Urban Network in Sumatra Island

Siti Rahma\textsuperscript{1}, Prof Ofyar Z Tamin\textsuperscript{2}, Zenia F Saraswati\textsuperscript{3}, Muhammad Zainal Ibad\textsuperscript{4}

\textsuperscript{12}Civil Engineering, Institut Teknologi Sumatera, South Lampung, Indonesia
\textsuperscript{34}Urban and Regional Planning, Institut Teknologi Sumatera, South Sumatera, Indonesia

Abstract. Studies of a region's growth can only be conducted thoroughly considering its position in a larger urban system. In this system a region interacts with another region resulting in a complex urban network. Inter-urban interactions manifest in various forms such as population migration, trade, or information exchange. This study shows that urban centrality based on its interactions differs from urban centrality based on size. These interactions can be seen from the intensity of urban functions based on labor as well as interactions that can be seen from the intent on movement. This research is aimed at explaining the centrality patterns of urban interaction in Indonesia as the first identification on the relationship of cities on the island of Sumatra based on gravity model on economy and passenger movement based. There is a positive relationship between transportation centrality and economic centrality in Sumatra Island. The highest centrality in Sumatra island can be found in the Medan Area and the lowest centrality in Bengkulu.

Keywords: inter-urban interaction, urban centrality, traffic density, sumatera, transportation network.

1. Introduction

Infrastructure is a stimulus in regional economic growth, no exception in Indonesia. Various researchers have found a close relationship between investment in infrastructure and regional economic development [1,2]. Among different types of infrastructure, transportation infrastructure is considered one of the most important by policymakers because transportation costs are very important in determining location choices for companies and therefore the economic development of an area.

On the other hand, the development of the city cannot be explained simply by looking at the city itself in isolation but rather must be explained in a larger constellation. It thrives in the areas of urban geography and regional economics. Not only is inter-city interaction shaped as a hierarchy, but it is also more interesting to discuss as a form of networking. The advantage of network analysis is its ability to describe the complexity of a wide range of simultaneous urban interactions [3].

In 2000, Sumatra Island's GDRP was known to be about 21.3\% of Indonesia's GDP. In 2017, the GDRP of Sumatra island increased against Indonesia's GDP to about 21.7\%. This indicates that the amount of economic activity that is currently located on the island of Sumatra. However, with high economic activity in Sumatra Island, there are still disadvantaged areas and disparities between high regions where the gap at the city/district level is higher than the provincial level, judging by the Williamson Index for GDRP per capita and HDO in 2010-2017 [4].

In the context of Sumatra Island, this is seen from the plan of development of transportation infrastructure as one of the efforts in addressing the problem of inequality in Sumatra Island. This is explained in the purpose of...
spatial arrangement of Sumatra Island namely "Intermodal transportation network that can increase inter-regional relations, economic efficiency, and open regional isolation". So, it is planned to improve the accessibility of the road network from Lampung Province to Aceh Province.

This research is aimed at explaining the centrality patterns of urban interaction in Indonesia as the first identification on the relationship of cities on the island of Sumatra based on gravity model on economy and passenger movement based on existing National Mobility Survey (ATTN). Practically this can be an early identification of urban relationships as well as cities that are the center of growth, especially in their relationship with the transportation that supports them. Theoretically, this study seeks to prove the relationship between transportation as a proxy of economic growth.

2. Literature Review

The conceptualization of urban systems began to develop in the 1960s to 1980s. The underlying concept is the thought that the growth of a city cannot be properly explained without seeing a larger system [5]. In addition to the global scale, air transport data is also used to determine urban interaction and centrality on a domestic scale, especially in China and America. In China, has been analyzed urban interactions using aircraft passenger movement data from 1980 to 2005[6,7].

In another study developed urban interaction research in China by comparing urban interaction patterns in infrastructure aspects that use air transport data and economic aspects that use socioeconomic data [8]. This comparison is done because so far studies on urban interactions are more widely conducted in each aspect and have not been the interconnectedness between aspects.

