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THE GEOGRAPHIC FACTORS-BASED OPTIMIZATION OF NATIONAL FLIGHT HUB AIRPORT LOCATIONS FOR ENHANCES AVIATION SAFETY STANDARD

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ABSTRACT
Indonesia's strategic geographical location and conditions are a result of its archipelagic status. Indeed, this significantly impacts the livelihoods of Indonesians, particularly in the area of transportation. In order to facilitate the mobility of individuals between islands, the government constructed transportation infrastructure and facilities. This will serve as a reference for government regulations that aim to reduce inequality, specifically in the development and distribution of products and services outside Java, particularly in Papua. The primary objective of this research is to conduct a connectivity analysis as an initial step towards optimizing the transportation network and determining the level of connectivity between Indonesian provinces through air transportation. Next, the researchers will study the existing air transportation network's structure to understand its characteristics clearly. It will be helpful material for formulating optimization and network management scenarios. The structuring pattern in question is the application of the hub-and-spoke network concept. The hub-and-spoke network pattern focuses on optimization problems from the perspective of economies of scale. The researchers optimized the provincial capital airport's location to establish a hub airport and subsequently refined the analysis results to enhance the efficiency of the new flight service network. The above steps will compare air travel performance before and after the network arrangement scenario. Indicators for the network connectivity level will also be present, indicating that the final product optimization is now ready for verification. The target of this research is to produce a concept or optimize the location of airport hubs through a comprehensive study taking into account geographic factors and conducting an analysis of the location of National Aviation Hub airports, which is the novelty of this research.
Keywords: *Optimization, Hub Airports, National Flights, Geographical Factors.*

1. Introduction

The air transportation sector plays a key role in driving the Indonesian economy. Air transportation can encourage tourism growth, facilitate trade flows, and attract investment, which in turn can create jobs and even boost the welfare of people in various regions. Air connectivity plays a crucial role It is enhancing connectivity between various regions in Indonesia (Nasution et al., 2018). This transportation can guarantee the availability of services between regions, especially in areas that state as disadvantaged, outermost, frontier, and border area or known as 3TP area. At the same time, air transportation also plays an important role in emergency situations, such as when a natural disaster or conflict occurs in an area (Fernando et al., 2024; Yang et al., 2022).

With a strong aviation network, we are able to bridge geographical distances, especially for remote areas and islands that are difficult to reach by land or sea transportation (Cai et al., 2023). The government is striving to harmonize the vision, strategy, and upcoming actions in the Indonesian air transportation industry, given that air transportation, specifically, serves as the foundation of the country's economy, facilitating faster, safer, and more efficient connections between different regions in Indonesia and the globe (Forsyth, 2021). The regulator, along with the transportation policy formulation team and researchers, will guide the steps, recognizing the potential for connectivity analysis beyond performance-based and flexible navigation (Kasim, 2017).

By optimizing the location of national aviation hub airports based on geographical factors, we can complete a connectivity analysis that will have a comprehensive impact on the islands of Indonesia (Sugiyanto et al., 2022, 2023). Indonesia's air transportation services face challenges due to its vast country territory and geographical distance between all provincial capitals. As a result, the issue of air transport network connectivity being the backbone of community activities has become prominent (Visser & Hartjes, 2013). The number of destinations, the frequency of service, and/or the number of onward connections served by destination airports all contribute to an increase in connectivity. The national aviation network connectivity indicator is determined by the quantity of seats that are available for each destination. Subsequently, the weight of available seats is determined by the scale of the destination airport and its annual passenger count (Graham, 2023).

The existence of flight routes, which form the air transportation network, determines the level of connectivity (Cristea, 2023). Flight routes serve to enhance transportation connectivity, thereby enabling them to offer convenience to a diverse range of societal segments. This is the foundation of the Ministry of Transportation's strategy for the development of infrastructure and routes, particularly aviation transportation between Indonesian regions, which can bolster national economic and tourism activities (Abad & Momayezi, 2024).

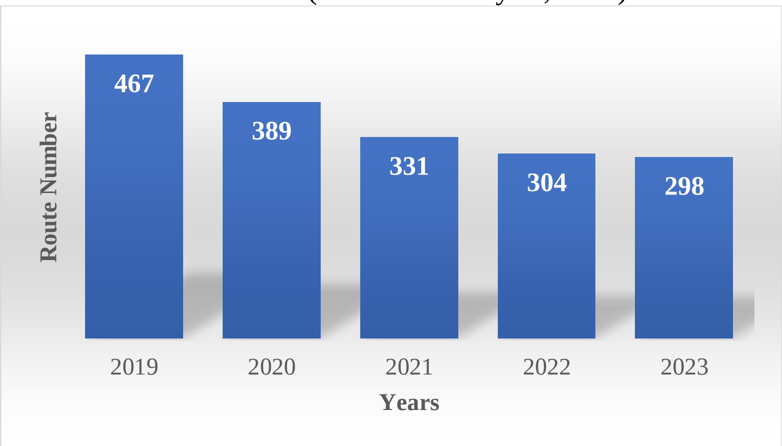

Fig. 1. Graph of The Number of Domestic Flight Routes

The Minister of Transportation's Regulation Number PM 88 of 2013 pertains to flight networks and routes stipulates that the primary factor determining flight networks is the fluctuating demand for air transportation services. This fluctuating demand allows for the on/off switching of connectivity between Indonesian airports. There are two actual issues regarding Indonesian aviation as mentioned by the President of the Republic of Indonesia, quoted from the CNBC Indonesia YouTube channel (https://www.youtube.com/watch?v=V5qK-BwqbZ4), including better arrangement of flight routes and determining hub and spoke, with the aim that the economic foundation in the tourism and transportation sectors will be stronger and better and can "run" even faster.

