Spatial planning for potential green TOD using suitability analysis at the metropolitan region scale

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Abstract. Public life is heavily influenced by the circulation and activity movements within the city. Transportation is one of the most influential factors in urban development. Transit Oriented Development (TOD) is one of the most innovative concepts in urban development related to transportation system. This paper aims to prescript potential areas for spatial planning of green TOD using a combined method of Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) approaches to be implemented in Jakarta Metropolitan Region (JMR). Multi-indicator and weighting techniques were applied based on the perceived conclusions of the respective experts and professionals. Our analysis showed that the highly suitable class covered small area and TOD planning was focused in a specific area. The conclusion of this paper exhibited that there was a higher potential green TOD cluster occurred compared to its surrounding area. It meant that the ideally proportional balanced area for urban residential-commercial mixed use was in high preference of green TOD level.

1. Introduction

Each country has unique territorial characteristics which require different planning. Spatial planning is part of the urban development with the aim to creating liveable, efficient, and sustainable life resulting in a spatial plan of activities. Optimal spatial planning depends on the capacity of natural resources and human interaction as a user space. Therefore, the result is the creation of a harmonious relationship between space and its inhabitants [1–3]. Good spatial planning is planning that has several things, namely (1) Planning has a relation system between the function or area that can be accessed by all citizens, not separated; (2) Good relationship between building mass and open space to meet the standards of the ideal planning; (3) Planning has its purpose as an activity-generator that becomes the activity center of its citizen. The spatial plan requires the support of accurate spatial and non-spatial data in order to illustrate the real conditions of a targeted area [4]. Furthermore, it requires appropriate decision-making methods on complex issues to achieve the best-case TOD locations scenario and highest priority. In this case, Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) can be utilized to answer the needs of spatial planning [4–8].

Geographic Information System (GIS) is a specific information system that manages various spatial data, non-spatial data, static data, and dynamic data (maps, satellite imagery, field surveys). The data processed in the GIS uses a database management system (DBMS) in which all types of data are stored in computer systems that could build, store, manage and display geographic information using software engine such as ArcInfo, MapInfo, or ArcView. Thus, it can build Decision Support System (DSS), especially for TOD location decisions [5]. AHP is a hierarchical structure method for solving complex
and unstructured decision-making problems by giving subjective values of the relative importance of each indicator. It specifies which indicator has the highest priority to influence the outcome of the situation. AHP's key advantage is its ability to control the consistency of the decisions obtained to establish the best alternative from several options, based on criterion with specific weights [6].

The integration of combinations between GIS and AHP developed by [7–9] is applicable to the planning of Green Transit Oriented Development (TOD). The physical structure of the region should be supported by the transport system network. Transit, pedestrian, and cyclists should have broader access and mobility throughout the region [10]. In contrast, the reduction of the level of car use, would lead to a creation of safer areas; meaning less ‘tailpipe emissions from vehicles’, traffic accidents and crime rate.

1.1. Study area of research
The government of Indonesia has determined the Botabek area (supporting cities around Jakarta) as a buffer zone of Jakarta. Botabek have Spatial Law (RTRW). These RTRWs automatically contain designated zones allocated for trade and commerce activities (Jakarta’s downtown); industrial development in Cibitung, Cikarang (Kab.Bekasi) and Cikupa (Kab.Tangerang); satellite cities in Bekasi City, Tangerang City, Serpong, South Tangerang City and Depok City and their supporting schools, shopping centers, hospitals and entertainment venues.

![Study area of Jakarta Metropolitan Region (JMR)](image)

**Figure 1.** Study area of Jakarta Metropolitan Region (JMR).

2. Materials and Methods

2.1. Data collection
AHP primary data were done by interviewing 12 experts for getting their opinions. While the secondary data on spatial were collected from the institutions and agencies afterwards observation survey in the field.
Table 1. List of data layer for the TOD suitability and their original sources.