At first glance, urban interaction patterns in China from air transport data have not had a significant difference since 1980. The main interaction pattern is still centered in the western region. In addition, from the pattern of urban interaction based on Jin, Wang, and Lao there is also still a connection between the western region and the eastern city, Urumqi. explained that the widening pattern of air transport to the east was the result of Chinese government policy requiring flights to the east [8].

The conclusions of government intervention on air transport are also supported by lao research findings when comparing urban interaction patterns in infrastructure aspects with economic aspects. Urban interconnectedness in economic aspects is more driven by market mechanisms centered in the western region. There is almost no, or very small, economic interaction between the western and eastern regions. Therefore, the Chinese government provides a policy to keep air transportation serving the needs of the movement of people even though the market demand is not much. In general, urban interaction in infrastructure and economic aspects in China has a correlation of 30%.

The last two studies also do not directly address urban areas in Indonesia, but the discussion covers several cities in Indonesia. [9] describes the growth of international flight routes in southeast Asia in 1979 and 1997. One of the results of his analysis related to urban in Indonesia is the rapid urban growth in Indonesia that is directly connected to the regional cities of Southeast Asia.

Another research on urban interaction based on the connectedness of transportation infrastructure consisting of land transportation, including roads and trains, air transportation, and marine transport. Based on the research, it was identified that 2 cities in Indonesia, Jakarta, and Surabaya, have a high position in the urban hierarchy of southeast Asia because it has good accessibility. In addition to inter-urban interconnectedness, Liu also suggested that further research be conducted that could consider the value of each of the transportations he reviewed [10].

In Indonesia, Mangkoesoubroto conducted research on urban interaction based on the interaction of cities in Indonesia based on economic and infrastructure aspects, in this case air transport passengers. The results of this study illustrate that urban interaction patterns in Indonesia are generally economically centered on Metropolitan Jabodetabek. It is just that, in the economic aspect, urban interaction tends to occur between Metropolitan Jabodetabek and urban in Java Island [11].
3. Methodology

This research was conducted to compare the value of urban interaction and centrality in economic aspects and in transportation movements. Urban interaction in transportation aspects can be easily defined as the amount of movement that occurs between cities, while centrality can be defined as the amount of movement made towards the city. However, the value of interaction and centrality in economic aspects cannot be easily defined. This is also an effort to overcome the limitations of data contained in this study.

3.1 Urban Interaction

In this study, the pattern of interaction in the economic aspect is illustrated by adopting gravitational models. The gravitational model itself was a model developed by Newton to explain the relationship between the two times in each other's position and began to be developed to describe social phenomena in the late 19th century because at that time, science was thought to be able to explain all-natural phenomena that occurred. Gravitational models that initially depict the tensile force between objects in natural phenomena are adapted into the intensity of inter-region interactions. On the basis of the same thinking, the intensity of interaction between regions is assumed to be directly proportional to the city's population and inversely proportional to distance [12].

In fact, in describing inter-urban interactions, gravitational models cannot be applied just because basically, the interaction between objects is different from human interactions where humans can choose and decide [13]. Readjustment to population variables and distances is required to be relevant in looking at inter-urban interactions. This adjustment is usually a coefficient whose value is obtained through regression analysis using empirical data. However, the data is often unavailable [14]. In Indonesia itself the study of economic interaction between cities using gravitational models is still limited. Therefore, some variable adjustments refer to the study of urban interactions in China. The calculation formula for describing inter-urban interactions in this study is as follows.

\[ I_{ij} = K \frac{M_i \times M_j}{D_{ij}^b} \]  

In this study, \( I_{ij} \) is represent the size of the economic link between the city \( i \) and the city \( j \). While \( M \) is an urban measure that in this study, referring to Lao [8], is defined not only as the population or the number of urban populations, but also the urban GDRP. Aggregation between population and urban GDRP is carried out by summing up the normalization value of the population and the normalization value of the population. The distance between cities, \( D \), is calculated based on the absolute distance from the centroids of each city. \( K \) is a constant that in this study is set to be worth 1 for ease of calculation. \( b \) as a coefficient of friction from a distance that is usually worth 2, in this study is set to be worth 1 to avoid the influence of variable distances that are too large. The determination of a value of 1 for the friction coefficient has been empirically diverged into urban interactions in China.