This research aims to delve deeper into these actual issues, generating a concept or optimization for flight route planning and hub-spoke determination through a comprehensive study that takes into account geographic factors. This is because geography is a fundamental approach that connects transportation patterns and the structure of community residential locations (Nang Fong & Law, 2014). This approach encompasses elements of connectivity, studying the structure of air transportation networks, and analyzing the location of National Aviation hubs and spoke airports, which is the novelty.

Flight networks and routes are the basis for plans to develop air transport service networks, as intended in Law of the Republic of Indonesia Number 1 of 2009 concerning Aviation. Network management is important for route management because it determines the network's scope and focus, determines seasonal schedules, and decides on capacity changes or route cancellations (Aboubakar et al., 2022; Zgodavova et al., 2018). Several flight routes combine to form a single air transportation service, known as a flight network of Transportation of the Republic of Indonesia has regulated the national aviation network through Minister of Transportation Regulation Number PM 88 of 2013 concerning flight networks and routes.

Several previous studies analyzed air transportation between provincial capitals in Indonesia using Graph Theory by Rodrigue in this research, we produce connectivity index values by modeling real transportation networks into graphical representations and connectivity matrices. Meanwhile, Gunawan's research generally describes a connectivity analysis of the national air transportation network with the aim of calculating connectivity between airports to determine appropriate strategies for mitigation when airport closures occur due to force majeure (Gunawan & Medianto, 2016).

According to (Rachmandika & Alamsjah, 2023) The research confirmed a decline in airline companies' performance due to the less-than-optimal structure of their flight network, with only 31% of domestic flight routes having good connectivity. This research uses the weighted connectivity ratio (WCR) method, which considers the connectivity value based on the weight of the temporal aspect (flight schedule) and does not fully consider the geographical aspect.

The current study, which optimizes the location of the national aviation center airport using a database of geographical factors that significantly influence the location of Indonesian islands, differs from previous research. Indonesia, a vast archipelagic country, prioritizes connecting and integrating land, sea, and air transportation. This research aims to develop an air transportation network concept that considers the geographical locations of airports within Indonesia's territory, ensuring the preservation of national connectivity (Graham, 2023; Mokhele, 2022). The concept in question is the implementation of a hub-and-spoke network. The hub-and-spoke network pattern focuses on optimization problems from the perspective of economies of scale.

The researchers optimized the research object airport's location to establish a hub airport and then further refined the analysis results to enhance the performance of the new flight service network (Atay et al., 2023; Zanin & Wandelt, 2023). In the meantime, the Minister of Transportation's Regulation Number PM 39 of 2019, which pertains to the National Airport Order, outlines the hierarchy of airports as a collection of hub and feeder airports. This hierarchy considers the fluctuating demand, which is challenging when determining an airport's status (Faturachman et al., 2023). Therefore, this research relies on the airport's geographical location (Cai et al., 2023; Thasni & George, 2022).

John McGraw in 2006 states air services employ flight routes that are continuously implemented through performance-based navigation, which are based on airspace routes and navigation services. By conducting this research and developing transportation networks that take into account geographical factors, we can more effectively identify the existence of a region and investigate its potential resources, thereby strengthening and enhancing the economic foundation in the transportation and tourism sectors. The researchers determine the domestic flight network by taking into account the following factors: a. the demand for air transportation services; b. the fulfillment of technical requirements for flight operations; c. airport facilities that adhere to aviation safety and security provisions; d. the service of all airport-served areas; e. the flight operations activity center of each scheduled commercial air transportation business entity; and f. the integration of domestic and overseas routes. The researchers have determined the main routes and feeder routes for the national aviation network based on these factors (Aboubakar et al., 2022; CAI et al., 2023a; Zanin & Wandelt, 2023b).

2. Literature Review

Transportation is a vital element in national life and in fostering national unity. The advancement in the transportation sector aids in the achievement of national development goals across all regions, encompassing both urban and rural areas. Indonesia's existing transportation system aims to enhance population mobility services and other resources, fostering economic and social growth in rural areas and across islands (Ranjan & Sinha, 2024). If we continue to view transportation problems from a fragmented perspective and approach them case-by-case, we will not be able to solve transportation problems or improve rural accessibility. We must carry out the improvement of the transportation system across a broad spectrum, comprehensively, in a coordinated manner, and of course, consistently. Therefore, every policy-determining factor, whose policies directly or indirectly influence the performance of the transportation system and accessibility from one place to another, especially on different islands, requires good coordination (Papatheodorou, 2021; Sallan & Lordan, 2023).

Flight networks and routes are the basis for plans to develop air transport service networks as intended in the Law of the Republic of Indonesia Number 1 of 2009 concerning Aviation. Network management is vital for route management, which will determine the scope and focus of the network, determine seasonal schedules, and decide on capacity changes or route cancellations (Zgodavova et al., 2018). Several flight routes combine to form a single air transportation service, a flight network. The Ministry of Transportation of the Republic of Indonesia has regulated the national aviation network through Minister of Transportation Regulation Number PM 88 of 2013 concerning flight networks and routes. The domestic flight network is determined by considering a) demand for air transportation services, b) satisfying the technical requirements for flight operations, c) airport facilities that adhere to aviation safety and security regulations, c) Providing service to all areas with airports, d) the flight operations activity center of each scheduled commercial air transportation business entity, and e) the integration of domestic and overseas routes (Chen et al., 2024; Eskenazi et al., 2023; O'Kelly & Park, 2023).

