Transit Oriented Development (TOD) index at the current transit nodes in Depok City, Indonesia

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Abstract. Depok is a rural area which developed by Perum Perumnas in 1976. And growth rapidly since University of Indonesia moved in 1986. Afterward, Depok became a new city at periphery of DKI Jakarta with numerous development and urbanizations.

Depok city is facing urban problems including population growth of 9% per year, the increasing regular and irregular settlements and transportation problems such as traffic congestion, the increasing of individual cars and motorcycles and lack of transportation development. Moreover, Jabodetabek Commuterline which is start from Bogor station and transits in 5 (five) stations in Depok city (Universitas Indonesia, Pondok Cina, Depok Baru, Depok and Citayam), become a potential alternative for commuters in Depok to go out of the city.

Depok should have sustainable transportation such as Transit Oriented Development (TOD) masterplan in a strategic place of railways area to conduct a sustainable city. This study discovered that TOD planning should be proceded by understanding the existing condition through measurement of TOD level. Therefore, the measurement of TOD level around the existing nodes is inevitable as transit node plays a central role in TOD, so it was defined as 800 meters walking distances. This paper focus on 3 (three) station areas along the way of Jalan Margonda, which has a very significant growth development area in Depok with the indicators are divided into spatial and non-spatial indicators. Geographic Information Systems (ArcGIS) is used to quantify all of the spatial indicators.

Keywords: Transit Oriented Development (TOD), TOD index, sustainable area, implementation, indicators, sensitivity analysis

1. Introduction
Peter Calthorpe at first codified the concept of Transit-Oriented Development (TOD) in the late 1980's. Then, TOD became a fixture of modern planning when Calthorpe published “The New American Metropolis” in 1993. TOD has been defined generally as “a mixed-use community that encourages people to live near transit services and to decrease their dependence on driving”[1]. TOD was to help “Redefine the American Dream”[2].

In many city regions worldwide, TOD becomes a pursued development strategy. It builds a system of integration between transportation and land use planning. Typically, TOD involves creating medium up to high density areas of mixed land use concentrated within an 800-meter walking distance of significant transit stops [3].

Whilst there are numerous definitions of TOD proposed by Calthorpe[2], Schlossberg and Brown [4], Boarnet and Crane [5], Parker et al. [6], Cervero[7], Dittmar and Poticha[8], and many others, the most common goal of planning for TOD remains to encourage people to walk, cycle and use public
transit instead of cars, which is typically achieved by developing mixed use communities around transit nodes, with moderate to high densities and a walkable environment [9].

There are four strategic planning tools for TODs, such as a strategic policy framework that asserts where centers need to occur and at what kind of density and mix; a strategic policy framework that links centers with a rapid transit base, almost invariably electric rail; a statutory planning base that requires development to occur at the necessary density and design in each centre, preferably facilitated by a specialized development agency, and a public-private funding mechanism that enables the transit and the TOD to be built or refurbished through a linkage between the transit and the centers[10].

The aim of this research is to develop and implement an Ar-GIS model for measuring the TOD levels around the transit nodes in Depok Baru, Pondok Cina and Universitas Indonesia Stations using a TOD index, in order to identify the areas where the TOD levels can be improved.

Geographically Depok city is located at coordinates 6º 19' 00" - 6º 28' 00" South Latitude and 106º 43' 00" - 106º 55' 30" East Longitude, with an area of 20.29 km² and consists of 11 districts And 62 urban villages.

Depok initially was made as the capital of Jakarta city buffer with the settlement it provides, based on Presidential Instruction number 13 of 1976 which became the basic framework of the buffer area of Jakarta capital in a Jabodetabek area (Jakarta-Bogor-Tangerang-Bekasi) [11]. The first public residence of the government, built by Perum Perumnas, was first implemented in the city of Depok in 1976.  Depok city grew after the establishment of Universitas Indonesia in 1986. In short, the transformation of the development of Depok city is described at figure 1.

![Figure 1. Transformation of Depok City.](image)

After becoming a municipality based on Law Number 15 Year 1999 [12], Depok City now has a fast growing city economic growth of 7.51% / year. In Republic of Indonesia Regulatian called Peraturan Pemerintah Number 26 Year 2008 on National Spatial Plan[13], Depok City is directed to become National Activity Center in “Jabodetabekpunjur” (Jakarta-Bogor-Depok-Tangerang-Bekasi-Puncak-Cianjur) urban unity. As a new attraction in urban development Jabodetabekpunjur area and as a city adjacent to the main city of Jakarta, Depok must be ready in facing the conditions of rapid growing trend as the National Center of Activities.

