Spatial Statistical Analysis for Potential Transit Oriented Development (TOD) in Jakarta Metropolitan Region

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Abstract

Spatial planning on Transit Oriented Development (TOD) concerns with the integration between land use and transportation aspects. However, in some places, public transport management based on transit nodes such as train services which are not well- integrated, and causing spatial chaos, especially surrounding station areas. It is essential to prepare a public transportation plan by maximizing regional potential capacity with TOD model. The purpose of this paper is to identify and prioritize potential areas for TOD using spatial statistical analysis with combined models of Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) for Jakarta Metropolitan Regional (JMR), Indonesia. This paper employed two major indicators: main- and sub-indicators depending on relevant references. The weight of each indicator was determined by chosen experts. The result showed that some of the metro areas of Jakarta were highly suitable for TOD and indicated the characteristics of the development of urban areas. This paper's outcome was useful in order to determine the potential location of TOD and was applicable to other areas within the same geographical conditions.

Keywords: Transit Oriented Development (TOD), Geographic Information System (GIS), Analytical Hierarchy Process (AHP), Spatial Statistical Analysis, Jakarta Metropolitan Region (JMR).

1. Introduction

The use of public transportation such as railway is one of the important characteristics of urban growth (Mohajeri and Amin, 2010; Taki, 2017). Many urban planning in the world relates to public service based transportation facilities that defined as compliance in the needs of present and future generations (Javadian et al., 2011; M Z Lubis et al., 2017). Moreover, rapid population growth and migration require the provision of public transport facilities as a primary need. However, in some places, the transportation management of the railway is not well integrated resulting inconveniences of city life, especially the surrounding area of the station. For example, traffic congestion, environmental pollution, unnecessary longer travel time, high fuel consumption. For this reason, it is very important to plan a public transportation such as railway that move fast by carrying maximum number of passengers to reach the maximization of the potential area (sunarto, 2009; Taki et al., 2017a). This is the part of the city development in the transportation sector, especially the renewal of stations or rail networks in accordance with the Transit Oriented Development (Binglei and Chuan, 2013; Feudo, 2014; Galelo et al., 2014).

TOD is a city development concept where attempts are made to incorporate various functional activities (mixed-use) in the area around the transit station to the extent of a pedestrian reachable radius (i.e. ± 400-800 m or equal to mileage on foot for 10 minutes). TOD has the goal of creating a green environment that is comfortable, safe, pleasant and sufficient for pedestrians (walkable environment). By mixing the various functions of the activities, the needed traveling can be combined to be shorter and faster. These functions are central to commercial areas, offices, retail, service, density to medium density as well as public open space. (Hasibuan and Soemardi, 2014) consider TOD emphasizes the integration of area-based transits, renewing individualist community and living structures.

This study has two objectives. First was to develop a method of spatial statistical analysis using AHP Techniques (Nguyen et al., 2015; Lubis et al., 2017). This approach, integrating various assessment criteria from experts including the criteria of transport facilities, urban environment, and economic performance. This research helped identify the most potential sites for TOD. Second objective was to apply this method in the context of GIS by conducting case studies in the metropolitan area of Jakarta. The spatial statistical analysis was employed to obtain a land suitability grouping for specific uses. The spatial statistical classification in one area may differ with other areas depending on the land use under

consideration. Spatial analysis for TOD using GIS and AHP was a geographical process used to determine the feasibility of area (whether it was potential or not) for the use of TOD.

1.1 Study Area

Jakarta Metropolitan Region (JMR) or called Jabodetabek located in Java Island, Indonesia (Fig. 1). The region of JMR includes Jakarta-Bogor-Depok-Tangerang-Bekasi Municipality. JMR is an integrated urban area between Jakarta and its surrounding area, one of the top ten metropolitan areas in the world and the largest metropolitan area in Southeast Asia. Based on data from BPS (Statistik, 2011) shows that JMR in 2010 has a population growth of 27 million people and 7.5 million units of motor vehicles. The number of trips from Botabek to Jakarta can be quantified as much as 1.1 million trips/day. Percentage of transportation mode used: private vehicle, 62.2% (private cars and motorcycles) and public transportation 12.9% (buses and trains). The commuters from Botabek to Jakarta are highly dependent on the railway and highway network facilities.

2. Methods

2.1 Data sources

Data collected in this study derived from The Ministry of Transportation, Ministry of Agrarian and Spatial Planning, Central Bureau of Statistics, Geospatial Information Agency. The range of data between 2010-2016 and the type of data was; First, AHP data were the primary data from interviews and questionnaires answered by 12 experts of various scientific fields related to this research for giving weight value of each indicator and sub-indicator. Secondary data in the form of GIS spatial data and attribute data, consisting of population statistic data, administrative boundary, land use, and transportation.

