

Langfeldt Liv. 2002. "Decision-Making in Expert Panels Evaluating Research: Constraints, Processes and Bias."

Legowo, Dewanti Aisyah, and Widyawati Sumadio. 2021. "Nilai Dan Pola Transit Oriented Development (TOD) Indeks Pada Jalur Commuter Line Bogor - Jakarta Kota." *Jurnal Wilayah Dan Lingkungan* 9 (2): 142–54. https://doi.org/10.14710/jwl.9.2.142-154.

Li, Zekun, Zixuan Han, Jing Xin, Xin Luo, Shiliang Su, and Min Weng. 2019. "Transit Oriented Development among Metro Station Areas in Shanghai, China: Variations, Typology, Optimization and Implications for Land Use Planning." *Land Use Policy* 82

(March):269–82. https://doi.org/10.1016/j.landusepol.2018.12.003.

Lingga, Rivan Awal. 2019. "Menhub Akui Layanan Kereta Api Masih Stagnan," 2019.

Matanasi Petrik. 2017. "Jalur KRL: Dari Angkut Hasil Kebun Berkembang Angkut 1 Juta Manusia."

Nurjanah Siti, Wahyudi Bambang, and Purwanto Purwanto. 2019. "Resolusi Konflik Lahan PT Kereta Api Indonesia (Persero) Dengan Warga Rw 12 Kelurahan Manggarai Jakarta Selatan Dalam Perebutan Lahan Di Wilayah Daerah Operasi 1 Jakarta."

Oguztimur, Senay. 2011. "Why Fuzzy Analytic Hierarchy Process Approach for Transport Problems?"

Poledníková Eva, and Melecký Lukáš. 2017. "Weighting Methods for Constructing Composite Indices in Regional Development."

Putranto, and Dwi Srie Adhimas. 2018. "Perkembangan PT Kereta Api Indonesia Pada Masa Kepemimpinan Ignasius Jonan, 2009-2014."

Qiang, Dan, Lingzhu Zhang, and Xiaotong Huang. 2022. "Quantitative Evaluation of TOD Performance Based on Multi-Source Data: A Case Study of Shanghai." *Frontiers in Public Health* 10 (February). https://doi.org/10.3389/fpubh.2022.82069.

Quijano, Ana, Jose L. Hernández, Pierre Nouaille, Mikko Virtanen, Beatriz Sánchez-Sarachu, Francesc Pardo-Bosch, and Jörg Knieilng. 2022. "Towards Sustainable and Smart Cities: Replicable and KPI-Driven Evaluation Framework." *Buildings* 12 (2): 233. https://doi.org/10.3390/buildings1202023.

Rustiadi, Ernan, Andrea Emma Pravitasari, Yudi Setiawan, Setyardi Pratika Mulya, Didit Okta Pribadi, and Narumasa Tsutsumida. 2021. "Impact of Continuous Jakarta Megacity Urban Expansion on the Formation of the Jakarta-Bandung Conurbation over the Rice Farm Regions." *Cities* 111 (April):103000. https://doi.org/10.1016/j.cities.2020.103000.

Saputra Dany. 2022. "MRT Jakarta Minta Restu Pemprov DKI Revitalisasi Terminal Blok M."

Setiawan Kartum. 2021. *Kereta Api Di Jakarta Dari Zaman Belanda Hingga Reformasi*. Penerbit Buku Kompas.

Siburian, Tomi Enjeri, Widyawati Widyawati, and Iqbal Putut Ash Shidiq. 2020. "Characteristics of Transit Oriented Development Area (Case Study: Jakarta MRT)." *Jurnal Geografi Lingkungan Tropik* 4 (1). https://doi.org/10.7454/jglitrop.v4i1.79.

Singh, Yamini Jain, Pedram Fard, Mark Zuidgeest, Mark Brussel, and Martin van Maarseveen. 2014. "Measuring Transit Oriented Development: A Spatial Multi Criteria Assessment Approach for the City Region Arnhem and Nijmegen." *Journal of Transport Geography* 35 (February):130–43. https://doi.org/10.1016/j.jtrangeo.2014.01.014.