The road networks and conditions in Depok City are still far from the ideal road performance standards for urban areas. It is clearly seen in the image of the existing road class is still dominated by local road class with road width ± 5-6 m. And only three main roads that have characterized the urban area of Bogor Highway, Margonda Road and Parung Highway with a width of ± 12 m. When viewed the pattern, the city of Depok is also more likely to still characterize the form of rural road network that grows organic, less regular and possibly unplanned with immature cityform masterplan. Transportation problems in the city of Depok appear to be increasingly serious due to the spreading population growth (urban sprawl) and the increasing number of ownership of two-wheeled and four-
wheeled vehicles. According to statistical data on Depok in Figures 2016 which published by Statistical Institution in Depok, the population in Depok in 2016 is 2,106,100 inhabitants [14], vehicle growth rate reaches 9% per year, while road growth in Depok City for the last five years is 0.7% [15]. The potential for the creation of transportation system is expected to be centered in the area of the railway line that divides the city of Depok into 2 parts and is strategically located in the middle of the region. There are 5 stations across the city of Depok with potential to move the inhabitants from and to Depok City namely the Universitas Indonesia, PondokCina, DepokBaru, Depok and Citayam stations as shown in figure 2.

![Train railway from Bogor to Jakarta, Tangerang and Bekasi through Depok City.](image)

According to Depok City Regional Regulation of Spatial Planning 2012-2032 No. 1 of 2015 which is known as “Rencana Tata Ruang Wilayah Depok 2012-2032”, article 24 it states that the railway transportation network system includes the development of integration of inter and intra-modal services based on Transit Oriented Development (TOD) [16]. Based on this local government's policy, this research analyzed the condition of TOD's supporting indicators in Depok city, especially in the center of the city with fast growing area along Jalan Margonda which is parallel to 3 (three) stations Universitas Indonesia, PondokCina and DepokBaru stations.

This paper is a case study [17] to calculate Transit Oriented Development (TOD) indicators in 3 Depok City stations, with an analogy indicator on the City Region of Arnhem and Nijmegen in the Netherlands case study conducted by Yamini Jain Singh, Azhari Lukman, Johannes Flacke, Mark Zuidegeist, MFAM Van Maarseveen [9].

2. Depok City and TOD Indicator

What kind of mixed land use pattern is formed around the transit points?; How is the density level in Depok City and what factors influence it?; To what extent and how is the concept of Transit Oriented Development implemented in Depok City?; And how is the direction to improve regional mobility, reduce congestion, use of time, comfort for Mixed Use area and high density in Depok City?; Research on this has been done by Widayanti and Susanto[18] with theoretical and observation approach. The result of the analysis concludes that mixed use patterns formed around the transit points are already partly formed even though the density in Depok City is higher and the planning is not good. Influential factors include: uncontrolled population growth, inadequate transportation systems, and poor pedestrian access. The weakness of the journal is the unanswered question: how good is a transportation system, capable of improving mixed land use, as the researcher intends.

The Potential Implementation of TOD in Depok, Raditya Eka Permana[19] recommends that it is worth to conduct other research such as on the calculation about TOD feasibility in Depok by assessing the potential market and its long term investment. The further observation shall address capacity projection on particular service which is integrated beneath TOD system. The calculation
based on certain factors that cover population, economic development, business density, and the variation of land use could determine the estimation and the type of anticipation for the expected TOD service. Understanding is required to support the success of TOD by increasing communication between governments, society in the potential transit area and users of public transport. Further potential research supposed to calculate the applicability of TOD in Depok.

There are also studies that measure TOD around transit nodes, mostly stations. One of the most recurring approaches to such station area studies is that of developing station typologies whereby all stations (in a study) are grouped into types. In Bertolini[20], various transit and urban development characteristics were measured for 17 station areas in the Netherlands. For each station, urban characteristics were used to calculate a place index while transit characteristics were used to calculate a transit index [4].