With this in mind, the researchers determine the main and feeder routes on the national aviation network. Figure 3 shows that the Main Route includes flights from 43 airports. According to PM 88 of 2013, 694 routes originate from the airports in Table 1, and 48%, or 330, of them are in the main route category. The remaining 364 routes fall under the feeder route category. This research limits the analysis to only flight origins from class II airports, so the flight origin nodes from 43 airports only remain at 36 airports for 290 main routes. Figure 2 displays the distribution map of airport locations originating from the main flight routes under analysis, while Figure 3 displays the flight network map based on the list of airports.

Fig. 2. Map of the distribution of airport locations that originate from the main flight routes

The researchers will form the Indonesian flight network pattern using a hub-and-spoke system based on the figure above and considering the geographical position of the provincial capital airports in Indonesia, as shown in Figure 2. Indonesia is accustomed to the passage of ships and planes from other nations as a participant in global commerce. Consequently, the development of sea and air transportation in our nation is facilitated. We will be able to more effectively identify the existence of a region and investigate its resource potential by comprehending flight routes through transportation network design that considers geographical factors (CAI et al., 2023b; Eskenazi et al., 2023; Schleicher et al., 2004; X. Sun et al., 2024a).

According to Figure 2, the primary route network pattern for national flights is point-to-point. The researchers carry out the next analysis, using the principles of Metcalfe's law and connectivity matrix analysis, to address the first problem, which concerns the performance of the existing aviation network. The current issues pertain to accessibility and mobility, which the researchers manage by merging a geographic land use management system with a transportation network system. By designing the national aviation transportation network based on geographical factors, the connectivity can meet the targeted goals.

After determining the object of analysis and drawing the map depicted in Figure 2, the researchers carry out the following analysis using the principles of Metcalfe's law and connectivity matrix analysis.

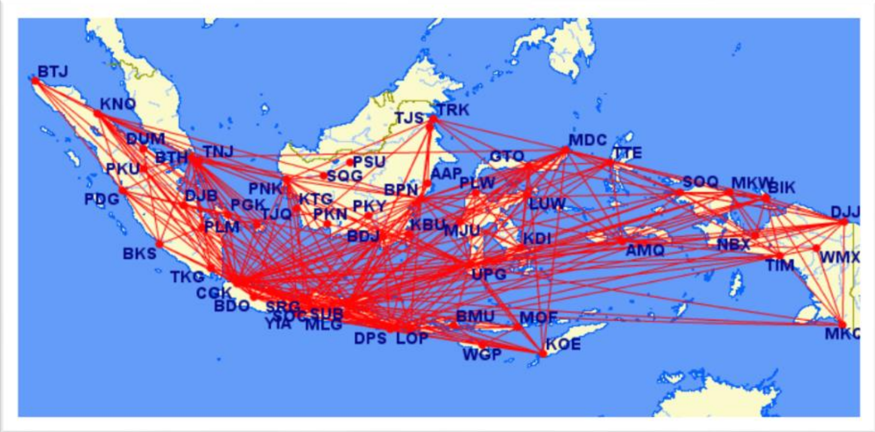

Fig. 3. Map Of The Main Route Flight Network

Research by (Zgodavova et al., 2018) states that there are two flight path configurations: point-to-point and hub-and-spoke systems. A point-to-point direct or line network is a flight model operated directly between two cities. This model makes saving 30% of costs possible because direct flights without stopovers increase aircraft speed (aircraft block speed). This model also lessens reliance on airports but requires certain conditions for flight operations with this network pattern: a) short flight distance, b) high flight demand, and c) small number of cities airlines serve.

In the hub-and-spoke system flight route configuration, the hub airport is a transportation node leading (Griffin & Jiao, 2019) to the intended final destination (Dodge & Nelson, 2023). This system optimally provides air transportation to the region by allowing passengers to travel between two cities with a single stop at the hub airport. The system covers a wide geographical area and serves numerous destinations, meeting the following criteria: a) the distance between two cities is significant, b) low demand, and c) the number of cities served is significant. The hub-and-spoke system mentioned in the research (Burghouwt & Redondi, 2013) allows for the maximization of the number of city pairs connected by a particular flight through the spatial and temporal concentration of the network.

With the Social Network Analysis (SNA) method, with data from three aviation alliances, 1060 airports, and 5580 routes in 173 countries. In SNA, airports become nodes and flight routes become connecting routes. Airports with high levels of centrality can activate routes, and airports with high levels have great potential to become hub airports because they act as bridges connecting other airports (Aboubakar et al., 2022; Zhao & Sun, 2024). The results of his research found that the airport with a high degree of betweenness centrality was Istanbul Ataturk Airport in Turkey, followed by Beijing, Chicago, Atlanta, and Frankfurt. In contrast, the airports with high betweenness centrality were Toronto Airport in Canada, Doha Qatar, Haneda Japan, and Jakarta, Indonesia.

(Bagler, 2008) examined the Airport Network of India (ANI), a complex network representing India's domestic civil aviation infrastructure. Large airports concentrate traffic at interconnected airport groups within the Airport Network of India (Hu et al., 2022) yet it is also concern to air traffic design in time and capacity (Rodríguez-Sanz & Rubio-Andrada, 2024b). The analysis shows the possibility of a mechanism for forming a national transportation network that is different from the global transportation network (the Worldwide Airport Network/WAN). This research analyzes the ANI topology in a weighted and unweighted manner. Some parameters include a) the degree of a node, b) the average shortest path length, and c) the clustering coefficient. (M. Sun et al., 2021) hub-and-spoke networks produce advantages by reducing flight operating costs to maintain competitive benefits and airline interests in development.

This research is to produce a concept or optimize the location of airport hubs through a comprehensive study taking into account geographical factors as well as conducting an analysis of the location of National Aviation Hub airports, which is the novelty of this research. The study aims to optimize the location of hub airports using industry-relevant geographical factors, specifically Perum LPPNPI (AirNav Indonesia). In addition, regulators can use the optimized hub airport locations to gauge their measurable effectiveness and efficiency. The researchers hope to further this study by measuring other references, such as demand and navigation routes.