Singh, Yamini Jain, Johannes Flacke, Mark Zuidgeest, and Martin van Maarseveen. 2018. "Planning for Transit Oriented Development (TOD) Using a TOD Index." In *GIS in Sustainable Urban Planning and Management*, 267–82. Boca Raton: CRC Press. https://doi.org/10.1201/9781315146638-15.

Singh, Yamini Jain, Azhari Lukman, Johannes Flacke, Mark Zuidgeest, and M.F.A.M. Van Maarseveen. 2017. "Measuring TOD around Transit Nodes - Towards TOD Policy." *Transport Policy* 56 (May):96–111. https://doi.org/10.1016/j.tranpol.2017.03.013.

Singh Y.J., Lukman A., He P., Flacke J., Zuidgeest M.H.P., and M.F.A.M. van Maarseveen. 2015. "Planning for Transit Oriented Development (TOD) Using a TOD Index."

Syabri Ibnu. 2011. "The Influence of Railway Station on Residential Property Values-SpaHedonic Approach the Case of Serpong's Railway Station."

Taki, H M, M M H Maatouk, and F Ahmadi. 2019. "Implementation of the Integrated TOD Spatial Model for Jakarta Metropolitan Region." *KnE Social Sciences*, July. https://doi.org/10.18502/kss.v3i18.4717.

Taki, Herika Muhamad, Mohamed Mahmoud H Maatouk, and Emad Mohammed Qurnfulah. 2017. "Re-Assessing TOD Index in Jakarta Metropolitan Region (JMR)." *Journal of Applied Geospatial Information* 1 (01): 26–35. https://doi.org/10.30871/jagi.v1i01.346.

Usman dan Rachmatsyah. 2017. "Kereta Api sebagai Sarana Transportasi Militer Kolonial Belanda dalam Perang Aceh (Suatu Kajian Historis dan Ekonomi di Pantai Timur Aceh Tahun 1900-1942)."

Valderrama Pilar, Evaristo Jiménez-Contreras, and Manuel Escabias & Mariano J. Valderrama. 2021. "Introducing a

Bibliometric Index Based on Factor Analysis."

Verma, J. P. 2013. "Application of Factor Analysis: To Study the Factor Structure Among Variables." In *Data Analysis in Management with SPSS Software*, 359–87. India: Springer India. https://doi.org/10.1007/978-81-322-0786-3_11.

VOI. 2022. "KAI Traces Assets in All Territories of Indonesia By Digging Deeper About The Truth Of History."

Whitaker, Rozann. 2007. "Criticisms of the Analytic Hierarchy Process: Why They Often Make No Sense." *Mathematical and Computer Modelling* 46 (7–8): 948–61. https://doi.org/10.1016/j.mcm.2007.03.01.

Wijayanto, Hendra. 2019. "Peranan Penggunaan Transportasi Publik Di Perkotaan (Studi Kasus Penggunaan Kereta Commuterline Indonesia Rute Jakarta-Bekasi)." *Kybernan: Jurnal Studi Kepemerintahan* 5 (2): 1–8. https://doi.org/10.35326/kybernan.v5i2.365.

Wikipedia. 2022. "Daftar Kecelakaan Kereta Api Di Indonesia."

Yang, Liu, and Xiaoyu Song. 2021. "TOD Typology Based on Urban Renewal: A Classification of Metro Stations for Ningbo City." *Urban Rail Transit* 7 (3): 240–55. https://doi.org/10.1007/s40864-021-00153-8.

Yanuaris Nurnita. 2018. "Studi Kasus Kecelakaan Kereta Api di Jabodetabek Tahun 2015-2018."

Yeh, A G O, and X Shi. 1999. "Applying Case-Based Reasoning to Urban Planning: A New Planning-Support System Tool." *Environment and Planning B: Planning and Design* 26 (1): 101–15. https://doi.org/10.1068/b260101.

Zagorskas Jurgis. 2016. "GIS-Based Modelling and Estimation of Land Use Mix in Urban Environment."

Author(s) contribution

Etty Retnowati Kridarso contributed to the research plan preparation, methodologies, literature review, visualization, data analysis, article drafting and revisions.

Julindiani Iskandar contributed to the field measurement, data analysis, article drafting, and visualization.

Agus Budi Purnomo contributed to the field measurement, data analysis, article drafting, and visualization.

This page is intentionally left blank