ITDP [21], has a similar attempt to quantify TOD using TOD standard scoring system. The focus of their work is to score a new development or a project in terms of its transit orientation only if it is within walking distance to the nearest transit station. For qualifying projects, the walking and cycling infrastructure, mix of land use, density, compactness of development and land occupied by motor vehicles are measured. These are covered under seven principles of Walk, Cycle, Connect, Mix, Density, Compact and Shift. Although the TOD standard measures urban development characteristics, it does not measure transit services and the scoring system is also subjective. It also relies on primary data collection mainly to urban design, which makes the applicability of this method to station areas much larger than a singular project or development was difficult. ITDP. Papa and Bertolini[22], have also tried to quantify TOD at city-level, for five European cities, by measuring a ‘TOD-degree’ for entire urban area, as the extent to which urban development is concentrated along rail corridors in the city. The method adopted in that study is inspired by the node-place model of Bertolini[20] but differs significantly as it used the correlation coefficient between node and place index values to denote the TOD degree of a city not individual transit nodes.

3. Methodology

Area of analysis used to measuring TOD around transit nodes. The concept of TOD is built around creating walkable-neighbourhoods and all the literature of TOD suggested that TOD should be developed within a typically comfortable walking distance.

There are 8 rules that identified regarding how urban development and characteristics of transit which affect TOD-ness in an area.

Rule 1 : Urban densities are important for developing TOD.
Rule 2 : Land use diversity creates a vibrant/lively place out of a node.
Rule 3 : Design of urban space that makes an area walkable and cyclable, is necessary for TOD.
Rule 4 : Higher economic development in an area leads to higher TOD.
Rule 5 : Higher ridership indicates higher TOD-ness. Transit systems should also have enough free capacity to remain attractive to more passengers.
Rule 6 : A user-friendly transit system is necessary to encourage people to use it.
Rule 7 : A node with better access and one that provides high accessibility and frequency of service increases chances of creating TOD.
Rule 8 : Parking supply for bicycles and cars will help more people to use transit for their longer commutes.

Based on Y.J Singh [23], those 8 rules generate 24 indicators to be measured, beside AzhariLukman [24] generate 18 indicators to be measured. So, the indicator depends on the situation area and purposes.

In order to carry all the indicators to comparable units, they were standardized using the ‘maximum standardization method’ where the maximum achieved value of an indicator becomes ‘1’ based on their ratio with the maximum value and all other values are given a value between 0 and 1. It is also required to represent how each indicator affects the value of TOD Index. Most of our indicators have a directly proportional relation with the TOD Index so that a higher value of that indicator contributes positively to the ‘benefit’ method. Three indicators – passenger load, parking utilization and mixed of land use were exceptions to this method. The ‘goal method’ was used for the first two so
that the indicator's value is represented as ‘benefit’ until it reaches a set goal value of 90% utilization of transit capacity and parking supply respectively. After the goal value, any increase in transit or parking use is treated as ‘cost’ to the TOD Index value because higher utilization levels indicate a pressure on the transit and parking systems. This figure is an assumption but a reasonable one. The combination of ‘benefit’ and ‘cost’ representations was used for mixed of land use, so that the indicator acts as a ‘benefit’ to the index until it reaches a value of 0.5, implying a good balance of residential and other land uses, after which, it acts like a ‘cost’ to the index and contributes negatively to the TOD Index.

Methodology uses case studies in Depok using geospatial mapping and primary data acquisition in field related to non spatial data. The calculations become easy to adapt to be applied to other areas, with the selection of indicators tailored to the situation as described in table 1.

Table 1. Rules, criteria and indicators of TOD index calculation.

| NO | DESCRIPTION | ICON | CRITERIA | INDICATOR |
|----|-------------|------|----------|-----------|
| 1  | Population density is important in building TOD | | Population density | The number of people per square kilometers, the number of building commercial per square kilometer |
| 2  | The number of people per square | | Allotment mix-use land | Diverse the function a land allotment |
| 3  | Design public space to walk an cycling needed in TOD | | Access on foot and ride a bike | Access on foot and cycling |
| 4  | Better economic development around the area drives the improvement of TOD function | | Economic Development | Number of business builds per square km; Earnings tax (last year); Level workers |
| 5  | The transit system must have sufficient capacity. Capacity that is too dense, not appealing to the user community. | | Capacity utilization of Transit | Number of Passengers at busy time; And Number of Passengers when empty |
| 6  | A "user-friendly" transit system is needed to mobilize the community using the transit system. | | The transit system is "user-friendly" | Security level on transit stops; Basic comfort level at station; The existence of a good information system (yes / no) |
| 7  | A point with good access and providing high accessibility, will increase the chances of creating TOD. | | Access and accessibility | Frequency of transit services (number of operated trains / hours); Deviations to different routes at the same transit point (number of routes); Deviations to other transit modes; Access opportunities within walking distance from the station (number of jobs) |
| 8  | Parking for bicycles and motor vehicles helps people use transit to travel long distances. | | Parking at the station | Supply-demand parking for cars / four-wheelers; Parking supply-demand for bicycles |

4. Calculating TOD Index
The indicators are calculated using ArcGIS to generate the TOD Index in each station area. In this case, there are spatially diverse indicators such as population density associated with land allocation and walking access as well as non-spatial indicators such as the frequency or passenger load in the transit system.