2.2 Determination of selective criteria

Determination of the criteria and sub criteria of the land suitability assessment for TOD was carried out by selecting and seeking for the appropriate criteria and sub criteria. It obtained from previous research and interviews by experts. These criteria and their references were; transport related (Mohajeri and Amin, 2010; Taki et al., 2017b; Atkinson-Palombo and Kuby, 2011), facilities services (Olaru et al., 2011; Ratner and Goetz, 2013; Vale, 2015), urban environment (Binglei and Chuan, 2013; Black et al., 2016; Prasertsubpakij and Nitivattananon, 2012) and economic performance (Fard, 2013; Singh et al., 2014; Taki and Lubis, 2017)

2.3 Methodology overview

The applied methodology was a combination of AHP and GIS technique involving the following major steps (Fig. 2):

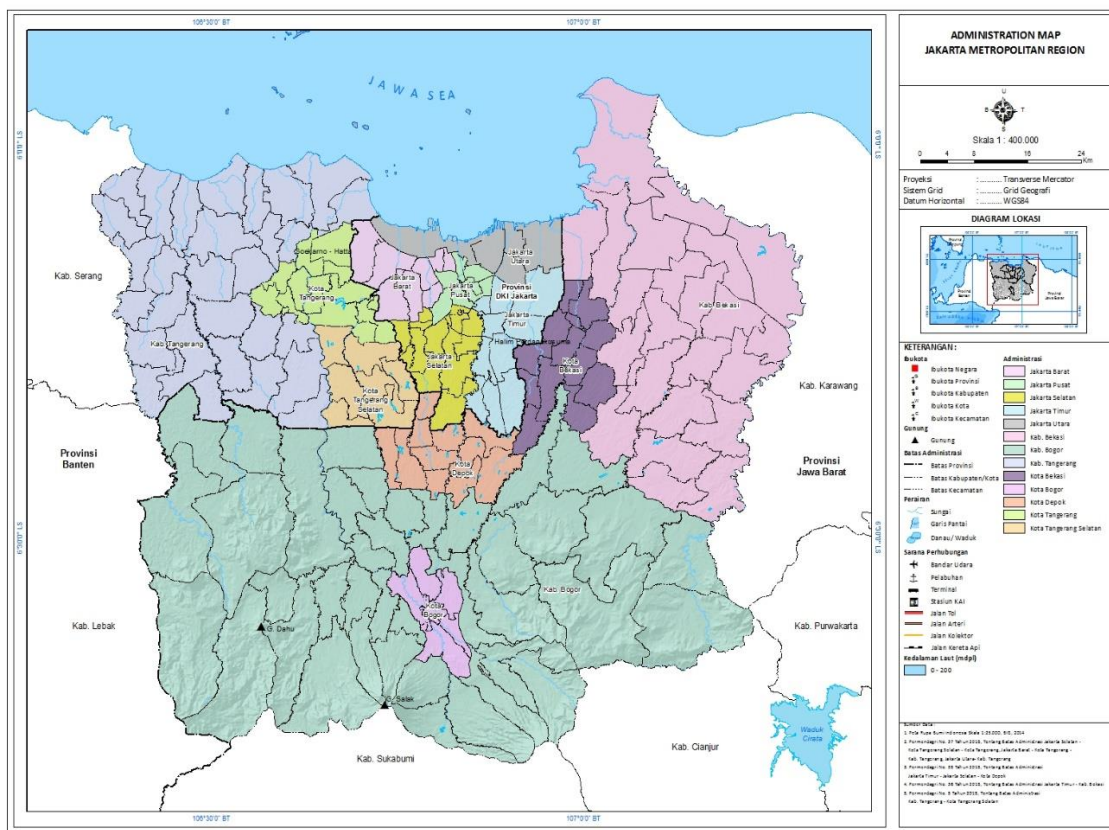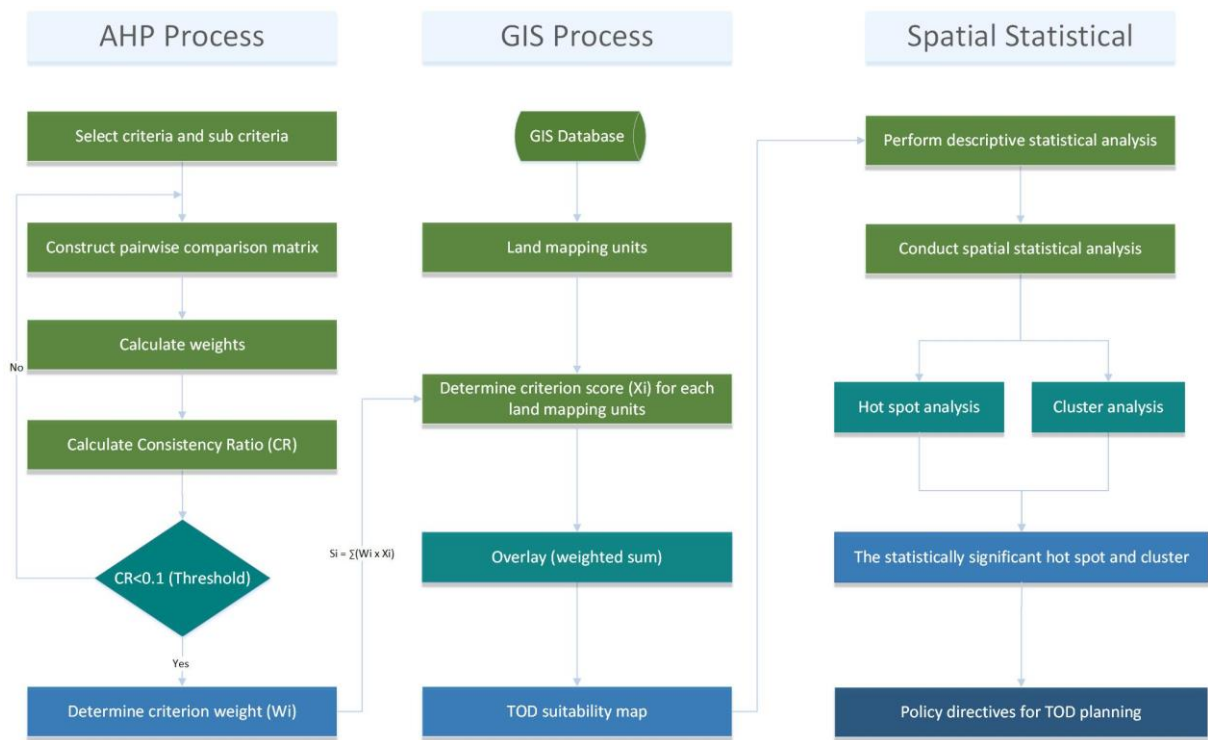Fig. 1 The metropolitan region of Jakarta