| Data name                          | Type    | Scale   | Date   | Source                                      |
|------------------------------------|---------|---------|--------|---------------------------------------------|
| Airport and Seaport                | point   | 50.000  | 2010   | Ministry of Transportation                  |
| Terminal                           | point   | 50.000  | 2010   | Ministry of Transportation                  |
| Busway shelter                     | point   | 50.000  | 2010   | Ministry of Transportation                  |
| Main road                          | line    | 50.000  | 2010   | Ministry of Transportation                  |
| Tollgate                           | point   | 50.000  | 2010   | Ministry of Transportation                  |
| Transportation facility            | area    | 50.000  | 2014   | Ministry of Agrarian and Spatial Planning   |
| Education and public facility      | area    | 50.000  | 2012   | Ministry of Agrarian and Spatial Planning   |
| Recreation facility                | area    | 50.000  | 2012   | Ministry of Agrarian and Spatial Planning   |
| Hospital                           | point   | 50.000  | 2014   | Geospatial Information Agency               |
| School                             | point   | 50.000  | 2014   | Geospatial Information Agency               |
| BCR (building coverage ratio)      | area    | 50.000  | 2015   | Consultant project archive                  |
| Park                               | area    | 50.000  | 2012   | Ministry of Agrarian and Spatial Planning   |
| Planned housing                    | area    | 50.000  | 2012   | Ministry of Agrarian and Spatial Planning   |
| Residential                        | area    | 50.000  | 2012   | Ministry of Agrarian and Spatial Planning   |
| FAR (floor area ratio)             | area    | 50.000  | 2015   | Consultant project archive                  |
| Population                         | attribute | 50.000  | 2016   | Central Bureau of Statistics                |
| CBD                                | point   | 50.000  | 2014   | Geospatial Information Agency               |
| Industrial                         | area    | 50.000  | 2012   | Ministry of Agrarian and Spatial Planning   |
| Commercial and business            | area    | 50.000  | 2012   | Ministry of Agrarian and Spatial Planning   |
| Real estate                         | area    | 50.000  | 2012   | Ministry of Agrarian and Spatial Planning   |

2.2. Criteria and sub-criteria
The explanations regarding these criteria and sub criteria were arranged in the hierarchy described in Figure 2 below.

![Figure 2. Criteria and sub criteria hierarchy.](image)

2.3. Methodology
Methodology in this paper includes: (1) Determining the criteria and sub criteria of TOD from study literature; (2) Developing AHP techniques by interviewing experts to obtain the weight values and priority each criterion and sub criteria using pairwise comparison matrixes; (3) Applying GIS techniques using spatial data in the form of layers; (4) Identifying and prioritizing potential areas for TOD.
2.4. Analytical Hierarchy Process (AHP)
AHP is a method for making the rank and selection of the best decision alternative with several criteria. The most important thing in the AHP is the functional hierarchy with the main input of human perception. Functional hierarchy within groups can solve complex and unstructured problems. The calculation of the AHP method using pairwise comparison matrix is developed by Saaty [11] using the 1-9 scale. This scale is a useful matrix to obtain the quantitative value of a relative assessment.

Table 2. Saaty weighting scale.

| Definition                              | Intensity of importance |
|----------------------------------------|-------------------------|
| Equally preferred                      | 1                       |
| Moderately preferred                   | 3                       |
| Strongly preferred                     | 5                       |
| Very strongly preferred                | 7                       |
| Extremely preferred                    | 9                       |
| Intermediate value between adjacent judgments | 2, 4, 6, 8             |

There are three main principles in problem-solving of AHP according to Saaty [11], namely: Decomposition, Comparative Judgment, and Logical Consistency. Understanding the AHP procedure includes the following stages: 1) Decomposition of the problem; 2) Assessment/weighting to compare elements; 3) Preparation of matrix and consistency test; 4) Prioritization on each hierarchy; 5) Synthesis of priorities; and 6) Decision-making.
Mathematical equations of AHP according to the formula below (Equation 1).

\[ Cr = \frac{C_i}{r_i} \]  

(1)

Where \( Cr \) is consistency ratio index, \( C_i \) is consistency index, \( r_i \) is random consistency index. While the consistency index (\( C_i \)) is derived using the following formula (Equation 2).

\[ C_i = \lambda_{max} - n \frac{n - 1}{n - 1} \]  

(2)

Where \( n \) is the criteria number and \( \lambda_{max} \) is the maximum value of eigenvector.

2.5. Z-score method for standard score of criteria

It is used to know more detail where the position of a score in a distribution. The position in a distribution itself is denoted by the +/- symbol indicating that if the positive is above the mean and the negative denotes otherwise. The equation of Z-score is given below (Equation 3).

\[ Z = \frac{(x - \mu)}{\sigma} \]  

(3)

Where; \( \mu \) = mean, \( x \) = score, \( \sigma \) = standard deviation

2.6. Land suitability evaluation

Land suitability evaluation for green TOD is the process of assessing the potential class for determining the potential area of TOD. The classification of land suitability is done by comparing the requested requirements by the characteristic of applied land. This method was adopted from FAO (Table 4). The results of it can be used as the basis for optimal and sustainable land.