3. Research Methods

This study uses quantitative methodologies to examine the impact of network performance on the connectivity and structure of the national aviation network. It analyzes Metcalfe's law and the connectivity matrix. The research question was about the performance of the current national aviation network. To answer it, the work stages included reading up on the rules for the national aviation network, focusing on the national aviation network, choosing the provincial capital airport as the object of analysis in the main route flight network, using Metcalfe's law parameters and the connectivity matrix to examine performance, and then talking about the results. This method is crucial in understanding the performance of the network. The relationship between this method and the formulation of the problem lies in the use of connectivity analysis to optimize the national aviation network. This pertains to the use of appropriate geographical factors with data collected at AirNav Indonesia and the system operating at their company. Then, it serves as a benchmark for airline companies to identify more effective and efficient flight route patterns.

Air Navigation Services Provider companies have validated the web-based Flight Plan as an international standard system to enhance the safety of aviation navigation services, particularly in the distribution of Air Traffic Services Messages, Flight Plans, NOTAMs, and Meteorological Messages. Therefore, the available systems provide appropriate data for determining the flight route. The web-based Flight Plan application collects numerical data about flight networks and routes. The researchers optimize the national aviation network by examining the link attributes derived from the distance matrix between airports. Then, apply the facility location problem approach to analyze two optimal location scenarios for hub-and-spoke airports. According to (Rodríguez-Sanz & Rubio-Andrada, 2024b) the most basic measure of accessibility is network connectivity, represented as a connectivity matrix (C1), which represents the connectivity of each node with other nodes. Each connected pair cell receives a value of 1, while unconnected cells receive a value of 0. The sum of these matrices gives a measure of accessibility known as a node's degree, with the equation:

$$C_1 = \sum_j^n C_{ij}$$

With:
C1 = *degree of a node*
C_{ij} = connectivity between node i and node j (1 or 0)
n = number of nodes

The connectivity matrix does not yet consider possible indirect paths between nodes; for this reason, the total accessibility matrix (T) is used, with calculation steps using the equation:

$$T = \sum_{k=1}^D CK$$

$$C_1 = \sum_j^n C_{ij}$$

$$C_k = \sum_i^n \sum_j^n C_{ij}^1 \times c_{ij}^{k-1} (\forall \neq 1)$$

With:
D = network diameter
T is a more comprehensive measure of accessibility

The Shimbel index calculates the minimum number of paths to connect a node to all nodes in a network, also known as the D matrix. This matrix holds the shortest path between nodes in the network, which is always equal to or smaller than its diameter. It only considers the shortest paths without considering alternative routes. The researchers extend the Shimbel Index and D matrix by including a distance attribute on each link, acknowledging that their distance may influence the topological relationship between two nodes. The value graph matrix, or L matrix, represents the effort and provides a minimal distance between each network node.

The following parameter is called geographic accessibility: the total distance between locations divided by the number of locations. The lower the value, the more accessible a location is. The equation is:

$$A(G) = \sum_i^n \sum_j^n \frac{d_{ij}}{n}$$

With:
d_{ij} = L
A(G) = geographic accessibility matrix
d_{ij} = shortest path distance between locations i and j
n = number of locations
L = *valued graph matrix*

The equation measures the potential accessibility parameter, a more complex parameter that simultaneously takes into account the weighted concept of distance as a location attribute:

$$A(P) = \sum_i^n P_i \sum_j^n \frac{P_j}{d_{ij}}$$

With:
A(P) = potential accessibility matrix
d_{ij} = friction distance between places i and j (from the valued graph matrix)
Pj = attribute of place j, such as population, commercial area, etc.
n = number of locations

The researchers utilize the facility-location problem optimization technique to identify the hub airport among the numerous research airports, and the researcher analyze the potential number of trips between cities (airports) using the gravity method's matrix as state in (Kong et al., 2010; Puspasari, 2019). This model operates under the premise that comprehending the current reasons for movement is crucial before making any predictions. The researchers then model these reasons by drawing analogies with natural laws, specifically the law of gravity. Tamin, O.Z. in year 2000, write in his book about geographic accessibility and potential accessibility. The gravity method uses the principle that movement between locations (origin to destination) is directly proportional to the amount of travel production at the origin location and travel attraction in the destination zone and inversely proportional to the distance or convenience between the origin and destination locations. Production characteristics and movement attractions are related to parameters of the location of origin, such as population and accessibility (convenience), which are a function of distance, time, and cost. Furthermore, refers to research by (Coletta et al., 2019; Naying et al., 2023), Isaac Newton stated that the force of attraction or repulsion between two poles of mass (F_{id}) is directly proportional to the masses, m_i dan m_d, and inversely proportional to the distance between the two masses, d_{id}^2, expressed by:

$$F_{id} = G \frac{m_i m_d}{d_{id}^2}$$

G is the gravitational constant

In geography, a force can be defined as the movement between two locations, and variables such as population, production, travel attraction, distance, time, or cost can replace mass as a measure of accessibility (ease). Transportation science formulates the gravity model as follows:

$$T_{id} = k \frac{O_i O_d}{d_{id}^2}$$

k is a constant

There are four types of gravity models, namely: 1) unconstrained gravity (UCGR), 2) production-constrained gravity (PCGR), 3) attraction-constrained gravity (ACGR), and 4) Double constrained gravity (DCGR). This research uses the DCGR model to predict travel potential between airports, with the variables being the flight distance between airports, the population of the city where the airport is located, and the gross regional domestic product (GRDP) figure of the city where the airport is located. The equation of this model is:

$$T_{id} = O_i . D_d . A_i . B_d . f(C_{id})$$

With boundary conditions:

$B_d = \frac{1}{\sum_i (A_i O_i f_{id})}$ for all d and $A_i = \frac{1}{\sum_d (B_d D_d f_{id})}$ for all i

According to (Song & Yeo, 2017), there are four factors to consider when determining location: 1. technological factors; 2. economic and geographic factors; 3. political factors; and 4. social factors. The researchers will form the Indonesian flight network pattern using a hub-and-spoke system, considering the geographical position of the provincial capital airports in Indonesia, as shown in Figure 2.