Fig. 2 Methodological framework of TOD

2.4 AHP pairwise comparison

AHP provides steps to ensure the credibility of relative significance used mathematically. The consistency ratio index (cr) in Equation 2 can be calculated based on the nature of the reciprocal matrix. According to Saaty (1990) that if cr <0.10, it indicates that the matrix of pair-wise comparison has acceptable consistency. Hence, the weighting value is valid. However, if cr > 0.10, this means that the pairwise ratio shows a lack of consistency or the matrix in which it should be modified.

$$c_i = \lambda max - n / n - 1 \qquad (1)$$

Where;
c_i = consistency index
n = the number of items being compared in the matrix
λmax = the largest Eigen value

$$c_r = c_i / r_i \qquad (2)$$

Where;
c_r = consistency ratio index
r_i = random consistency index

Table 1. r_i for n = 10 (Saaty, 1990)(Saaty, 1990)

n	1	2	3	4	5	6	7	8	9	10
r_i	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

2.5. Standardized criteria using Z-score

Z score is a standard score of the distance of a value of the sample or population in the standard deviation unit. It is generally used to change raw scores obtained from the different types of measurements. The Z-score also tells how much distance the score itself with mean. The formula for calculating the standard score is given on Equation 3 below:

$$Z = (x-\mu) / \sigma \qquad (3)$$

Where; x = score, μ = mean, σ = standard deviation

2.6. Land suitability assessment

Land suitability evaluation of the Food and Agriculture Organization (FAO, 1976) was adopted for land suitability assessment of potential TOD in which the FAO's classifications proposed 'appropriate' (S) and 'unsuitable (N) classes. The Equation 4 was used to combine evaluation criteria (factor) according to weighted linear combination method.

$$Si = \sum_{i=1}^{n} (Wi \, X \, Ri) \qquad (4)$$

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

2.7. Spatial statistical analysis

Spatial data used in this analysis are coordinated grids on the map or pixels form from

the satellite image. Thus, the spatial statistical analysis is presented in the form of a thematic map. Spatial distribution patterns are generally divided into three groups (random, uniformed, and clustered).

2.7.1. Spatial autocorrelation analysis (Global Moran's I Statistic) for identifying existence of spatial clusters

The Moran's Index (I) is a spatial autocorrelation measurement that can be applied at intervals related to a point or area. For area data, the coefficient equation of Moran (Equation 5) is as follows:

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} \left(x_j - \bar{x}\right)\left(x_j - \bar{x}\right)}{\sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2}$$

(5)

Where, n is the number of cases. x is the mean of the variable. x_i is the variable value at a particular location. x_j is the variable value at another location. W_{ij} is a weight indexing location of i relative to j.

2.7.2. Hot spot and outlier analysis (Getis-Ord Gi* and Anselin Local Moran's I Statistics) for mapping spatial clusters

Hot Spot Analysis (*Getis-Ord Gi**) is contained in the mapping cluster set to identify statistically and formulated as Equation 6 follows:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij}(d) x_j}{\sum_{j=1}^{n} x_j}$$

(6)

Where, W_{ij} is a spatial weight matrix element and *(d)* is the spatial object spacing element, while *xj* is the attribute value for feature *j* in distance *d*.

3. Results

3.1. Classification of assessment criteria

This study identifies the following criteria (Table 2) as an indicator of suitability assessment in the selection of potential sites for the development of TOD. The assessment for this location is based on four main-criteria and 20 sub-criteria selected.

