Spatial Patterns Analysis of Jabodetabek Electric Rail Transportation Using Spatial Autocorrelation Approach

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Abstract. This study investigates the density level of the Jabodetabek KRL stations and routes and the spatial pattern of the Jabodetabek KRL. The method used is spatial autocorrelation calculation using the Moran's Index putting on data PT KCI from 2014 through 2020, spatial data from BIG, and BPS population data. The study results show that the stations and the routes were congested. Still, there was a drastic decrease in passengers when the Covid-19 outbreak entered Indonesia in March 2020. There was positive autocorrelation and spatial patterns forming Clusters which means that it is necessary to create new lines and stations to break up the current overcrowding of train passengers. As a result, understanding the density level of stations and routes and the passenger density distribution pattern at Jabodetabek stations may be utilized to design the building of new stations and lines at KRL Jabodetabek, thereby increasing the degree of comfort, safety, and security.

1. Introduction

Rail transportation has many advantages over other modes of transportation, including mass capacity, environment-cordial and safer. The urban transportation system of Jakarta, Bogor, Depok, Tangerang, and Bekasi (Jabodetabek) as part of the national transportation system has a strategic role in supporting national development. The Jabodetabek Commuterline Electric Rail Train (KRL) enacts a notable role in the Jabodetabek area, managed by PT Kereta Commuter Indonesia (PT KCI). TomTom, a traffic-control technology company, announced the Traffic Index 2020, emphasizing traffic congestion in 416 cities across 57 countries, with Jakarta ranking 31st, after Cairo, Egypt, with a 53 percent increase in journey time [1]. The worsening and persistent congestion in the DKI Jakarta area has made the commuter train a mainstay for around 921,300 [2] Jabodetabek residents daily for activities, such as working, trading, studying, and other activities in Jakarta and returning to their respective homes in Jabodetabek. Furthermore, road congestion causes problems, namely the increasing number of KRL passengers from year to year, thereby reducing the level of comfort, safety, and security of KRL passengers. For that reason, this study aims to investigate how the density level of the Jabodetabek KRL stations and routes is and the distribution pattern of the Jabodetabek KRL. Knowing the density level of stations and routes and the distribution pattern of passenger density at Jabodetabek stations can be used as the basis for planning the construction of new stations and lines at KRL Jabodetabek so that the level of comfort, safety, and security of KRL will increase.
Research on urban railways spatially using GIS has been done before abroad, namely Land use as motivation for railroad violations [3], Spatiotemporal trait of shared bicycle use around rail transit stations [4], CPT-Based Prediction Model for Spatial Distribution of Passenger Flow for Urban Transit Railway in Emergencies [5], Complex network analysis of China metro network topology [6]. With intelligent card data and train schedules, a method for calculating the spatial trajectory of passengers is developed [7], WebGIS for Historical Activity-Based Visualizing Photos [8]. However, research on spatial analysis of the electric railroad itself is still very little done in Indonesia, where after being identified, three studies have been done those were the use of GIS in the management of open and closed railroad crossings [9], Changes in land use influenced by light rapid transit corridor Cawang Jakarta-Bogor [10], GIS for Railway Potential Development (Case Study of Pasar Turi Station to Bojonegoro Station) [11]. This study is different from the previous research mentioned. The difference lies in methods and research locations where no one has ever investigated the Jabodetabek KRL using the spatial autocorrelation approach.

It has been studied that the spatial pattern of bicycle use around the station area is influenced by the level of train use and the built environment around the station in Beijing [4]. Another study inspected the temporal and spatial disseminations beneath crisis conditions of Beijing's rail traffic. The cumulative prospective theory can better depict train travellers' route-choice behaviour in crisis circumstances than the past one [5]. The drawback of both previous studies is that it does not look at the spatial pattern of passenger density at the station. At the Jabodetabek KRL station, no published work describes the density level of routes and stations and the spatial distribution pattern of passengers. The author is tasked with filling in the gaps in this study.

This spatial autocorrelation may also be used to detect a spatial autocorrelation in station distribution and determine stations' geographical distribution patterns in the Greater Jakarta area. Thus this research is critical. This research will aid the government in generating rail transportation infrastructure policy [12] and policymaking materials to ease the Jabodetabek KRL stations' and crossings' expanding capacity issues.