3.2 Urban Centrality

Urban centrality in the model approach is described through the external functions of such urban areas. The concept of urban external function itself was first put forward by Alexander [15] with a different term namely base sector, sector that can serve other urban needs. The opponent of the base sector is the non-base sector, the sector indicated to serve the urban needs itself. The concept of urban external functions is then used by the China Academy of Urban Planning and Design to look at the size of the economic overflow of an urban against other urban areas or also called urban flow intensity. Large urban flow intensity illustrates the large external influence of urban areas on other urban areas. Therefore, the concept of urban flow intensity is considered appropriate to describe urban centrality in an urban system. The formulation of urban flow intensity is:

\[ F_i = N_i \times E_i \]
Where $F_i$ is the urban flow intensity of the city $i$, $N_i$ is the efficiency of the external function of the city $i$, and $E_i$ is the external function of the city $i$. Efficiency of external functions of the city $i$ ($N_i$) is defined as the value of GDP per number of labor or in the following formula, the city labor $i$ symbolized with $G_i$.

$$N_i = \frac{GDP_i}{G_i}$$ (3)

Related to urban external functions, because it has the same concept as the base sector and non-base, then in its calculation also uses a similar element namely Location quotient (LQ) analysis. LQ itself is an analysis used to describe the proportion of industry or industrial sector of a region compared to a larger region (reference area). The basic assumptions used in the use of LQ are (1) identical worker productivity in each industrial sector, (2) worker consumption which is also identical in each industrial sector, and (3) the same type of production in each sector in each region [16]. In fact, these three assumptions are difficult to prove empirically however, the use of LQ analysis is still used today due to the concept of analysis and relatively simple data usage. In this study, the variables used in the LQ analysis were labor in three main economic sectors namely, primary, secondary, and tertiary. The calculation of LQ is as follows:

$$N_i = \frac{G_{ij}/G_i}{G_j/G}$$ (4)

$G_{ij}$ is the number of sector $j$ workers in the city $i$. $G_i$ is the number of labors of all sectors in the city $i$. $G_j$ is the number of sector $j$ workers in the reference area. While $G$ is the number of labors of all sectors in the reference area. Based on these calculations, it can be interpreted that the value of LQ $< 1$ means that the proportion of sector $j$ labor in the city $i$ is smaller than the labor of sector $j$ in the scale of the reference area. While the value of LQ $> 1$ means that the proportion of sector $j$ labor in the city $i$ is greater than the labor of sector $j$. The influence of LQ in determining the amount of external function of the city $i$ for sector $j$ ($E_{ij}$) is translated into the calculation as follows.

$$E_{ij} = G_{ij} - \frac{G_{ij}}{LQ_{ij}}$$ (5)

In this case the size used in the calculation of LQ is the number of residents and residents aged 15 years and over who work according to the field of trade, restaurants, and accommodation services, as well as residents aged 15 years and over who work according to the field of business tourism sector.

In the calculation above, $E_{ij}$ is negative when the value of LQ $< 1$. It can be interpreted that urban $i$ have no external function. Therefore, a negative result is defined as equal to 0 ($E_{ij} < 1$ then $E_{ij} = 0$). As for when the value of LQ $> 1$, then urban $i$ has an external function whose value corresponds to the calculation results.

On the other hand, the analysis of urban centrality urban centrality in the empirical approach of transportation aspects is illustrated by the number of passengers from all routes, both incoming and out of the study area. The calculation formula is as follows.

$$C_i = \sum a_{ij}$$ (6)

4. Study area

Sumatra island is the island with the 2nd largest population in Indonesia. Although the population density on Sumatra Island is far below the population density in Java Island, Sumatera Island has several metropolitan areas that become the concentration of population. Currently 63% percent of the total population on the island of Sumatra is in the metropolitan area. Can be seen in Figure 1 distribution of population on the island of Sumatera.
An overview of the distribution of population in the study area in the 2016 data year. Among the 12 cities studied, MDN (Medan Area) has the most population. In 2016 the population of MDN 4.1 million people, when compared to the second place, PLG (Palembang Area), the population in MDN is more than 17%. This is much better than java island whose first city, Jakarta Metropolitan, has a population of three times the population of the second city, Surabaya Metropolitan in the same year. The 5 cities with the least population are BNA (Banda Aceh), TPG (Tanjungpinang) with consecutive populations of 574 thousand, 329 thousand. Both cities have a small growth rate with an average value of less than 2.5% 2016.