4. Results and Discussions

The location of diverse living facilities has become a comprehensive, multi-criteria, and complicated task due to the complexity of indicators. The approach will require phases, accurate data, and meticulous analysis techniques to provide a scientific and rational contribution to the decision-making process regarding numerous alternatives and issue resolution. Following the principles of operations research science, the researchers must exercise caution, as operations research cannot resolve all location-related problems readily. Consequently, the researchers continue to necessitate the wisdom, intuition, and experience of various other supporting disciplines. Location optimization analysis techniques, mainly the solver function in MS Excel, can alleviate the burden in this scenario (Pribadi et al., 2023).

According to Figure 2, the primary route network pattern for national flights is point-to-point. The researchers carry out the following analysis, using the principles of Metcalfe's law and connectivity matrix analysis, to address the first problem, which concerns the performance of the existing aviation network, after determining the object of analysis and drawing the map as depicted in Figure 2.

a. Metcalfe's law analysis involves squaring the number of links. Since there are 361 main route links, the square value equals 130,321;
b. Connectivity matrix analysis uses the indicators 1) degree of nodes and 2) total accessibility matrix.

Based on the list in Minister of Transportation Regulation 88 of 2013, the researchers create a matrix containing the main airports and limited the analysis to a minimum of class 2 airports. The matrix's size was 49 x 49 grid (49 airport matrix).

Fig. 4. Scenario 1 is one of the five proposed aviation network map scenarios. The scenario of Banjarmasin (Hub) encompasses 48 airports in Indonesia (Spoke).

The collected matrix yields the degree of a node, an indicator of connectivity. By adding up the values in each row horizontally, the researchers can determine that Jakarta Row has the most significant value of 31, indicating that Jakarta Airport is the most connected among the top five airports. Airports in Balikpapan (node 24), Batam (node 20), Ambon (node 16), and Bandung (node 16) are among the nodes. In contrast, Tanjung Karang, Tanjung Pandan, Tanjung Pinang, Tarakan, Ternate, and Wamena have low degrees, even with a value of 0.

The total accessibility matrix analysis reveals 2101 possible flight links in the existing aviation network, with Balikpapan Airport holding the most significant value of 224, making it the most accessible airport. Next in line are Batam, Jakarta, Bandung, Ambon, and Denpasar airports, which have high accessibility. The average value of the number of possible flight links for all research airports is 42.8776, and the number of airports whose value is below the average is 32 (65.3% of main airports have accessibility below the average value).

The following analysis, which addressed the second problem, involved optimizing the facility location problem using data from two matrices: the distance matrix between airports and the travel potential matrix between airports. The researchers create the distance matrix between airports using open-source flight distance calculation tools like www.distancesfrom.com. Then, the researchers present the results of our work on calculating the flight distance matrix between airports. Next, the researchers create the distance matrix between airports using open-source flight data and analyze the facility location problem optimization, utilizing the distance matrix to identify hub and spoke airports in a scenario ranging from 2 to 5. The researchers conduct the analysis using Microsoft Excel software and solver functions, aided by OpenSolver, an open-source program available at www.opensolver.org.

According to the analysis results (Dobruszkes et al., 2023) the hub airport for Scenario 1 is Banjarmasin Airport, with a total flight distance in the national aviation network of 30,765 nm; Scenario 2 is Nabire and Pangkalan Bun airports, with a total flight distance of 20,295 nm; Scenario 3 is Mamuju Airport, Nabire, and Pangkal Pinang, with a total flight distance of 14,316 nm; Scenario 4 is Jambi, Mamuju, Nabire, and Solo airports, with a total flight distance of 11,773 nm; and Scenario 5 is Bima, Jambi, Nabire, Palu, and Semarang airports, with a total flight distance of 10,483 nm.

According to research (Lordan et al., 2014), the resilience of network infrastructure, such as air transport networks, is a central issue in transportation geography. Despite advancements in other transportation networks, previous research on the resilience of air transportation network infrastructure using complex network analysis still falls short in examining network topology and robustness. These activities have identified a key research area in the geography of air transport, namely the resilience of complex networks. Theoretical analysis has begun to model and analyze air route networks as complex networks. Researchers (Cheung et al., 2020), looked at the structure and growth of the global air transportation network by creating and using the Global Airport Connectivity Index (GACI). This index considers the topological and volumetric features of airports and features that are important to specific regions in the global air transportation network. GACI combines centrality indicators such as degree, closeness, and eigenvectors with two new volume-based indicators, flow betweenness and regional importance.

Flow betweenness measures the importance of airports as transit points on connection paths between origin-destination pairs. Regional importance measures the intensity of airport connection links within its region. This research will focus on the aviation industry. Researchers (Arvis & Shepherd, 2011) created the Air Connectivity Index (ACI), a simple yet consistent measure of how connected airports are to the global air transport network. Network features like a hub-and-spoke structure exist, and the number and strength of flight connections are essential. Necessary economic measures, such as the degree of liberalization policies in the air services market and specialization in parts and components trade, strongly correlate with the ACI, as a proxy for trade openness in high-value-to-weight sectors.

