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Air Transport Centrality as a Driver of Sustainable Regional Growth: A Case of Vietnam

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Abstract: With fast-growing aviation markets, many developing countries are showing remarkable economic development in global terms. As significant growth of air transportation is crucially interrelated with regional growth, it is essential to identify relevant criteria to ensure effective allocation of investments in this regard. This study aimed to investigate airport centrality using social network analysis to detect the key hubs and examine the interrelationship between airport centrality and regional economy indicators in Vietnamese regions. The results revealed that the cities of Tan Son Nhat, Noi Bai, and Da Nang were the key regional hub airports in the air transport network and the development of these leading cities had played a significant role in promoting the improvement of the entire domestic air network. Moreover, the results showed a strong positive correlation between airport centrality and regional growth features. Therefore, policymakers can optimize their decision-making processes in relation to sustainable regional development by considering air transport mobility and network in addition to conventional socioeconomic criteria.

Keywords: airport; centrality; social network analysis; regional growth indicator; Vietnam

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1. Introduction

The selection of regions to develop needs careful consideration due to a shortage of government resources, especially in developing countries. Many factors have been considered in the process of allocating resources for regions, such as regional product per capita, population size, and population density [1], preference in terms of efficiency for productive regions or equity for disadvantaged regions [2], and political factors [3]. Generally, central governments focus their investments in areas with higher growth potential [4]. Overall, political and regional economic indicators are primarily considered. However, transportation plays a critical role in promoting economic growth [5] and can create a competitive advantage for the concerned region. Identifying relevant traffic-related indicators is likely to be helpful in selecting geographic areas as a development priority to promote regional growth and increase the efficiency of public investment.

According to Oh et al. [6], Vietnam's transport infrastructure includes roads, railways, inland waterways, maritime, and airways. The country has about 30,900 km of road length, including 2130 nodes and 20,512 links connecting all 63 provinces. The maritime network is the second largest logistics network in freight transport after the road system. The waterway system is a regional network locating separately in the two regions of the Red River Delta (in the North) and the Mekong River Delta (in the South). The railway system does not connect all provinces but links the two north–south dynamic cities, Hanoi and Ho Chi Minh City. The outdated railway system and single-track technology limits

railway accessibility. The air transport network includes 23 airports scattered throughout the country. The three major aviation hubs (international airport and service volume) are situated in the country's northern, central, and southern regions. The share of air transport of the total cargo transported in Vietnam is rapidly increasing. Few studies [7,8] affirm the role of transport modes, especially air transport, in promoting tourism and economic growth. Yu and Luu [9] state that investment in transport infrastructure in Vietnam can increase the employment rate across industries. In addition, developing transport infrastructure can improve the connection between the regional and national economies. This suggests the role of transportation infrastructure network and its connectivity on regional/national development.

The relationship between airports and economic development has long been a topic of interest in research. Various studies have demonstrated the active role of airports in regional economic development [5,10–12]. Further, some studies have shown the positive impact of regional development on the growth of passenger numbers and cargo traffic through regional airport [13,14], and other studies have highlighted a significant bidirectional relationship between having an airport and regional growth [15–17]. Pot and Kosster [18] affirm the major impact of large airports in regional economy compared to that of small airports. Therefore, it seems plausible that using airport centrality as an indicator to select an area for resource development is likely to help increase the efficiency of investments.