2. Methodology
This research was conducted for two months, from March to April 2021. Primary data in the form of Jabodetabek KRL station coordinates were obtained with Google Earth Pro. Secondary data were obtained from passenger numbers [2], earth maps 1: 25,000 scale [13], Jabodetabek commuter surveys [14,15], population data [16, 17, 18, 19, 20, 21, 22]. In addition, data analysis was conducted, making use of overlay analysis through the Geographic Information System (GIS) and using R studio software. The distribution of stations can be analyzed spatially, using spatial autocorrelation, namely Moran Index, to determine the correlation pattern between locations. The spatial autocorrelation method used is Moran's Index method. This method can determine the spatial autocorrelation relationship in passengers distribution in stations in the Jabodetabek area. Knowing the density level of stations and routes and the spatial pattern of passenger density at Jabodetabek stations can be used as the basis for planning the construction of new stations and lines at KRL Jabodetabek.

For autocorrelation of global geographic measurement, Moran's Index approach is utilized. Moran's Index can be used to find random spatial features that indicate cluster, scattered, or random patterns. The Moran Index computes the difference between each element's value and the average value for all components and the difference between each neighbour's feature value and the mean value [23]. The formula [23] is used to perform the calculation.

$$I = \frac{\sum_{i \neq j} (X_i - \bar{X})(X_j - \bar{X})}{\sum (X_i - \bar{X})^2}$$  \hspace{1cm} (1)

$I$ = Moran's I value
$N$ = locations number

Where:

$X_i$ = value at location i
$X_j$ = value at location j
$\bar{X}$ = variables average number
$W_{ij}$ = elements on weighting between areas i and j
The Moran I (I) value obtained from the calculation of spatial autocorrelation can indicate the feature pattern that is formed. The feature pattern formed based on Moran's I value can be found in Table 1 below:

**Table 1. Formed feature pattern.**

| Moran's I | Information               |
|-----------|---------------------------|
| I > 0     | Clusters (there are many similarities in features) |
| I < 0     | Random (unclear feature pattern) |
| I = 0     | Scatter (high and low feature values spread in the dataset) |

Source: [23]

Besides knowing the feature patterns formed, the calculated Moran's I Index value is also used to calculate spatial autocorrelation. Moran's I was used to test a dataset against its predicted value. The following are the steps of statistical testing [24]:

a. Determination of the null hypothesis (H0) and the alternative hypothesis, the one-way hypothesis test of spatial autocorrelation, namely:
   - H0: I = 0, there is no spatial autocorrelation. The alternative hypothesis is: H1: I > 0, which means that there is positive spatial autocorrelation
   - H: I < 0, meaning that there is negative spatial autocorrelation
   - H0 is rejected if the value | Z (I) | > Z (α) or | Z (I) | < -Z (α) so there is spatial autocorrelation

b. Determination of the critical value, the critical Z value (Z (α)) is calculated by α / 2 for the 99% degree of confidence.

c. Determination of the test value, the test value (Z (I)) is calculated in the following stages:
   1) Calculating the statistical expectation value (E (I)) using the formula:
      \[ E(I) = \frac{1}{(n-1)} \]  
   2) Calculate the variance using the formula:
      \[ \text{VAR}(I) = \frac{n^2Z^1-nS^2+3(C)^2}{(C)^2(n^2-1)} \]  
      Where:
      \[ C = \sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij} \]  
      \[ S1 = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} (C_{ij} + C_{ji})^2}{2} \]  
      Where:
      \(C_{ij}\) = contiguity matrix element
      \(C_i\) = total value of the first row of the contiguity matrix
      \(C_j\) = the total value of the I column of the contiguity matrix
   3) Calculating the statistical test value using the formula:
      \[ Z(I) = \frac{I - E(I)}{\sqrt{\text{VAR}(I)}} \]  
      \(I\) = Moran's I value
      \(Z(I)\) = Moran's I
      \(E(I)\) = Moran's I expected value
      \(\text{VAR}(I)\) = Moran's I variance

d. Decision making, the decision taken refers to whether the null hypothesis is accepted or not, and
the alternative hypothesis is, as for the conclusions that can be taken, namely:
1) Receive H0 if the test value is below the upper critical value
2) Receiving H0, the value of the test scores above the lower critical value
3) Rejects H0 if the test value is below the lower critical value. Rejects H0, if the test value is above the critical value