Table 2. Classification of assessment criteria

Main criteria	Sub-criteria	Unit	Suitable rating				
			Suitable			Not suitable	
			High	Moderate	Marginal	Current	Permanent
			S1	S2	S3	N1	N2
Transportation-related	Airport and Seaport	distance	<250m	250-500m	500-800m	800-1000m	>1000m
	Terminal	distance	<250m	250-500m	500-800m	800-1000m	>1000m
	Busway shelter	distance	<250m	250-500m	500-800m	800-1000m	>1000m
	Main road	distance	<250m	250-500m	500-800m	800-1000m	>1000m
	Tollgate	distance	<250m	250-500m	500-800m	800-1000m	>1000m
	Transportation facility	distance	<250m	250-500m	500-800m	800-1000m	>1000m
Facilities services	Education and public facility	ratio	0.37-0.81	0.009-0.36	0.004-0.008	0.01-0.003	0.00
	Recreation facility	ratio	0.50-0.86	0.23-0.49	0.05-0.22	0.01-0.04	0.00
	Hospital	distance	<250m	250-500m	500-800m	800-1000m	>1000m
	School	distance	<250m	250-500m	500-800m	800-1000m	>1000m
Urban environment	BCR (building coverage ratio)	percentage	>80%	61-80%	41-60%	20-40%	<20%
	Park	percentage	2.55-9.08%	1.26-2.54%	0.48-1.25%	0.12-0.47%	0.00-0.11%
	Planned housing	ratio	1.23-2.32	0.72-1.22	0.32-0.71	0.08-0.31	0.00-0.07
	Residential	ratio	1.98-4.62	0.92-1.97	0.44-0.91	0.14-0.43	0.00-0.13
	FAR (floor area ratio)	FAR	4	3	2	1	0
Economic development	Population	density	28607-49345	14808-28606	6967-14807	2003-6966	0-2002
	CBD	density	0.000001	0.000001-0.000000	0.000001-0.000000	0.000001-0.000000	0.000000
	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

3.2. Criteria maps for TOD suitability analysis

The map of potential TOD's assessment criteria is compiled based on a GIS database of 20 sub-criteria (Fig. 3-6). The process of map analysis conducted using overlay technique is to unite all layers of the map into a joined and comprehensive layer. Hence, it presents a result map that shows a potential suitability map of potential TOD in the final stage.
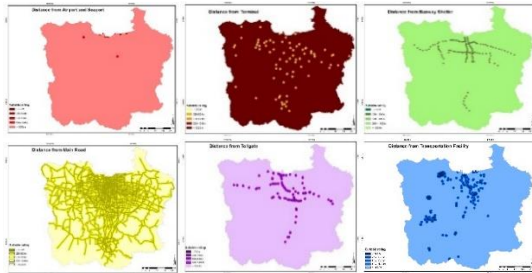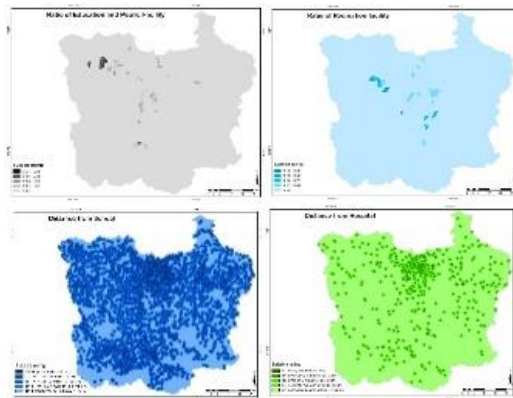

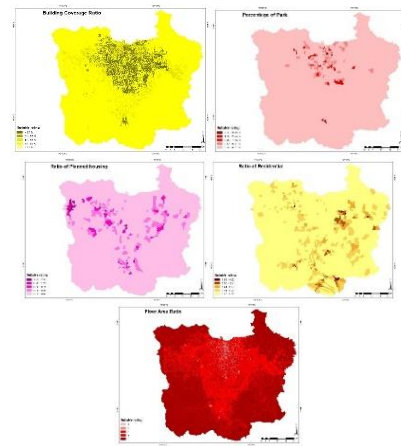Fig. 3 Transportation-related
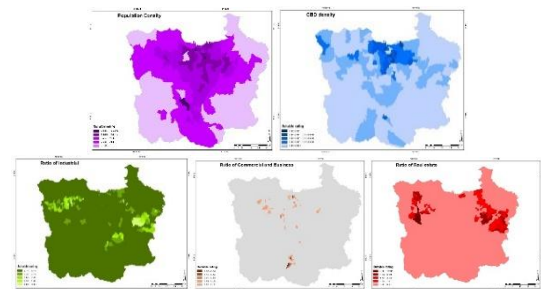

Fig. 4 Facilities services

Fig. 5 Urban environment

Fig. 6 Economic performance

3.3. Calculation of criteria weight by AHP

This study uses the opinion of experts in their fields to assess the relative importance of the selected criteria. There were 12 experts and they were required to answer and submit their opinions through a set of questionnaires, which consist of contained pairwise comparisons of the 4 main criteria and 20 sub criteria (Table 3 and 4).