Within Southeast Asia, Vietnam has recently led with a precipitous growth at 3.6 times from 2002 to 2021 [19], with a remarkable surge in foreign direct investment (FDI), stimulating economic development [20]. The middle class in Vietnam—people who earn an average monthly income of at least 15 million Vietnam dong—is growing faster than other Southeast Asian regions [21]. As the national economy grows and many cities become developed through rapid urbanization and industrialization, the annual amount of logistical engagement between cities has been increasing. In particular, Vietnam has become one of the fastest growing aviation markets in the world following the recent surge in domestic and foreign tourism industries [22]. Geographically, Vietnam is characterized as narrow in east–west terms and long, at approximately 1650 km, in north–south terms. However, the surface transportation system and railway infrastructure are no longer adequate, but new developments in related infrastructure have not been implemented. The aging railway system and its trains cause long travel times. Although a high-speed train network has been under discussion for the last decade, no further development has occurred [23]. The projected 1st National Highway from Ho Chi Minh City to Hanoi, which is intended to link most provinces, has been delayed for several decades, with only a few sections under construction and other sections facing various issues such as lack of investment and delayed compensation [24]. Consequently, Vietnam's aviation industry is now growing at a tremendous yearly rate of 16%, twice as fast as Asia's average aviation market growth, and the size of the market is expected to reach 785 billion US dollars in 2038 [25]. However, despite being declared as one of the fastest recovering countries from the COVID-19 pandemic [26], the supply chain disruption owing to the pandemic has affected the Vietnam air transport market significantly. In 2020, Vietnam's air transport market witnessed a revenue drop by about 4.35 billion USD compared to 2019. The Civil Aviation Administration of Vietnam has re-evaluated the market outlook. The passenger and cargo growth are 7.5–8.5% and 8.4–9.7%, respectively [27]. This shows that Vietnam's aviation market still displays great prospects for the future. Despite the significant growth in air transportation and its essential role in regional growth, investment decisions for regional development are still far from the existence of airports in the region. Traditional approaches prefer using traffic statistics. However, constructing a macrolevel criterion based on aggregate microinformation at the individual passenger level seems costly (both time and money). The detailed, diverse, and fragmentary information is a major obstacle in describing a general picture. Here, the connection among airports has the advantage of ease of observation. Therefore, we considered airport connection over the centrality approach as it is easier to observe, more superficial, and more generalized.

In seeking to understand the relationship between airport infrastructure and regional development, this study aimed to (1) investigate airport centrality using social network analysis (SNA) to detect the key hubs of Vietnamese regions and (2) examine the interrelationship between airport centrality and regional economy indicators. Research concerning Vietnamese airports has rarely investigated matters such as connectivity and centrality, despite the remarkable and ever-increasing rate of national economic growth particularly in relation to the extensive development of air transportation infrastructure and networks. Therefore, this study provided relevant and evidence-based recommendations concerning what needs to be prioritized for effective national resource allocation and redistribution, based on the results of airport centrality analysis. Furthermore, this study identified a key indicator, namely airport centrality, for consideration when selecting potential development areas for regional economic growth.

This study is organized as follows: Section 1 introduces research backgrounds, purposes, and the structure of this study. Section 2 includes a theoretical review of the relationship between airport connection and regional economy, regional centrality, and empirical studies of airport centrality. Section 3 discusses research methods such as data collection, rearrangement, analysis modeling, and procedures. Section 4 presents analysis results of centrality and correlations, findings, and discussions of airport centrality as a driver of sustainable regional growth. Finally, Section 5 concludes the study by including a summary of key findings and their implications, study limitations, and further research directions.

2. Literature Review

2.1. The Interactive Relationship between an Airport and the Regional Economy

The transportation infrastructure of a country is one of the most important indicators of its economic growth [28]. Airports are often located in densely populated areas in which there are many industries, leading to high volumes of products and greater travel needs [11]. Debates concerning the interaction between infrastructure supply and economic productivity at regional and national levels are ongoing, with important implications for public decision-making [10,11,13,14,27,29]. Aschauer and Alan [29] have shown the correlation between transport infrastructure and productivity growth at the national level. Airports influence the growth of a region through allowing faster and greater volumes of passenger and cargo flows and improving economic output per capita. The larger an airport, the stronger its effect [11]. Air transport services lead to a statistically significant increase in economic growth in the regions [10]. Similarly, using Granger causality testing, Button and Yuan [12] confirmed a causal relationship between air transport as a positive driver and local economic development after conducting a data analysis of 35 airports in 32 metropolitan areas in the United States. In contrast, certain other features such as gross regional domestic product (GRDP), economic decision-making power, tourist characteristics, and the distance to a large aviation hub have been proposed as deciding factors for air traffic volume [13]. Besides, Fernandes and Pacheco [14] claimed there was a causal relationship between the economic growth and demand for domestic air transport in Brazil.