In this study, the delineation of the study area was limited to the kegitan temple centers located on the island of Sumatra. The center of the activities in question is based on the National Spatial Plan, a study conducted by the World Bank [17], and the spatial plan of each region. Urban areas that have not been officially designated are assumed to have connections with districts that cover or are around the main city. In more detail, the cities and airports included in the study area of this study are listed in Table 1.

Table 1. Metropolitan area in Sumatra Island

| No | Code of Urban Area | Main City       | City/District                  |
|----|--------------------|-----------------|-------------------------------|
| 1  | PBR                | Pekanbaru City  | Pekanbaru City                |
|    |                    |                 | Kampar                        |
|    |                    |                 | Pelalawan                     |
|    |                    |                 | Siak                          |
|    |                    |                 | Palembang City                |
|    |                    |                 | Banyuasin                     |
|    |                    |                 | Ogan Ilir                     |
|    |                    |                 | Ogan Komering Ilir            |
|    |                    |                 | Banyuasin                     |
|    |                    |                 | Palembang City                |
|    |                    |                 | Ogan Ilir                     |
|    |                    |                 | Ogan Komering Ilir            |
|    |                    |                 | Pangkal Pinang City           |
|    |                    |                 | Bangka                        |
| 2  | PLG                | Palembang City  | Pekanbaru City                |
|    |                    |                 | Kampar                        |
|    |                    |                 | Pelalawan                     |
|    |                    |                 | Siak                          |
|    |                    |                 | Palembang City                |
|    |                    |                 | Banyuasin                     |
|    |                    |                 | Ogan Ilir                     |
|    |                    |                 | Ogan Komering Ilir            |
|    |                    |                 | Banyuasin                     |
|    |                    |                 | Palembang City                |
|    |                    |                 | Ogan Ilir                     |
|    |                    |                 | Ogan Komering Ilir            |
|    |                    |                 | Pangkal Pinang City           |
|    |                    |                 | Bangka                        |
| 3  | PPG                | Pangkal Pinang City | Pekanbaru City                      |
|    |                    |                 | Kampar                        |
|    |                    |                 | Pelalawan                     |
|    |                    |                 | Siak                          |
|    |                    |                 | Palembang City                |
|    |                    |                 | Banyuasin                     |
|    |                    |                 | Ogan Ilir                     |
|    |                    |                 | Ogan Komering Ilir            |
|    |                    |                 | Banyuasin                     |
|    |                    |                 | Palembang City                |
|    |                    |                 | Ogan Ilir                     |
|    |                    |                 | Ogan Komering Ilir            |
|    |                    |                 | Pangkal Pinang City           |
|    |                    |                 | Bangka                        |
Results and Discussion

As bada chapter has explained before, the pattern of economic interaction between cities is known through gravitational models based on PRDB data, population numbers and distance between cities.

As shown in Figure 3, it appears that a strong association is characterized by a thick line. On the contrary, a thin line indicates a weak association. At first glance, it is seen that urban interactions are common in urban areas in the western part of Sumatra Pulua. Urban interaction is clearly visible between urban areas in Medan Area and Pekanbaru (PBR) High interaction between urban areas in the western part of Sumatra Island can be understood from the determination of the value of interactions influenced by urban values and distance to related cities. Distribution of population and GDRP, as an approach to the value of an urban, which is relatively evenly coupled with adequate road infrastructure compared to other regions, causes the value of urban interaction is relatively high even though sumatra island has a relatively low urban value compared to Java Island [11]. However, Lampung Metropolitan (LAM) has very low interaction when compared to regions with similar populations. Its connection with Java may explain this relationship. the ten greatest interactions can also be seen in Figure 3.
In terms of transportation infrastructure, interaction patterns are formed from the movement of passenger data based on ATTN 2016 data. In general, the interaction patterns formed are seen in Figure 3.