It also determines the sort of autocorrelation that occurs, such as whether it is positive or negative. A Moran scatter plot can represent the clustering and distribution pattern between locations, which shows the relationship between the observed values at one location (standardized) and the average observed value from neighbouring locations with the respective location. The Moran scatter plot is one way to interpret Moran's I statistic. The Moran scatter plot is a tool to view the relationship between Zstd (standardized observation value) and the local mean calculated from the weighted matrix WZstd (local mean calculated from the weighted spatial matrix). Moran's scatter diagram is divided into four quadrants. Quadrant I (top right) is called High-High (HH) and indicates an area with a high observation value surrounded by an area with a high observation value. Quadrant II (top left) is called Low-High (LH) and indicates an area with low observations but is surrounded by areas with high observations. Quadrant III (lower left) is called Low-Low (LL) and indicates an area with low observations surrounded by areas with low observations. Quadrant IV (lower right) is called High-Low (HL) and denotes an area with high observation values surrounded by areas with low observation values [25].

3. Results and Discussion
DKI Jakarta is an epicentre of government and business with a reasonably dense occupancy. It is encircled by supporting areas of Bogor, Depok, Tangerang and Bekasi, which are arising rapidly, require adequate transportation to support economic activities. In 2017, The Jakarta inhabitants were 10.18 million people with compactness of 15,367 residents per km² [26]. Jabodetabek commuters are 3,566,178 with 2,429,751 people who undertake school and work activities in Jakarta, 1,067,762 people who work in Bogor, Depok Tangerang and Bekasi, and who carry out liveliness there out Jabodetabek is 68,665. At the same time, the commuters within Jakarta are 1,382,296 people [14]. Therefore, public transportation is a clamorous need where the growing transportation sector will significantly contribute to the development of other sectors. One of the massive transportation needed is KRL Jabodetabek which serves 921,300 Jabodetabek residents daily for activities, such as working, trading, studying, and other activities. PT KCI currently has 80 stations. More details can be found in figure 1 below:

Source: processed & modified from [2]

Figure 1. KRL passenger volume.
Figure 2. The left side is stations density 2014-2019 map. The right side is stations density 2020 map in Covid-19 era.

From figure 2 above, there are the five stations with the densest number of passengers were Tanah Abang Station with 19,996,990 passengers; Bogor Station 17,843,254; Bekasi Station 14,859,618; Citayam Station 11,823,813; Bojong Gede Station 11,761,571. While the five stations with the least passengers are Ancol Station 206,343; Cikoya Station 230,080; Citeras Station 272,327; Pondokjati Station 302,704; Metlen Telaga Murni Station 395,017. Tanah Abang Station is the most congested because Tanah Abang Station is a transit station for various routes. Tanah Abang Station is also close to the Tanah Abang Market Business Centre, where the station is surrounded by locations with a population density of 15,000 - 60,000 km². Ancol Station is the least congested because Ancol station is in the northernmost part of Jakarta. Ancol Station is also close to the Taman Impian Jaya Ancol Recreation Centre. Although locations surround the station with a population density of 15,000-20,000 km², because indeed most of the main activities of Jabodetabek commuters using KRL are not for recreation, but work (80.6%), followed by schools (19.2%), and the latter is coursework (0.2%) [15].

There was a drastic decrease in passengers when the Covid-19 outbreak began to enter Indonesia in March 2020. As a result, the government, through the ministry of transportation, issued regulation number PM 18 of 2020 concerning control of transportation in spread prevention of the Covid-19 and circular of the minister of transportation number: 14 of 2020 concerning technical instructions for railway transportation control in the new habits adaptation period for the Covid-19 spread prevention where made the five stations with the densest number of passengers were Tanah Abang Station with 19,996,990 passengers becoming 4,294,063; Bogor Station from 17,843,254 decreasing to 3,887,994; Bekasi Station from 14,859,618 droppings to 2,992,655; Citayam Station 11,823,813 decreasing to 2,822,798; Bojong Gede Station 11,761,571 decreasing to 2,742,474.
Table 2. Commuters’ movement using KRL 2019.