Airports are among the core infrastructures that explain the effect on productivity [30]. Allroggen and Malina [31] refer to the requirement of a synchronous investment to enrich "core connectivity" in the airport system to achieve economic growth. In addition, investing in airports is a way for policymakers to make the region more attractive to investors. Sheard [32] deals with the impact of airport infrastructure on labor and employment. Thus, airports at different levels can become indicators of economic development potential in different ways. Given that investigations have found the two-way relationship between air transport and economic growth to be generally positive, airports are viewed as vital infrastructure not only for the economy but also for local governments promoting regional development. There is an awareness that funding needs to be attracted for targeted airports to support growth [15]. It has been claimed that a two-way relationship between air transport and the economy is more evident in developing countries, whereas a one-way

relationship between air transport and economic growth is more apparent in developed countries [17]. Mukkala and Tervo [16] found a causal relationship between regional growth and air traffic, especially in remote areas, that led to subsidies to local airports in those regions. There seems to be sufficient evidence to indicate that there is a relationship between the distribution of an air transport network and economic activities. Moreover, Jia, Quin, and Shan [33] found that an airport network had a significant impact on stimulating notable regional economic growth after conducting an exploratory analysis on airport networks from 1990 to 2010. Therefore, it appears that consideration of the characteristics of an airport network is likely to be of value for policymakers across multiple domains beyond purely research. Specifically, assessing the key locational factors affecting regional airports within the national air transport network is essential in understanding how the development of economic activities regionally can be undertaken more effectively.

An aviation connectivity report by IATA [34] (p. 12) stated, "Air connectivity generates benefits for local and national economies, including improved competitiveness and enhanced employment and economic growth opportunities." This report also refers to their previous research with Inter VISTAS and Oxford Economics that showed a 10% increase in air connectivity boosts labor productivity by about 0.07% and creates a 1.1% GDP increase in the long run [34]. Bel and Fageda [35] concluded that a 10% increase in new international routes could increase the number of large corporate headquarters by 4%, especially those with intensive knowledge, thus contributing to urban economic development. The study concluded that policies to attract companies should accompany the investment in developing international flights. Moreover, the presence of new flight routes, that is, increased airport connections, witnessed an increase in FDI inflows [36]. Bilotkach [37] asserts that, in addition to traffic flow, the number of destinations creates the most obvious influence on employment, the number of new businesses, and the level of regional average salary. Discussions on air connectivity promote orientations toward the role of airports and their connection with regional development and emphasize the attention to the connection level of the airport with regional economic development indicators.

2.2. Airport Centrality Measurement as an Indicator of Economic Growth

A busy airport is often the driving force of the economy, as it promotes other airports to thrive through connected networks and boosts the country's economy [38]. Chen and Lee [39] measured the degree centrality, betweenness centrality, and closeness centrality of 10 major airports in Southeast Asia and concluded that urban interactions could benefit from reducing the complexity of airport networks. Airport centrality is commonly measured by degree, betweenness, and closeness centrality using SNA [40–42].

SNA was first introduced by Moreno [43]. It is applied to increase the understanding of the complexity of systems, such as that of a transport network [44]. It provides a capability to analyze connections in a transport network, which shares some fundamental characteristics with social networks. In addition to the fields of physics, data science, computational linguistics, epidemiology, fashion, information exchange, and marketing [44], SNA has been applied in transport planning and economics since the 1930s [45]. Furthermore, SNA is more cost-effective than traditional traffic network analysis as it does not require the fulfillment of stringent data requirements but can still deliver reliable results [46]. Furthermore, compared to standard analysis methods that focus heavily on individual attributes, SNA examines and evaluates individual attributes in the context of overall network relationships [44].

In applying SNA in this study, degree centrality is used in reference to a large-scale or busy airport, betweenness centrality refers to the influence of an airport in terms of its intermediary role, and closeness centrality refers to an airport that is closest to the remaining nodes. Finally, Bonacich beta (β) centrality illustrates how well an airport connects to the more significant nodes. Besides discovering important nodes to improve the network, the high-centrality nodes boost tourism in the country [47]. Sapre and Parekh [47] further emphasize the role of the city's centrality in the spatial description of economic

activities. Note that this study calculates the city center values by air connections. Some studies [48,49] show a strong correlation between socioeconomic indicators and centrality values. These studies calculated the central nodes in a transportation system to specify the indicative relationships for regional development. Their findings indicated that it was not necessary for a hub airport to have very high centrality values, as some airports were found to have notably high centrality, whereas others did not. Airports with high centrality would be expected to become hubs as they trigger flight routes and act as connectors to other airports. Generally, results of investigations showing consistent high centrality indicators for hub airports suggest that SNA can be a valuable tool for analysis.