Indicators (I) in each area of the station are spatial and non-spatial. The transit point (S) representing the point in space and all spatial criteria such as population density associated with land allocation and access on foot can be analyzed spatially and aggregated in ArcGIS to generate value at that transit point. Other non spatial criteria that are some related to transit characteristics have represented a value at that point. Detailed compilations of all indicators are as shown in figure 3.
The indicator chosen to be the TOD level measurement index is adjusted to the conditions around the station area. The weight of the criteria is determined by stakeholders such as city government, railway company and investors. However, in this study, the criteria weight of the stakeholders is ignored, so only the TOD index is obtained from some indicators that are in accordance with the condition of the area in Depok. The weight does not significantly affect the TOD level of a station, but serves to provide elements of the policy priorities of stakeholders. By simply assessing the indicator, the real level of measurement of a transit area will be transparent as shown in table 2.

| Criteria | Indicators |
|----------|------------|
| 1 transit nodes should have optimum capacity utilization | 1 passenger load in peak hours (gate in) |
| | 2 passenger load in off-peak hours (gate in) |
| 2 transit nodes should be user friendly and attractive | 3 the presence of information display system |
| | 4 safety |
| 3 transit nodes should be accessible and provide good accessibility | 5 service frequency of transit system in peak hours |
| | 6 Number of connections to different routes |
| | 7 Number of interchange to other mode |
| | 8 Access to the station/stop |
| 4 transit nodes should provide optimum parking supply for different modes | 9 Parking supply demand for cars (four wheelers) |
| | 10 Parking supply demand for cycles |
| 5 TOD area should have a minimum transit supportive density | 11 population (residential) density in TOD area |
| | 12 Commercial intensity/density in TOD area |
| 6 TOD area should have mixed use so it can create vibrant and livable environment | 13 diversity of land uses |
| 7 TOD area should have pedestrian friendly environment | 14 quantity of accessible path |
| | 15 Intersection density |
| | 16 Impedance Pedestrian Catchment Areas (IPCA) |
| 8 TOD area should have better economic development | 17 Number of business establishment |

The indicator value was obtained from non-spatial primary field data and spatial geo mapping of Depok region from previous research at Faculty of Geography Universitas Indonesia using ESRI and...
ArcGIS program. Comparison between the three stations resulted in a scale of values 0 to 1. The highest value of an indicator at a station, being a comparator factor of the same indicator value at another station (the highest 1, the lowest is 0).

The passenger data at peak and off peak time is obtained from PT. CommuterlineJabodetabek, by taking samples of gate in data at 3 stations on May 8-10, 2017. Peak data is taken in the time range 06.00 WIB to 09.00 WIB while data off peak taken within 10.00 WIB until 13.00 WIB, so the duration of time is 4 hours.

Non spatial indicators are taken through field surveys and observations, while spatial data use the ArcGIS program. Some formulations such as:

\[
LU_d(i) = \frac{-\sum_{l} Q_{lu_i} \cdot \text{ln}(s_{lu_i})}{\ln(n)}\]

where

\[
Q_{lu_i} = \frac{S_{lu_i}}{S_i} \]

\(LU_d(i)\) = land use diversity in analysis area \(i\)
\(lu_i\) = land use class (1,2,3,..., \(n\)) within analysis area \(i\)
\(Q_{lu_i}\) = Share of specific land use within the analysis area \(i\)
\(S_{lu_i}\) = Total area of the specific land use within the analysis area \(i\)
\(S_i\) = Total area of analysis \(i\)

5. Result and Discussion

The result of TOD index at 3 (three) stations in Depok City can be seen in table 3. From the table we can compare the TOD level in UI station area, PondokCina and DepokBaru so we can know which area with the highest and lowest TOD level. There is no definitive reference in measuring the TOD level, but the potential comparison of areas represented by the TOD level indicators illustrates that the New Depok Station is a busiest transit area with urban activity compared to the PondokCina and Universitas Indonesia Stations.