| No | Residence | Amount (people) |
|----|-----------|-----------------|
| 1  | Jakarta   | 191,090         |
| 2  | Bogor     | 22,454          |
| 3  | Depok     | 12,283          |
| 4  | Tangerang | 39,086          |
| 5  | Bekasi    | 26,073          |

| Location of Commuter Activities | Jakarta | Bogor | Depok | Tangerang | Bekasi |
|---------------------------------|---------|-------|-------|-----------|--------|
| 1 Jakarta                        | 76,815  | 1,437 | 4,621 | 10,176    | 5,993  |
| 2 Bogor                          | 15,208  | 13,851| 5,263 | 4,812     | 4,723  |
| 3 Depok                          | 26,980  | 4,778 | -     | 3,210     | 867    |
| 4 Tangerang                      | 36,512  | 758   | 934   | 19,911    | 554    |
| 5 Bekasi                         | 35,575  | 1,629 | 1,465 | 977       | 13,936 |

Source: processed & modified from [15].

Figure 3. Route density map. The left side is route density in 2014 and the right side is route density in 2019.

Figure 3 depicts the decrease in route density from 2014 to 2019. Bogor - Manggarai - Jakarta Kota is the busiest KRL route, followed by Bogor – Tanah Abang - Pasar Senen - Jatinegara. With 48,692 passengers, the Bogor line is the busiest in the world. Bekasi – Jatinegara – Manggarai – Jakarta Kota is the third busiest route, with 43,637 passengers (see table 2). The number of commuters utilizing KRL in 2014, which was 249,320 or 6.9% of modal share, climbed to 298,834 or 9.1% of modal share in 2019 [14,15], causing the density of KRL routes to grow compared to the thickness of courses in 2019.

Furthermore, using data on average passenger density at KRL stations from 2014 to 2020 [2], the

Source: processed & modified from [2, 13, 16-22]
results show that the parameters, including the Moran's Index value 0.37651608, the value is less than 2.58, the hypothesis H0 is rejected, indicating autocorrelation exists (see Table 3, Figure 4). Spatially at the Jabodetabek KRL Station, the expected value (Expected Value) is -0.01208515, the variance value is 0.01208515, the z-score value is 3.5401, and the p-value is 2e-04. These parameters are then used to calculate statistical tests to see whether or not there is spatial autocorrelation in the data on the number of KRL Stations cases and how the distribution patterns are formed. The statistical tests provide information that there is a spatial relationship in KRL stations where the results of the calculation of H0 are rejected, and H1 is accepted so that they. It can be found in Table 3 below:

| Moran's I | Z(I) | Z(α/2) | Statistic test | Remark |
|-----------|------|--------|----------------|--------|
| 0.37651608 | 3.5401 | 2.58 | 3.5401 > 2.58; the test value Z(I) is above the critical value Z(α/2) so that H0 rejected | Positive autocorrelation, spatial patterns forming Clusters |
| 0.37651608 > 0 so that H1 accepted | | | |

Source : analyzed from [2]

To make the results of the statistical calculation of the Moran index spatial above are easier to understand, the author will explain further into the Moran scatter plot, which can be seen in Figure 4 below:

Figure 4. Moran's scatterplot of passenger density at the Jabodetabek KRL Station

Cilebut, Palmerah, Citayam, Tanah Abang, Karet, Bogor, Depok Baru, Bojong Gede Stations, and several more are in quadrant I, according to Moran's Scatterplot (Figure 4). This means the station is in the HH or High-High cluster, which means the station has a high observation value and is surrounded by stations with a high observation value. Meanwhile, the Bekasi Station is in quadrant IV or the High-Low cluster. Thus, the Bekasi Station has a high observation value but is surrounded by low observation values. Furthermore, the average density of KRL Jabodetabek Stations in 2014-2020
shows a positive autocorrelation, as most of the observations are in quadrants I and III or clusters High-High and Low-Low, according to Moran's Scatterplot. Based on the RStudio software calculations, the Moran index (I) value is obtained for the density of the Jabodetabek KRL Stations for 2014 - 2020 and the average in that period. As a result, all Moran index values from 2014 to 2020 and the average are more than 0. So, the feature pattern formed based on these results is a cluster pattern. It means that there are many similar values in the feature.