**Figure 3.** Urban interaction patterns based on transportation aspects in 2016

| Rank | Start  | Destination |
|------|--------|-------------|
| 1    | MDN    | PBR         |
| 2    | PBR    | MDN         |
| 3    | PAD    | PBR         |
| 4    | PLG    | PBR         |
| 5    | PLG    | MDN         |
| 6    | BTM    | PBR         |
| 7    | PAD    | MDN         |
| 8    | JMB    | PBR         |
| 9    | PBR    | PAD         |
| 10   | PBR    | PLG         |

Similar to the image of economic interconnectedness, the thickness of the line in the image shows the strength of its interconnectedness. Based on the picture, it appears that urban interaction is centralized in Medan Area (MDN). In the table attached to Figure 4 that shows the 10 highest interaction values, it appears that the priority of mobility that occurs is the internal mobility of the metropolitan area. MDN internal interactions are even seen to be 2 times greater than the second largest interaction, namely Palembang Metropolitan internal interaction (PLG). The interaction between MDN and other urban areas on Sumatra Island looks very vague.

Furthermore, centrality analysis is carried out both in economic aspects and transportation aspects. Comparison of both centrality of cities that we examined earlier can be seen in Figure 5. In general, centrality in both aspects
is not much different and there can be direct relationships in the same direction. Trendline formed in Figure 5, can be interpreted as any change in transportation centrality unit, causing a change of $4.10^{-6}$% in the centrality of the economy. This relationship looks quite convincing with $R^2$ of 0.9265.

Based on city-by-city hierarchy on Sumatra Island on the analysis conducted Medan Area (MDN) occupies the first position in both aspects. PBR, PLG, and PAD exchange places in the order of 2.3 and 4. This indicates a link between mobility and economic activity in these regions. The striking area of BNA is very low in transportation but quite high on the economic aspect. This gives an indication that BNA has isolation to other regions on the island of Sumatra causing interactions that occur far below the hypothetical linkages provided through the centrality value of economic aspects.

Figure 4. Graph of relationships between centrality value in Metropolitan area in Sumatra Island

6. Conclusion

Urban areas can not be isolated entities or considered to have only connections with the surrounding area. Each urban city interacts without limited distance in various forms ranging from financial transactions, population movements, and trade. In addition to its shape, the patterns and intensity of interactions between cities also vary so that it has a different impact on each urban. Therefore, urban interaction studies are needed to be able to study urban development more comprehensively. With this understanding, efforts to increase growth can also be made using different approaches.

This research is aimed at explaining the centrality patterns of urban interaction in Indonesia as the first identification on the relationship of cities on the island of Sumatra based on gravity model on economy and passenger movement. This research, the interaction of 12 urban areas on Sumatra Island are mapped based on two different aspects, economic aspects, and aspects of transportation infrastructure. Identification of urban interactions based on two different aspects provides an understanding of relationship between economic and infrastructure connectedness in Indonesia. Based on this interaction study, it is also known that urban centrality based on its interaction is different from urban centrality based on urban size. This study shows that urban centrality based on its interactions are difference but have positive relation to each other. In accordance with the mentioned relation the highest centrality in Sumatra Island still can be found in Medan Area which have the largest population number.

This research is limited to urban relations on the island of Sumatra. The results of this study cannot be generalized on urban existence in Indonesia as a whole. The pattern of interaction and urban centrality in Indonesia based on economic aspects and aspects of transportation infrastructure shows different things. Differences in
interaction patterns are caused by the nature of transportation infrastructure in serving inter-urban movements with relatively long distances. While economic interaction occurs more strongly in urban areas that are close to each other. In urban centrality, the difference is caused by the tendency of transportation infrastructure to serve the tertiary economy sector compared to other economic sectors. While the assessment of centrality based on economic interaction results from the aggregation of all sectors of the economy. The study of urban interaction also described urban centrality as different from urban centrality produced based on its urban size. There are urban areas that are not very central in terms of size but have an important role when viewed from their interactions with other urban areas.