This study demonstrates how the industry, particularly Perum LPPNPI (AirNav Indonesia), maximizes the efficiency of hub airport locations by considering geographical considerations (Graham, 2023; X. Sun et al., 2024b) Regulators can use the optimal hub airport sites to measure efficacy and efficiency. This research considers additional factors, including demand and navigation routes (Chai et al., 2022; Dobruszkes et al., 2023; Dodge & Nelson, 2023).

5. Conclusion

Based on the performance of the existing national aviation network, Jakarta Airport leads the list of the most connected airports, followed by Balikpapan Airport, Batam Airport, Ambon Airport, and Bandung Airport. Tanjung Karang, Tanjung Pandan, Tanjung Pinang, Tarakan, Ternate, and Wamena are the airports with lower connectivity. Balikpapan Airport boasts the highest number of possible flight links and is considered the most accessible. Next in line are Batam, Jakarta, Bandung, Ambon, and Denpasar airports, which have high accessibility. The average value of the number of possible flight links for all research airports is 42.8776, and the number of airports whose value is below the average is 32 (65.3% of main airports have accessibility below the average value). The optimization process involves determining the hub airport's location. The design aims to maximize the placement of hub airports by considering various factors. The industry, specifically Perum LPPNPI (AirNav Indonesia), can optimize the location of hub airports by utilizing geographical factors. Regulators can measure more precise effectiveness and efficiency. The availability of routes between airports in Indonesia, taking into account geographical factors, will enhance connectivity and facilitate the use of various modes of transportation. Future research can employ various methods to analyze connectivity, but the reference based on geographical factors holds significant importance. The reason for this is that Indonesia, being the largest archipelagic country, boasts a strategic geographical location and conditions that enable the realization of connected and integrated transportation between modes. The researchers hope to continue this research by measuring other references, such as demand and navigation routes.

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References

Abad, Z. A. N., & Momayezi, F. (2024). Optimizing Modular Hub Location in Air and Road Transportation Systems. *Journal of Project Management (Canada)*, *9*(3), 277–300. https://doi.org/10.5267/J.JPM.2024.3.001

Aboubakar, M., Kellil, M., & Roux, P. (2022). A Review of IoT Network Management: Current Status and Perspectives. In *Journal of King Saud University - Computer and Information Sciences* (Vol. 34, Issue 7, pp. 4163–4176). https://doi.org/10.1016/j.jksuci.2021.03.006

Arabzadeh Nosrat Abad, Z., & Momayezi, F. (2024). Optimizing Modular Hub Location in Air and Road Transportation Systems. *Journal of Project Management (Canada)*, *9*(3), 277–300. https://doi.org/10.5267/J.JPM.2024.3.001

Arvis, J.-F., & Shepherd, B. (2011, June 1). *The Air Connectivity Index: Measuring Integration in the Global Air Transport Network*. https://ssrn.com/abstract=1876298

Atay, M., Eroglu, Y., & Ulusam Seckıner, S. (2023). Domestic flight network hub location problem under traffic disruption with sustainability provision. *Case Studies on Transport Policy*, *12*, 101011. https://doi.org/10.1016/J.CSTP.2023.101011

Bagler, G. (2008). Analysis of the airport network of India as a complex weighted network. *Physica A: Statistical Mechanics and Its Applications*, *387*(12), 2972–2980. https://doi.org/10.1016/J.PHYSA.2008.01.077

Burghouwt, G., & Redondi, R. (2013). Connectivity in Air Transport Networks An Assessment of Models and Applications. *Journal of Transport Economics and Policy*, *47*(1), 35–53.

Cai, H., Gong, X., & Han, J. (2023). Analysis on the Spatial Structure and Interaction of Aviation Network and Tourism Efficiency Network in Major Cities in China. *Academic*

Journal of Management and Social Sciences, *2*(1). https://doi.org/10.54097/ajmss.v2i1.6504

CAI, K., LI, Y., ZHU, Y., FANG, Q., YANG, Y., & DU, W. (2023a). A Geographical and Operational Deep Graph Convolutional Approach for Flight Delay Prediction. *Chinese Journal of Aeronautics*, *36*(3), 357–367. https://doi.org/10.1016/j.cja.2022.10.004

CAI, K., LI, Y., ZHU, Y., FANG, Q., YANG, Y., & DU, W. (2023b). A geographical and operational deep graph convolutional approach for flight delay prediction. *Chinese Journal of Aeronautics*, *36*(3), 357–367. https://doi.org/10.1016/J.CJA.2022.10.004

Chai, J., Liu, X., Usdrowski, H., Deng, F., Li, Y., & Zhao, J. (2022). Geography, niches, and transportation influence bovine respiratory microbiome and health. *Frontiers in Cellular and Infection Microbiology*, *12*. https://doi.org/10.3389/fcimb.2022.961644

Chen, X., Zhang, Z., Xuan, C., & Qiu, R. (2024). Evolutionary analysis of airline networks under different airport-provided subsidy regimes in the context of multiple airport systems. *Journal of Air Transport Management*, *119*, 102650. https://doi.org/10.1016/J.JAIRTRAMAN.2024.102650

Cheung, T. K. Y., Wong, C. W. H., & Zhang, A. (2020). The evolution of aviation network: Global airport connectivity index 2006–2016. *Transportation Research Part E: Logistics and Transportation Review*, *133*, 101826. https://doi.org/10.1016/J.TRE.2019.101826

Coletta, V. P., Bernardin, J., Pascoe, D., & Hoemke, A. (2019). Feeling Newton's Second Law. *The Physics Teacher*, *57*(2). https://doi.org/https://doi.org/10.1119/1.5088467