Table 4. Moran index value (I) for the density of Jabodetabek KRL Stations for the period 2014-2020.

| Year | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Average |
|------|------|------|------|------|------|------|------|---------|
| moran index value | 0.533 | 0.530 | 0.542 | 0.493 | 0.503 | 0.512 | 0.559 | 0.527 |

Source: analyzed from [2]

Figure 5. The recommendation map for new networks of electric rail train.

Analyzing passenger density, routes, and spatial distribution patterns of passengers at the Jabodetabek KRL Station above can be the basis for planning new lines and routes to overcome the inconvenience of train services experienced by current trains passengers. Planning is a rational way for humans to deal with uncertainty. An urban rail transportation strategy is required to lower the level of uncertainty in the Jabodetabek Area. Jabodetabek is a collection of relationships and interactions between regions that constitute an economic function with a single central point, a hierarchy, and growing power over other regions [27].

The busiest KRL route is the Bogor - Manggarai - Jakarta Kota route followed by the Bogor - Tanah Abang - Pasar Senen - Jatinegara Route. Seventy-nine thousand five hundred eighty-nine passengers use trains from the Bogor regency and the city of Bogor [15]. In the future, new KRL lines and routes will be needed to split up the densest route and provide residents of Bogor Regency and Bogor City. They previously only had Bogor Station, Cilebut Station, Bojong Gede Station, and Citayam Station as their only KRL route options from the Bogor Area, with new stations in the Bogor Area. As a result, it is appropriate to propose new lines and stations with the Dramaga Route connecting to the Lebak Bulus South Jakarta MRT Station and the Dramaga Route connecting to the Parung Panjang Station in the West Bogor Area (see Figure 5).

In the future, it is necessary to have regional planning to meet the community's needs to make changes or prevent unwanted changes from occurring, create a balance of development between regions, and create a balance in the use of resources. One of the nature of regional development is to
attain well-matched growth to fulfill development potentials in consort with each region's development capacity, which is different [28]. Because the East Bogor Area was already adjacent to the Jagorawi Toll Road and the LRT line crossing one Baranangsiang - Cibubur - Cawang - Dukuh Atas Route was being built, West Bogor was chosen to build the additional KRL lines and routes. The West Bogor Area also can be developed because there is still quite a lot of vacant land available. The population density is still relatively low, namely 0 - 5,000 per Km² [16, 17, 18, 19, 20, 21, 22].

From the station's density analysis, route density analysis, and spatial pattern analysis above, the results of the study show that the stations and routes were congested, and positive autocorrelation and spatial patterns were forming clustered, meaning new lines and stations need to be created to resolve the current overcrowding of travellers. The density that occurs in the train network also occurs in China, where the behaviour of train users shows that users choose the same route on two consecutive days by 91.2%, so that there is a tendency for congestion on specific routes [7]. This finding fills a void in previous work [4], [5] where both past considers is that it does not see at the spatial design of traveller thickness at the station. It can be a theoretical basis for decision-making related to training planning in the future.

4. Conclusion

Based on the research results above, it is known that the five stations with the densest passengers were Tanah Abang Station, Bogor Station, Bekasi Station, Citayam Station, Bojong Gede Station. Most of the main activities of Jabodetabek commuters from the densest stations using KRL are not for recreation but work and are followed by schools. The busiest KRL route is the Bogor-Manggarai-Jakarta Kota Route, followed by the Bogor-Tanah Abang-Pasar Senen-Jatinegara Route. These results have met expectations for knowing the density of stations and routes on the Jabodetabek KRL, which has not been previously explained.

The deployment of stations in Jabodetabek has positive spatial autocorrelation and the distribution pattern formed is a cluster pattern. From the station density analysis, route density analysis, and spatial pattern analysis above, the development of new KRL lines and routes is needed in the future to embody balanced development. Spatial Patterns of Jabodetabek Electric Rail Transportation can be used as a theoretical basis that the government can use to formulate future policymaking. It can also give a new insight into the scientific body of spatial pattern analysis, specifically in traveller thickness at the stations spatially.

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