| Class | Name                  | Definition                                                                                     |
|-------|-----------------------|------------------------------------------------------------------------------------------------|
| S1    | Highly Suitable       | Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level. |
| S2    | Moderately Suitable   | Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land. |
| S3    | Marginally Suitable   | Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified |
| N1    | Currently Not Suitable| Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner. |
| N2    | Permanently Not Suitable| Land having limitations which appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner. |

The land suitability assessment was obtained by multiplying the suitability scores each factor involved (i.e, each raster cell on the map) with the factor weight. Calculation of suitability index was
stored in one column. Integrating both the spatial components and the suitability index produced a land suitability map. The equation 4 is a formula of the land suitability assessment.

\[
S_i = \sum_{i=1}^{n} (Wi \times Ri)
\]

(4)

Where:

- \( Wi \) = the result of multiplication of all related weights in the factor hierarchy level
- \( Ri \) = the standard assessment of each pixel assigned to the class on the criteria map
- \( n \) = the number of criteria under element.

3. Result

3.1. Evaluation criteria

Evaluation criteria cover urban environment, economic performance, facilities services, transportation-related. 20 sub-criteria were selected according to the expert's experience, opinion, and information from various sources. The acquisition of knowledge was achieved through discussions with related field experts, authentic literary surveys, and analysis of historical data.

Table 4. Criteria and sub-criteria of evaluation.

| Main criteria               | Sub-criteria               | Unit            | Suitable rating | Not suitable | Permanent |
|-----------------------------|----------------------------|-----------------|-----------------|--------------|-----------|
|                             |                            |                 | High S1         | Moderate S2  | Marginal S3| Current N1 | Permanent N2|
| Urban environment           | BCR (building coverage ratio) | percentage     | >80%            | 61-80%       | 41-60%    | 20-40%    | <20%       |
|                             | Park                       | percentage     |                 |              |           |           |            |
|                             | Planned housing            | ratio           |                 |              |           |           |            |
|                             | Residential FAR            | ratio           |                 |              |           |           |            |
| Economic development        | Population                 | density         | 28607-49345     | 14808-28606  | 6967-14807|            |            |
|                             | CBD                        | density         | 0.000001        | 0.000001     | 0.000000  | 0.000001  | 0          |
|                             | Industrial ratio           |                 | 4.77-8.78       | 2.32-4.76    | 1.05-2.31 | 0.31-1.04 | 0.00-0.30  |
|                             | Commercial and business    | ratio           | 0.33-0.54       | 0.03-0.08    | 0.09-0.18 | 0.19-0.32 | 0.33-0.54  |
|                             | Real estate                | ratio           | 6.90-12.91      | 3.24-6.89    | 1.62-3.23 | 0.48-1.61 | 0.00-0.47  |
| Facilities services         | Education and public facility | ratio           | 0.37-0.81       | 0.009-0.36   | 0.004-0.008| 0.01-0.003| 0          |
|                             | Recreation facility        | ratio           | 0.50-0.86       | 0.23-0.49    | 0.05-0.22 | 0.01-0.04 | 0          |
|                             | Hospital                   | distance        | <250 m          | 250-500 m    | 500-800 m | 800-1000 m| >1000 m    |
|                             | School                     | distance        | <250 m          | 250-500 m    | 500-800 m | 800-1000 m| >1000 m    |
| Transportation-related      | Airport and Seaport        | distance        | <250 m          | 250-500 m    | 500-800 m | 800-1000 m| >1000 m    |
|                             | Terminal                   | distance        | <250 m          | 250-500 m    | 500-800 m | 800-1000 m| >1000 m    |
|                             | Busway shelter             | distance        | <250 m          | 250-500 m    | 500-800 m | 800-1000 m| >1000 m    |
|                             | Main road                  | distance        | <250 m          | 250-500 m    | 500-800 m | 800-1000 m| >1000 m    |
|                             | Tollgate                   | distance        | <250 m          | 250-500 m    | 500-800 m | 800-1000 m| >1000 m    |
|                             | Transportation facility     | distance        | <250 m          | 250-500 m    | 500-800 m | 800-1000 m| >1000 m    |
3.2. Assessment of pairwise comparisons and calculation of priorities

The AHP method was chosen for this study with the aim of being able to determine the relative importance of all selection criteria. The total suitability value gained through this process is the result of a linear combination of suitability scores from each criterion on each unit of land that is displayed in raster cell form on the map layer. The AHP method is generally implemented using the pairwise comparison technique that is a mathematical calculation that simplifies the rank preference among the proposed criteria. The computation matrix of pairwise comparison along with the calculation phases is described in the Table 5.