7. Acknowledgements

This research is funded by a collaborative research grant from the Institut Teknologi Sumatera with a contract number: B / 413 / IT9.C1 / PT.01.03 / 2020

References

[1] Fan, Shenggen & Chan-Kang, Connie. (2008). Regional road development, rural and urban poverty: Evidence from China. Transport Policy. 15. 305-314. 10.1016/j.tranpol.2008.12.012.
[2] Lall, S. V. (2007). Infrastructure and regional growth, growth dynamics and policy relevance for India. The Annals of Regional Science, 41(3), 581-599.
[3] Smith, D. A., & Timberlake, M. (1995). Cities in global matrices: toward mapping the world-system’s city system. In P. L. Knox & P. J. Taylor (Eds.), World cities in a world-system (pp. 79–97). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511522192
[4] Brodjonegoro, B. (2018). Discovering Indonesia’s happiness pyramid. Retrieved from https://www.youtube.com/watch?v=trCG6UfY9q4 [Online Resource]. Accessed 20th July 2019.
[5] Bourne, L. S., Simmons, J. W., & Alonso, W. (Eds.). (1978). Systems of cities:readings on structure, growth, and policy. New York: Oxford University Press.
[6] Jin, F., Wang, F., & Liu, Y. (2004). Geographic Patterns of Air Passenger Transport in China 1980–1998: Imprints of Economic Growth, Regional Inequality, and Network Development. The Professional Geographer, 56(4), 471–487.
[7] Wang, J., & Jin, F. (2007). China’s Air Passenger Transport: An Analysis of RecentTrends. Eurasian Geography and Economics, 48(4), 469–480. https://doi.org/10.2747/1538-7216.48.4.469
[8] Lao, X., Zhang, X., Shen, T., & Skitmore, M. (2016). Comparing China’s city transportation and economic networks. Cities, 53, 43–50. https://doi.org/10.1016/j.cities.2016.01.006
[9] Bowen, J. (2000). Airline hubs in Southeast Asia: national economic development and nodal accessibility. Journal of Transport Geography, 8(1), 25–41. https://doi.org/10.1016/S0966-6923(99)00030-7
[10] Liu, X., Dai, L., & Derudder, B. (2017). Spatial Inequality in the Southeast Asian Intercity Transport Network. Geographical Review, 107(2), 317–335. https://doi.org/10.1111/j.1931-0846.2016.12181.x
[11] Mangkoesoebroto, Ganesha G. (2018): Urban Interaction in Indonesia. Master’s Program Thesis, Institut Teknologi Bandung.
[12] Taaffe, E. J. (1962). The Urban Hierarchy: An Air Passenger Definition. Economic Geography, 38(1), 1. https://doi.org/10.2307/142321
[13] Schwind, P. J. (1978). The spatial structure of migration behavior. In L. S. Bourne, J. W. Simmons, & W. Alonso (Eds.), Systems of cities:readings on structure, growth, and policy (pp. 379–393). New York: Oxford University Press.
[14] Tan, R., Zhou, K., He, Q., & Xu, H. (2016). Analyzing the Effects of Spatial Interaction among City Clusters on Urban Growth—Case of Wuhan Urban Agglomeration. Sustainability, 8(8), 759. https://doi.org/10.3390/su8080759
[15] Alexander, J. W. (1954). The Basic-Nonbasic Concept of Urban Economic Functions. Economic Geography, 30(3), 246. https://doi.org/10.2307/141870
[16] Isserman, A. M. (1977). The Location Quotient Approach to Estimating Regional Economic Impacts. Journal of the American Institute of Planners, 43(1), 33–41. https://doi.org/10.1080/01944367708977758
[17] World Bank. (2012, August 8). Indonesia - The rise of metropolitan regions : towards inclusive and sustainable regional development. The World Bank. Retrieved from http://documents.worldbank.org/curated/en/520931468269430645/Indonesia-The-rise-of-metropolitan-regions-towards-inclusive-and-sustainable-regionaldevelopment