Further analysis of the relationship between airport centrality indexes and other socioeconomic variables and airport characteristics has been conducted. The approach by Wang, Mo, Wang, and Jin [48] to analyze the centrality of an airport network established a high correlation between the three centrality indicators and air passenger volume, population, and GRDP. The central nodal positions of the airports identified in their study were explained in terms of economic power, tourist attractions, and the advantages of central geographic locations for connecting flights. These findings further support an airport's central role in the spatial formation of economic activities and the usefulness of SNA in determining the key transportation hubs within specific and important geographical locations.

Hence, airport centrality appears likely to be useful as a potential indicator of areas with significant economic development potential, while SNA appears to be an appropriate analytical method for determining the critical nodes in a transport network.

3. Research Methods

3.1. Data Collection and Rearrangement

As traffic volume was considered to meet the requirements of SNA in the context of a transport network, this study used data concerning the number of domestic air passengers who travelled through 20 Vietnamese airports located across the country. To analyze airport centrality rank fluctuations, passenger origin–destination (O–D) datasets for 5 years (2014–2018) were obtained with the support of the Civil Aviation Authority of Vietnam. The relevant panel data included the number of passengers on each route for the study period. Then, the data were reorganized using a three-dimensional matrix structure. The number of passengers present at 20 domestic airports in Vietnam over the 5-year period was symmetrized using the MAX method with UCINET 6 after switching to the O–D matrix. This was used to reconstruct the data because aviation O–D data provided a useful indicator in defining regional centrality and relevant networks. As this matrix contains information concerning the air traffic between regions, it can readily estimate traffic volume in the network [50]. In addition, other regional data were sourced from the General Statistics Office of Vietnam (https://www.gso.gov.vn, accessed on 7 September 2020) in the years corresponding to the transport data.

3.2. Analytical Framework

Centrality concepts used in SNA discover important network actors and evaluate the impact of network structure and surrounding factors on the changes in nodes' importance [51]. Centrality values commonly used in studies include degree centrality, which considers agents with more interactions as superior [52,53] and eigenvector centrality, which favors agents connected to many influential nodes. Degree centrality indicates the number of direct connections, whereas eigenvector centrality emphasizes the relationship governed by weights. According to the literature [54], Bonacich β centrality is a generalization of degree centrality and eigenvector centrality. For Bonacich β centrality, direct and indirect connections are essential [55]. The β can adopt either positive or negative values. When β is negative, the network actors are mutually influenced but competitively. Conversely, a positive value of β indicates that the network is complementary.

This study calculated the annual centrality values of all of Vietnam's operating airports according to degree centrality and Bonacich β centrality. Degree centrality represents

the linkage power among actors [56]. Actors with a positional advantage have many alternatives to meet the needs of other actors and are less dependent on other actors around them. If centrality is defined as a pathway, there are both opportunities and risks involved in terms of exposure to whatever flows through the network [57]. In this study, degree centrality was determined in relation to air traffic volume. Airports with high degree centrality have high power compared to other airports. The following degree centrality formula was used [57]:

$$C_D(N_i) = \sum_{j=1}^{g} R_{ij},\ i \neq j \quad (1)$$

where

$C_D(N_i)$: i degree centrality of airport;
g: number of airports;
$\sum_{j=1}^{g} R_{ij}$: number of connections between airport i with $(g - 1)$ other airports.

Bonacich β centrality is an indicator used to identify and reflect the overall nature of the network comprising all the actors that focuses on measuring the centrality index of each node or actor. Bonacich [58] clarified that the power of an actor comes not only from the actors close to that actor but also from actors further away and is ultimately determined within the entire network structure. This is advantageous in that "the Eigenvector and Bonacich power methods explain how nodes play an important role in a social network structure and how such a node has a higher power in the network" [44]. The formula used for Bonacich β centrality was as follows:

$$c_i(\alpha,\ \beta) = \sum_{j}^{g} (\alpha\ +\ \beta c_j) R_{ij} \quad (2)$$

where

c_i: β centrality columns of the actor;
α: parameter to standardize the centrality;
β: weighted parameter based on traffic volume from the actor;
R_{ij}; adjacent matrix with R_{ij} as element.