Table 3. The weight of criteria from 12 experts and calculation of weight

No	Main-criteria	Weight	Sub-criteria	Experts												SUM	Weight	Ranking
				E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12			
I	Transportation-related	0.40	Terminal	0.22	0.21	0.29	0.22	0.19	0.41	0.41	0.41	0.13	0.13	0.13	0.40	3.16	0.26	1
			Transportation facility	0.09	0.08	0.14	0.33	0.32	0.16	0.16	0.16	0.41	0.41	0.41	0.25	2.89	0.24	2
			Main road	0.12	0.13	0.14	0.09	0.10	0.21	0.21	0.21	0.11	0.11	0.11	0.10	1.65	0.14	3
			Airport and Seaport	0.28	0.33	0.09	0.08	0.10	0.10	0.10	0.10	0.15	0.15	0.15	0.12	1.74	0.14	4
			Busway shelter	0.18	0.15	0.24	0.17	0.16	0.07	0.07	0.07	0.13	0.13	0.13	0.07	1.58	0.13	5
			Tollgate	0.11	0.11	0.11	0.12	0.14	0.05	0.05	0.05	0.07	0.07	0.07	0.06	0.98	0.08	6
			inconsistency	*0.09*	*0.09*	*0.08*	*0.08*	*0.09*	*0.03*	*0.03*	*0.03*	*0.06*	*0.06*	*0.06*	*0.09*			
II	Economic development	0.31	Population density	0.45	0.41	0.34	0.40	0.29	0.46	0.46	0.46	0.44	0.44	0.44	0.23	4.82	0.40	1
			CBD	0.35	0.24	0.25	0.27	0.18	0.25	0.25	0.25	0.21	0.21	0.21	0.19	2.85	0.23	2
			Industrial	0.14	0.11	0.14	0.20	0.33	0.15	0.15	0.15	0.18	0.18	0.18	0.23	2.15	0.17	3
			Commercial and business	0.23	0.19	0.18	0.05	0.08	0.07	0.07	0.07	0.06	0.06	0.06	0.13	1.25	0.10	4
			Real estate	0.08	0.06	0.09	0.07	0.11	0.07	0.07	0.07	0.11	0.11	0.11	0.23	1.18	0.10	5
			inconsistency	*0.09*	*0.08*	*0.06*	*0.05*	*0.08*	*0.04*	*0.04*	*0.04*	*0.01*	*0.01*	*0.01*	*0.09*			
III	Facilities services	0.17	School	0.08	0.05	0.08	0.09	0.23	0.59	0.59	0.59	0.50	0.50	0.50	0.24	4.06	0.34	1
			Education and public facility	0.48	0.53	0.42	0.41	0.52	0.20	0.20	0.20	0.23	0.23	0.23	0.14	3.78	0.32	2
			Recreation facility	0.25	0.28	0.33	0.38	0.16	0.08	0.08	0.08	0.08	0.08	0.08	0.36	2.26	0.19	3
			Hospital	0.20	0.14	0.16	0.12	0.09	0.13	0.13	0.13	0.19	0.19	0.19	0.26	1.90	0.16	4
			inconsistency	*0.05*	*0.06*	*0.08*	*0.09*	*0.06*	*0.02*	*0.02*	*0.02*	*0.01*	*0.01*	*0.01*	*0.08*			
IV	Urban environment	0.13	FAR	0.07	0.11	0.09	0.49	0.49	0.48	0.48	0.48	0.28	0.28	0.28	0.48	4.03	0.34	1
			BCR	0.36	0.33	0.21	0.31	0.31	0.10	0.10	0.10	0.11	0.11	0.11	0.13	2.28	0.19	2
			Formal housing	0.18	0.18	0.22	0.06	0.06	0.17	0.17	0.17	0.21	0.21	0.21	0.16	2.00	0.17	3
			Informal housing	0.13	0.14	0.17	0.09	0.09	0.12	0.12	0.12	0.26	0.26	0.26	0.13	1.90	0.16	4
			Park	0.26	0.24	0.31	0.05	0.05	0.13	0.13	0.13	0.13	0.13	0.13	0.11	1.78	0.15	5
			inconsistency	*0.09*	*0.09*	*0.06*	*0.09*	*0.09*	*0.07*	*0.07*	*0.07*	*0.05*	*0.05*	*0.05*	*0.01*			

Table 4. (cont.) The weight of criteria from 12 experts and calculation of weight

Criteria	Experts												SUM	Weighting	Ranking
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12			
Transportation-related	0.53	0.45	0.50	0.41	0.41	0.52	0.52	0.52	0.26	0.26	0.26	0.12	4.75	**0.40**	1
Economic development	0.08	0.08	0.07	0.38	0.38	0.26	0.26	0.26	0.48	0.48	0.48	0.49	3.68	**0.31**	2
Facilities services	0.25	0.27	0.26	0.12	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.18	2.05	**0.17**	3
Urban environment	0.14	0.20	0.17	0.09	0.08	0.08	0.08	0.08	0.13	0.13	0.13	0.20	1.51	**0.13**	4
inconsistency	0.08	0.06	0.06	0.09	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.08			
Consistency Index (c_i) =	0.07	0.06	0.06	0.08	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.07			
Random Index (r_i) =	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90			
Consistency Ratio (c_{ri}) =	0.08	0.06	0.06	0.09	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.08			