In this study, the weight of each indicator is obtained / determined from stakeholders such as Local Government, PT. CommuterlineJabodetabek / PT. KAI and potential investors are ignored. So the value of the mass indicator has not considered the policy elements of the stakeholders.

The map on figure 4 illustrates that the area of DepokBaru Station is surrounded by more residential areas than the PondokCina and the Universitas Indonesia Station areas (settlements in the buffer area of DepokBaru Station = 496,536 m² whereas the settlements in buffer area of PondokCina and Universitas Indonesia = 329,583 m²). Similarly, the composition of commercial functions are dominated in the area of DepokBaru Station (119.405 m²), while the dominant educational function is in the area of PondokCina Station, because there are 2 (two) universities in these area: Universitas Indonesia and Universitas Gunadarma.

Universitas Indonesia Station does not have a parking land because of the limited area of the fence wall; it is difficult to reach from residential area except through rail crossing ladder entering UI campus area.
The use of parking space is also dominated in DepokBaru Station because there are parking areas provided by DepokBaru Station, there is also a motorcycle parking in people's houses around station and parking buildings that stand legally.

Mapping of access roads around the Station area can be seen in Figure 5. The length of pedestrian access that can be reached, calculated based on access roads that can be passed and not a dead end.

The principle of walking and cycling in TOD area in Depok City is not supported by supporting facilities. Most of the commuter line users in the morning are workers whose activities are to the central areas of Jakarta, Tangerang or Bekasi which generally use motorcycles, private cars, city transport and online transport to come to the station. In this case the concept of TOD that uses the principle of walking and cycling, avoiding the parking area with "kiss and drive" becomes an interesting thing to be developed.
Based on the results of field observation and geospatial calculations using ArcGIS, the following results are obtained in Table 3:

| Station                | Passenger Load (Peak) | Passenger Load (Off-Peak) | Display System | Safety | Service Frequency (Peak & Off-Peak) | Connections | Interchange (Bus) | Location Accessibility |
|------------------------|-----------------------|---------------------------|----------------|--------|-------------------------------------|-------------|-------------------|------------------------|
| Universitas Indonesia  | 0.83                  | 0.50                      | 0.56           | 0.71   | 1.00                                | 0.67        | 0.33              | 1.00                   |
| Pondok Cina            | 1.00                  | 0.85                      | 0.89           | 1.00   | 1.00                                | 1.00        | 0.67              | 1.00                   |
| Depok Baru             | 0.94                  | 1.00                      | 1.00           | 1.00   | 1.00                                | 0.67        | 1.00              | 1.00                   |

| Station                | Parking Utilization | Cycles Utilization | Population Density | Commercial Density | Diversity | Pedestrian Friendly | Economic Business Density | SUM |
|------------------------|---------------------|--------------------|--------------------|--------------------|-----------|---------------------|----------------------------|------|
| Universitas Indonesia  | 0.00                | 0.00               | 0.23               | 0.42               | 0.20      | 0.85                | 1.00                       | 0.97 | 0.07 | 10.39 |
| Pondok Cina            | 0.89                | 1.00               | 0.27               | 0.55               | 0.79      | 0.74                | 1.86                       | 0.66 | 0.27 | 14.53 |
| Depok Baru             | 1.00                | 0.95               | 1.00               | 1.00               | 1.00      | 1.00                | 1.20                       | 1.00 | 1.00 | 17.76 |

6. Conclusion
This research using 8 rules to generate 17 indicators consist of spatial and non spatial data to be measured. Non spatial analysis using observation method in buffer area, while spatial analysis using ArcGIS.
The result of analysis and calculation of indicators, it is found that TOD level in DepokBaru Station area has the biggest value (17.76) which means that Depok Baru area is the busiest activity as a transit nodes, compared to PondokCina and Universitas Indonesia areas.

Area buffer of DepokBaru Station also has potential land in the development of mixed-use function and economic growth which is idle to develope. Another advantage of this location is a strategic place to reach by residents from the residential area inDepok City, it is located at the center of the city.

Base to this research, public system of transportation should connected to Depok Baru station as well as services to the citizens in residential area to connected as the center of TOD in Depok Baru Stations. So in the near future, the BRT plan in Depok city suggested to develope here including develop walkable environment.

However, the consideration of government policies and developers will certainly have a major impact on the weighting 8 rules (criteria) that may affect the value of each indicator, so that the stakeholder role is needed in further research.

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