![Image of Table 5](https://i.imgur.com/5WZ5Q5G.png)

3.3. Land suitability map of green TOD

The spatial pattern of potential suitability areas of TOD is shown in Figure 4. The spatial pattern formed showed that the moderate suitability area (yellow colour) was randomly distributed almost all regions, the high suitability area (red colour) indicated clustering pattern in the middle of study area and the pattern of low suitability area (blue colour) showed clustered pattern by dominating the entire study area.

![Image of Figure 4](https://i.imgur.com/2wW1Z5Q.png)
Figure 4. Suitability map of green TOD.
3.4. The distribution land of potential green TOD

Comparison of land suitability analysis (Table 6 and Figure 5) shows that the highest class is permanently not suitable (36.4%) with the area of 2769.68325 ha. While the lowest class is highly suitable (2.3%) with the area of 174.69302 ha. Moderately suitable (9%) with the area of 682.65415 ha can be used as an alternative area to be a developing area of potential green TOD.

| Suitable rating                  | class | percentage (%) | area (ha)  |
|----------------------------------|-------|----------------|------------|
| Highly suitable                  | S1    | 2.3            | 174.69302  |
| Moderately suitable              | S2    | 9.0            | 682.65415  |
| Marginally suitable              | S3    | 28.1           | 2135.25561 |
| Currently not suitable           | N1    | 24.3           | 1847.69085 |
| Permanently not suitable         | N2    | 36.4           | 2769.68325 |
| Total                            |       | 100            | 7609.97688 |

Figure 5. Chart of distribution land.

4. Discussion

The mobility of inhabitants in the JMR is a daily commuting to job places in Jakarta City, hence transportation modes and transit areas should be integrated, not only limited in administrative boundaries but also it could cope congestion, pollution, cost, and accidents. Development and improvement of transportation services could be achieved by implementing effective and efficient organizational governance, especially the management of transit areas such as TOD.

Moreover, JMR inhabitants are right now faced with the challenge of getting occupied under the circumstances of green open area. JMR especially the Jakarta City currently has low availability of green open spaces. Seeing the longing of the inhabitants would be dwelling which surrounded by a beautiful environment. TOD presents the green concept in which indicates not only by less emission of vehicles, since the community uses the last-mile travel by walking, from their homes; but also, TOD provides a strategic transit location with green area, consisting of gardens, pedestrian and cycling track, as well as easy access to the office area with a variety of commercial areas [12].

The potential area of green TOD development in JMR (highly and moderately suitable) based on this study has an area of 857 hectares or 11.3% of the total JMR area. It is concentrated in the central region that is Jakarta capital and surrounding areas. This TOD, if developed with the green concept, will
reflect the typical characteristics of Indonesian heritage [13], and offers a green environment that is organized together with the natural elements around it. TOD of the railway station is located close to the outer ring road and toll gate, equipped with the planned Light Rail Transit (LRT) as well as direct access to international airport.

The rapid growth of office and industrial areas as well as the increasing infrastructure in the suburbs (Botabek) to Jakarta City and vice versa, significantly makes Botabek a buffer area for favorite choice as the housing location. Likewise, the changes in the Spatial law/RTRW due to special circumstance should be paid consideration by the municipality. Accommodating those needs, the government policy is trying to develop the TOD project, which will be a strategic area and facilitate the needs of green residential for the employee to work in the office or industrial area and its surrounding.

The next study for future research, there is an endeavour to ‘retrofit’ with a decision-support system (DSS) modelling with a ‘what-if’ capability, which relates to the GIS-based MCE Analytics above, and the carrying capacity raster calculation feature in GIS layers (economic exploitation vs environmental protection) of the surrounding locations of the TODs. Our recommendation proposed TOD as the foundation to work with the Smart-City Movement and Urbanism, where smart-mobility will use Internet-of-Things (IoT), transportation sensors, automations, robotics, early warning systems for safety, security and disaster management. This will almost make sure to erase fossil-based fuel vehicles for the advent of full electric vehicle (EV) environment.

5. Conclusion
The potential area of green TOD is identified based on the calculation of selected criteria to produce the desired condition. The spatial planning of TOD for JMR makes this transitional area is a service center with mixed functions and modal transfer shelters. JMR is expected to be a model of sustainable development through the multifunctionality services of social and regional facilities, therefore rapid commuting can be optimally served within an integrated service area.

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