3.4. Land suitability map for potential TOD

All criteria values were standardized by the Z-score method using ArcGIS Software (Fig. 7-8). Each main-criteria had a different land suitability pattern. The highest index was found in the urban environment (4.0) and the lowest index was found in transportation related (0.0033). Variations pattern of land suitability map consisted of the spread points (facilities services and urban environment), area-polygon (economic development) and line buffer (transportation related). The red color showed the altitude value of the suitability, otherwise the blue colour indicated the lowness of land suitability value.
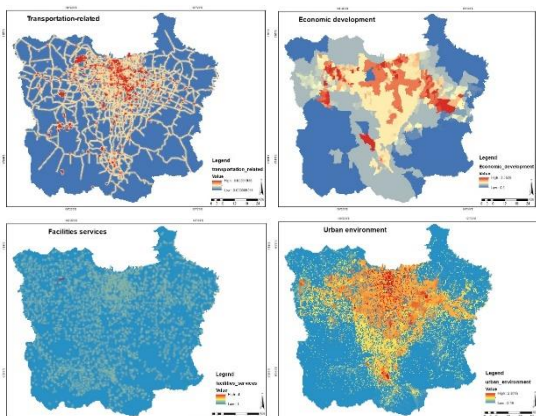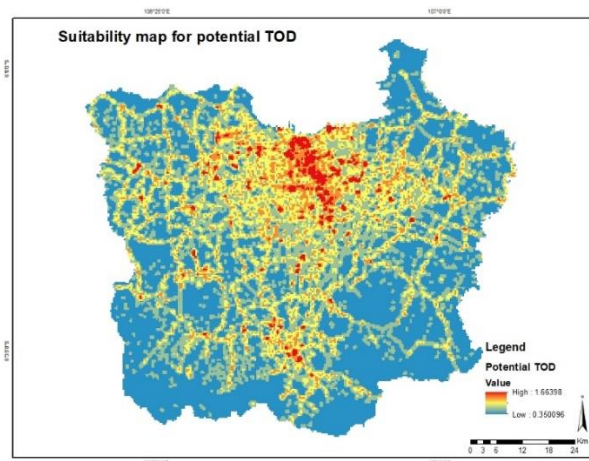

Fig. 7 Criteria map

Fig. 8 Suitability map for potential TOD

4. Discussion

4.1. The distribution of potential TOD using suitability analysis result

Based on the suitability map (Fig. 8) of potential TOD, suitability analysis conducted a comparative class analysis based on percentage and proportion of the study area (Table 5). It is permanently not suitable class (N2) has the biggest percentage (36,4%) with wide area about 7609.97 ha. The highly suitable class (S1) only has 2.3% of the study area with wide area about 74.69 ha. Thus, TOD planning is focused in areas with highly suitable categories.

Table 5. The distribution of potential TOD based on percentage and area

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

4.2. Descriptive statistical analysis

Table 6 of descriptive statistical analysis indicated mean and standard deviation values for each main criteria and potential TOD index. The highest of mean (2.17) and standard deviation (1.04) was facilities services, while the lowest of mean (0.00) and standard deviation (0.00) was transportation related. All the indexes were positive, indicating high index value. Otherwise, there were no low negative index.

Table 6. The descriptive statistics of main criteria.

Statistics	Transportation related	Economic development	Facilities services	Urban environment	Potential TOD
Minimum	0.000989011	0.50	1.00	0.19	0.35
Maximum	0.00331986	3.05	4.00	2.87	1.66
Mean	0.00	0.90	2.17	0.55	0.71
Std. Deviation	0.00	0.43	1.04	0.49	0.27

4.3. Spatial statistical analysis

4.3.1. Spatial autocorrelation using Global Moran-I

The calculation results of Global Moran's I statistic can be seen that the value of Z-score = 4,838 > $Z0.99$ = 2.58. Therefore, H_o is rejected or the conclusion that there is spatial autocorrelation. The Moran Index is 0.247 in the range $0 < I \leq 1$ and indicates a positive spatial autocorrelation. It concluded that inter area each other have similarity values or indicate that data in the clustered (Fig. 9).
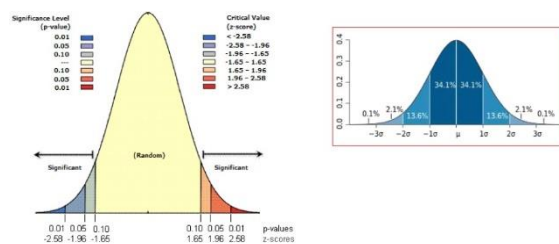

Fig. 9 The standard normal distribution.

4.3.2. High/low clustering using Getis-Ord General G

Analysis result of High/Low Clustering using Getis-Ord General G shows that the Z-Score value of 19.6713 with p-value 0. Based on the result can be stated that the spatial TOD index in the region has a global pattern or a clustering trend or highs

cluster because there are no spatial clustering feature values. This happens because the p-value is small and statistically significant, so the value of the Z-Score becomes important. If the Z-Score is positive, it shows high value clustered in the research area (high cluster). Conversely, if the Z-Score is negative, it shows low values clustered in the study area (low cluster).