Cristea, A. D. (2023). The role of aviation networks for urban development. *Journal of Regional Science*, *63*(4), 947–980. https://doi.org/10.1111/JORS.12645

Dobruszkes, F., Chen, C.-L., Cidell, J., Condeço-Melhorado, A., Goetz, A., Ryley, T., & Thévenin, T. (2023). *New and Emerging Pathways for Transport Geography*. 39–59. https://doi.org/10.1007/978-981-99-6604-2_3

Dodge, S., & Nelson, T. A. (2023). A framework for modern time geography: emphasizing diverse constraints on accessibility. *Journal of Geographical Systems*, *25*(3). https://doi.org/10.1007/s10109-023-00404-1

Eskenazi, A. G., Joshi, A. P., Butler, L. G., & Ryerson, M. S. (2023). Equitable optimization of US airline route networks. *Computers, Environment and Urban Systems*, *102*, 101973. https://doi.org/10.1016/J.COMPENVURBSYS.2023.101973

Faturachman, A., Lestary, D., Agustono, & Satria, A. (2023). Safety Risk Management Bow-Tie Analysis and Safety Promotion in The Operations of Small Unmanned Aircraft Systems. *Journal of Theoretical and Applied Information Technology*, *101*(21). https://www.mendeley.com/catalogue/58b8f0d1-e368-3c3c-a246-9896c639d714/

Fernando, F., Simangunsong, F., Rusfiana, Y., & Achmad, M. (2024). Quality of Air Transportation Services in Supporting Accessibility of Tourist Destinations in West Java Province. *ARISTO*, *13*(1), 172–189. https://doi.org/10.24269/ARS.V13I1.10335

Forsyth, P. (2021). Assessing the Wider Economic Benefits of Air Transport. *Transport Policy*, *104(3)*, 11–18. https://doi.org/10.1016/j.tranpol.2020.06.007

Graham, A. (2023). Managing Airports: An International Perspective. In *Managing Airports: An International Perspective* (6th Edition). https://doi.org/10.4324/9781003269359

Griffin, G. P., & Jiao, J. (2019). The Geography and Equity of Crowdsourced Public Participation for Active Transportation Planning. *Transportation Research Record: Journal of the Transportation Research Board*, *2673*(1). https://doi.org/10.1177/0361198118823498

Gunawan, G., & Medianto, R. (2016). ANALISIS KONEKTIVITAS JARINGAN TRANSPORTASI UDARA NASIONAL. *Angkasa: Jurnal Ilmiah Bidang Teknologi*, *8*(2), 99–110. https://doi.org/10.28989/ANGKASA.V8I2.123

Hu, R., Feng, H., Witlox, F., Zhang, J., & Connor, K. O. (2022). Airport capacity constraints and air traffic demand in China. *Journal of Air Transport Management*, *103*, 102251. https://doi.org/10.1016/J.JAIRTRAMAN.2022.102251

Kasim, K. O. (2017). Assessing the Benefits of Performance-Based Navigation Procedures. *Journal of Aviation Technology and Engineering*, *7*(1), 3. https://doi.org/https://doi.org/10.7771/2159-6670.1145

Kong, F., Yin, H., Nakagoshi, N., & Zong, Y. (2010). Urban green space network development for biodiversity conservation: Identification based on graph theory and gravity modeling. *Landscape and Urban Planning*, *95*(1–2). https://doi.org/https://doi.org/10.1016/j.landurbplan.2009.11.001

Lordan, O., Sallan, J. M., & Simo, P. (2014). Study of the topology and robustness of airline route networks from the complex network approach: a survey and research agenda. *Journal of Transport Geography*, *37*, 112–120. https://doi.org/10.1016/J.JTRANGEO.2014.04.015

Mokhele, M. (2022). The Geography of Logistics Facilities Relative to Airports: Taxonomy of Literature and Research Agenda. *Journal of Transport and Supply Chain Management*, *16*. https://doi.org/10.4102/jtscm.v16i0.770

Nang Fong, L. H., & Law, R. (2014). Managing airports: An international perspective. *Tourism Management*, *42*, 194–195. https://doi.org/10.1016/j.tourman.2013.12.004

Nasution, A. A., Azmi, Z., Siregar, I., & Erlina, I. (2018). Impact of Air Transport on the Indonesian Economy. *19th International Scientific Conference - LOGI 2018*, *236*. https://doi.org/10.1051/matecconf/201823602010

Naying, G., Yuexian, G., Khalid, M. N. A., & Iida, H. (2023). A computational game experience analysis via game refinement theory. *Telematics and Informatics Reports*, *9*. https://doi.org/https://doi.org/10.1016/j.teler.2022.100039

O'Kelly, M. E., & Park, Y. (2023). Contrasts in Sustainability between Hub-Based and Point-to-Point Airline Networks. *Sustainability 2023, Vol. 15, Page 15111*, *15*(20), 15111. https://doi.org/10.3390/SU152015111

Papatheodorou, A. (2021). A review of research into air transport and tourism:: Launching the Annals of Tourism Research Curated Collection on Air Transport and Tourism. *Annals of Tourism Research*, *87*. https://doi.org/10.1016/j.annals.2021.103151

Pribadi, O. S., Nurhadi, M., & Hermawan, B. A. (2023). Analisis Pembangunan Zona Lalu Lintas dengan Standard Deviation Control Kepadatan Area Terbangun Studi Kasus: Kabupaten Klungkung, Provinsi Bali. *Jurnal Manajemen Transportasi & Logistik (JMTRANSLOG)*, *10*(3). https://doi.org/http://dx.doi.org/10.54324/j.mtl.v10i3.1250