4.3.3. Cluster and Outlier using Anselin Local Moran's I

Cluster area based on a difference Global Moran's TOD index is a measure that has not been able to show in the area where cluster occurs. Therefore, the test continues using Moran scatterplots (Fig. 10 and 11). The results show that most areas are in the LH (Low-High) and HL (High-Low) quadrant, which has a high index and is surrounded by low neighbouring areas and vice versa.
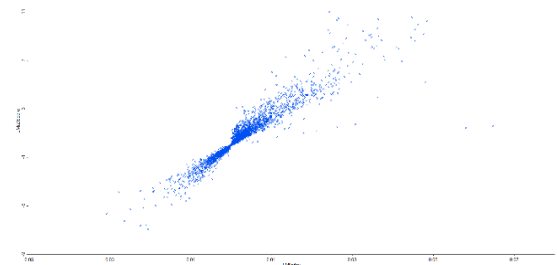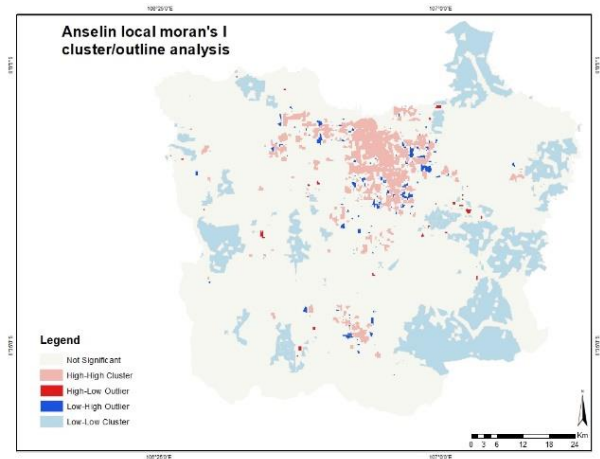

Fig. 10 Moran scatterplot

Fig. 11 Mapping cluster

4.3.4. Hot spot and cold spot analysis using Getis-Ord Gi*

Based on hot spot results map using Getis-Ord Gi * statistic in Fig. 12, there are 7 groups of interval classes in each class distribution describing distinct colour intensity levels in each color. The higher intensity of color indicates that the area has a high spatial concentration, also with the surrounding area (for areas with hot spot status), in contrast with areas that have cold spot status (blue color).
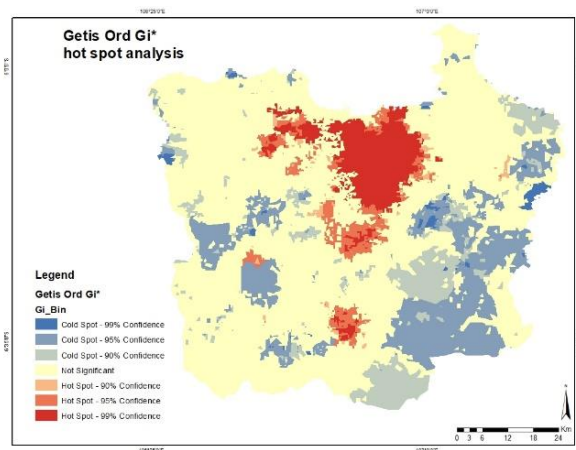
Fig. 12 Mapping hot spot

4.3.5. The statistically significant hot spots

Fig 13 show some areas in red color. It means that the area being the centre of the hot spot of the potential TOD index. Statistically significant hot spots have been identified at a 99% confidence. The significant hot spots cluster in Fig 14 indicates that the area has a high value and is surrounded by high-value areas. Those areas in this cluster are the capital of Jakarta, Tangerang City, Depok City, and the city of Bogor.
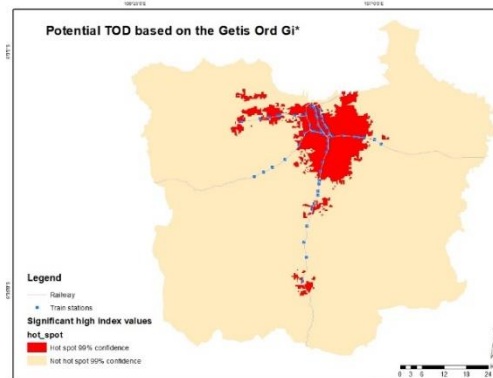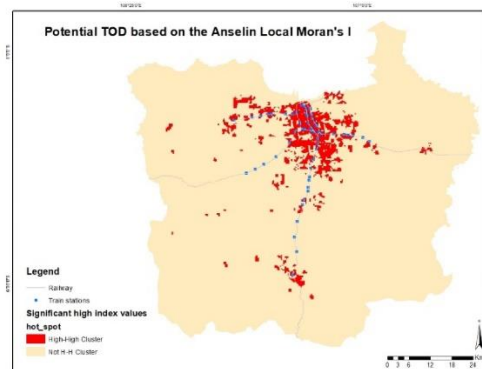

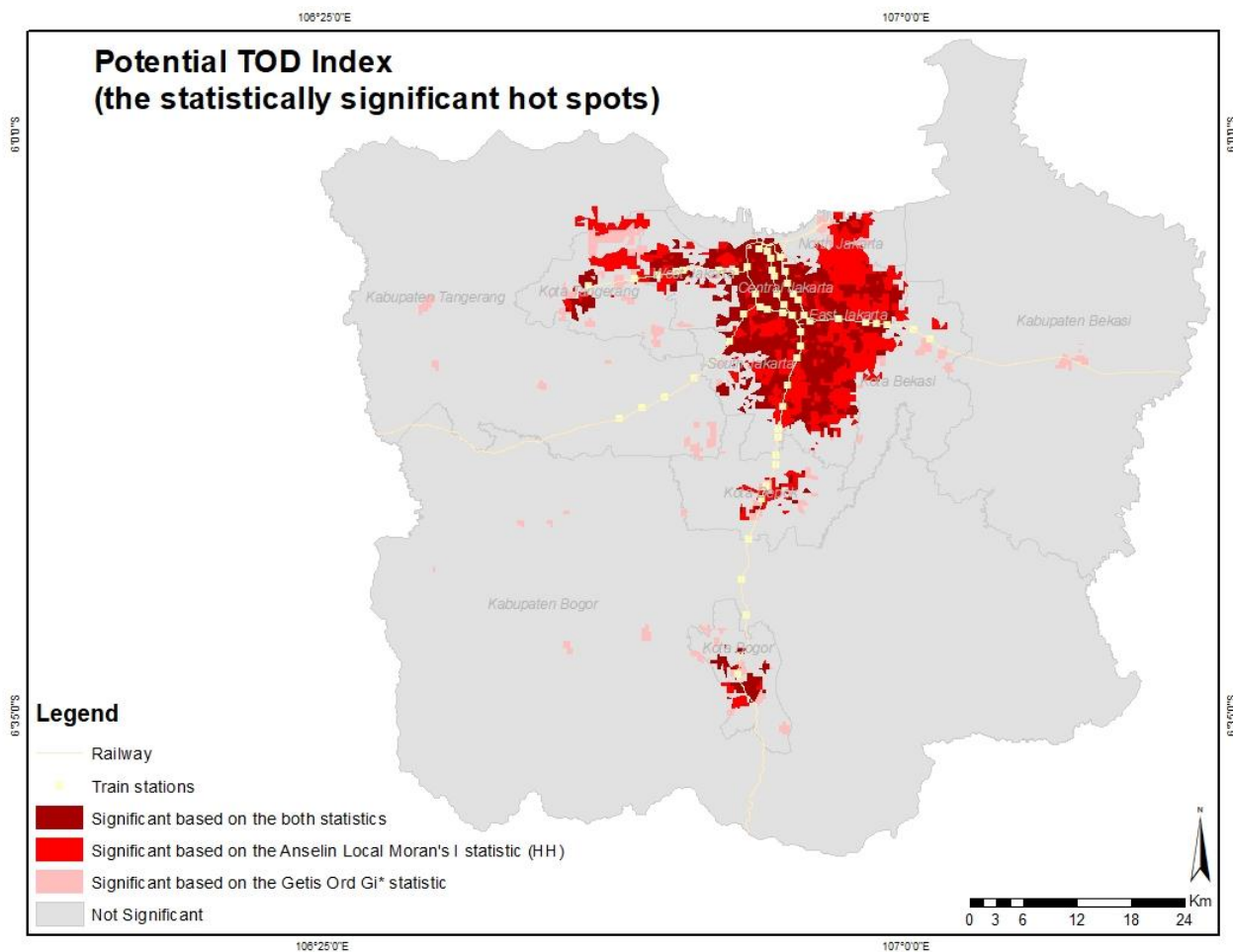Fig. 13 Potential TOD based on Moran I (above) and Getis Gi* (below)

Fig. 14 Potential TOD Index based on the statistically significant hot spots

4.3.6. Policy directives

In accordance with the results of the above-mentioned analysis, some development directives can be compiled as an internal policy election potential area of TOD in Jakarta Metropolitan Region. *First*, the policy of making land zoning of each sub-district on a more detailed scale, so there should be comprehensive regulation on the land allocation to the developed area. *Second*, the building permit regulation/policy in areas classified as hot spots to keep the TOD area around the station from disordered land use.

5. Conclusion

Based on the analysis of research on spatial statistical for potential TOD area in Jakarta Metropolitan Region (JMR), it can be concluded that there is spatial regularity of TOD area class in the study area. where area with high TOD index tend to concentrate in the middle of city, while area class with low TOD index tend to show spatial spread patterns. Central JMR especially the capital of Jakarta along with Tangerang City, Depok City, and Bogor City have a TOD distribution pattern that belongs to highs cluster. The pattern of TOD distribution in the territory of the region has a strong relationship with the level of urban development and regional economy in accordance with the selected research criteria. This indicates that there is a higher development of the city and the economy of the region compared to the surrounding area. Spatial planning that can be done to organize this TOD area is by directing the arrangement of the developed region according to the allocation of land use, regulate the built area and the supporting policies contained in the regulation. The use of the spatial autocorrelation method using GIS and combined with AHP in the planning of potential areas of TOD has advantages because it can give the description of the high significance level and spatial clustering of hot spots among criteria to provide sharper spatial analysis.

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