Puspasari, R. (2019). Pengembangan Buku Ajar Kompilasi Teori Graf dengan Model Addie. *Journal of Medives : Journal of Mathematics Education IKIP Veteran Semarang*, *3*(1). https://doi.org/10.31331/medivesveteran.v3i1.702

Rachmandika, P., & Alamsjah, F. (2023). A Modified Weighted Connectivity Ratio for Measuring a Low-cost Carrier's Connectivity at its Major Airports: An AirAsia Group Study on its Informal Hub-and-spoke Network. *Periodica Polytechnica Transportation Engineering*, *51*(4), 436–450. https://doi.org/10.3311/PPTR.21503

Ranjan, R., & Sinha, S. (2024). Impact of Socio-Economic Factors on The Transportation Mode Preferences of Work Trips in Medium-Sized Cities of Developing Countries. *International Research Journal on Advanced Engineering Hub (IRJAEH)*, *2*(11), 2593–2600. https://doi.org/10.47392/IRJAEH.2024.0357

Rodríguez-Sanz, Á., & Rubio-Andrada, L. (2024a). An empirical evaluation of airport capacity and demand: insights regarding air traffic design hours and delay. *Aircraft Engineering and Aerospace Technology*, *96*(1), 41–62. https://doi.org/10.1108/AEAT-04-2023-0117/FULL/XML

Rodríguez-Sanz, Á., & Rubio-Andrada, L. (2024b). An empirical evaluation of airport capacity and demand: insights regarding air traffic design hours and delay. *Aircraft Engineering and Aerospace Technology*, *96*(1). https://doi.org/10.1108/AEAT-04-2023-0117

Sallan, J. M., & Lordan, O. (2023). Recent Trends in Air Transport Research: A Bibliometric Analysis. *Future Transportation*, *3*(3). https://doi.org/10.3390/futuretransp3030058

Schleicher, D. R., Huang, A. S., Kiger, B. V., & Ramamoorthy, K. A. (2004). Benefit-cost analysis of a 2022 point-to-point ATM concept. *Collection of Technical Papers - AIAA Guidance, Navigation, and Control Conference*, *5*, 3271–3293. https://doi.org/10.2514/6.2004-5410

Song, M. G., & Yeo, G. T. (2017). Analysis of the Air Transport Network Characteristics of Major Airports. *The Asian Journal of Shipping and Logistics*, *33*(3), 117–125. https://doi.org/10.1016/J.AJSL.2017.09.002

Sugiyanto, G., Santoso, P. B., & Wibowo, A. (2022). Aircraft Routes and Flight Frequency of Domestic Cargo Transport in Indonesia. *International Journal of Engineering Trends and Technology*, *70*(12). https://doi.org/10.14445/22315381/IJETT-V70I12P229

Sugiyanto, G., Santoso, P. B., Wibowo, A., & Santi, M. Y. (2023). Aircraft routes of domestic cargo transport based on the Indonesian National Logistics System. *AIP Conference Proceedings*, *2482*. https://doi.org/10.1063/5.0110640

Sun, M., Tian, Y., Zhang, Y., Nadeem, M., & Xu, C. (2021). Environmental Impact and External Costs Associated with Hub-and-Spoke Network in Air Transport. *Sustainability 2021, Vol. 13, Page 465*, *13*(2), 465. https://doi.org/10.3390/SU13020465

Sun, X., Zheng, C., Chen, X., & Wandelt, S. (2024a). Multiple airport regions: A review of concepts, insights and challenges. *Journal of Transport Geography*, *120*, 103974. https://doi.org/10.1016/J.JTRANGEO.2024.103974

Sun, X., Zheng, C., Chen, X., & Wandelt, S. (2024b). Multiple airport regions: A review of concepts, insights and challenges. *Journal of Transport Geography*, *120*, 103974. https://doi.org/https://doi.org/10.1016/j.jtrangeo.2024.103974

Thasni, M. A., & George, S. (2022). Structural analysis of Air Transport Network using Network indicators. *2022 IEEE International Power and Renewable Energy Conference, IPRECON 2022*. https://doi.org/10.1109/IPRECON55716.2022.10059483

Visser, H. G., & Hartjes, S. (2013). Economic and environmental optimization of flight trajectories connecting a city-pair. *Http://Dx.Doi.Org/10.1177/0954410013485348*, *228*(6), 980–993. https://doi.org/10.1177/0954410013485348

Yang, Z., Chen, X., Pan, R., & Yuan, Q. (2022). Exploring location factors of logistics facilities from a spatiotemporal perspective: A case study from Shanghai. *Journal of Transport Geography*, *100*, 103318. https://doi.org/10.1016/J.JTRANGEO.2022.103318

Zanin, M., & Wandelt, S. (2023a). An overview of network structures and node importance in the global aviation system from the year 2011 to 2022. *Journal of the Air Transport Research Society*, *1*(1), 63–80. https://doi.org/10.59521/5E2DDEC9FAD4593B

Zanin, M., & Wandelt, S. (2023b). An overview of network structures and node importance in the global aviation system from the year 2011 to 2022. *Journal of the Air Transport Research Society*, *1*(1), 63–80. https://doi.org/https://doi.org/10.59521/5E2DDEC9FAD4593B

Zgodavova, Z., Rozenberg, R., & Szabo, S. (2018). Analysis of Point-to-Point versus Hub-and-Spoke Airline Networks. *NTAD 2018 - 13th International Scientific Conference - New Trends in Aviation Development, Proceedings*. https://doi.org/10.1109/NTAD.2018.8551733

Zhao, S., & Sun, S. (2024). A study on centrality measures in weighted networks: A case of the aviation network. *AIMS Mathematics*, *9*(2), 3630–3645. https://doi.org/10.3934/math.2024178