The calculation of the two centrality measures extended the depth and complexity of the analysis. The more the indicators pointing toward an actor, the more likely the actor is accurately identified as a central node. Data on annual changes in the centrality ranking of airports need to be recorded to ensure consistency when using SNA. If one or some nodal hubs clearly do not shift in ranking over the selected time, SNA can be considered reliable. Meanwhile, any centrality shift also indicates that one airport has a high-volume traffic compared to other nodes, implying a relatively stronger inner dynamic in certain areas. Furthermore, the correlation between the centrality indicators and the key regional variables of population density and GRDP was analyzed to assess the plausibility of using centrality analysis in relation to regional growth.

3.3. Data Analysis

Using UCINET 6, this study calculated nodal centrality by deriving degree centrality and Bonacich β centrality. The mean values of internal and external degrees were used for degree centrality at each airport to select representative values for the degree of connection at each airport. To identify network characteristics, Pearson correlation was calculated using R programming. We observed that the airport network in Vietnam had complementary connections, so the β value was taken as 1/max eigenvalue. This study identified the network relationships and characteristics of each airport with its surrounding airports. Based on all the airport networks in Vietnam, centrality between 2014 and 2018 was analyzed to determine the reasons for each selected airport's growth, decline, and change in centrality.

4. Findings and Discussions

4.1. Degree Centrality

The results indicated that the three leading airports were Tan Son Nhat (1st), Noi Bai (2nd), and Da Nang (3rd), while the three least important airports were Dien Bien (19th), Con Dao (18th), and Tuy Hoa (17th) in 2018 (Table 1). In terms of degree centralities, Tan Son Nhat, Noi Bai, and Da Nang were shown to have many routes to other airports in the domestic network and carried the largest volume of air traffic. Notably, these airports remained the leading airports in terms of connectivity over the 5 years. All three airports are in major cities, namely Ho Chi Minh City, Hanoi, and Da Nang, respectively. Hanoi and Ho Chi Minh City are the major economic hubs in the north and south, respectively, while Da Nang is the major economic and tourism hub in central Vietnam.

Table 1. Degree centrality and rank of each airport in Vietnam.

Airport	2014		2015		2016		2017		2018		2014–2018	
	Centrality	Rank	Centrality	Rank	Centrality	Rank	Centrality	Rank	Centrality	Rank	Centrality Change	Rank Change
Tan Son Nhat	6,459,327	1	4,531,344	1	6,444,682	1	11,012,848	1	11,519,483	1	5,060,156	0
Noi Bai	4,302,185	2	2,527,916	2	3,580,582	2	7,446,083	2	7,914,024	2	3,611,840	0
Da Nang	1,985,482	3	1,252,799	3	1,629,011	3	3,450,339.5	3	3,535,767	3	1,550,285	0
Cam Ranh	724,533.5	4	369,982	6	620,540.5	5	1,313,413	4	1,435,516	4	710,982	0
Phu Quoc	486,557.5	7	394,081	5	620,647.5	4	1,193,770.5	5	1,329,164	5	842,606.5	−2
Phu Bai	573,761.5	5	283,550.5	8	394,840	8	846,411.5	6	892,827	7	319,065.5	2
Cat Bi	464,808	8	410,472.5	4	585,827	6	834,299.5	7	955,200	6	490,392	−2
Vinh	535,428	6	363,863.5	7	520,689.5	7	780,170.5	8	774,976	8	239,548	2
Lien Khuong	298,806	10	185,369.5	11	365,107	9	610,637	9	605,597.5	9	306,791.5	−1
Phu Cat	209,674.5	11	149,672	12	308,799	11	555,924.5	10	595,432	10	385,757.5	−1
Tho Xuan	82,298	15	216,731.5	9	314,662	10	392,621	12	434,296.5	11	351,998.5	−4
Chu Lai	20,340.5	19	62,142	15	272,599.5	13	337,538	13	362,373.5	13	342,033	−6
Buon Ma Thuot	308,288.5	9	195,434.5	10	280,519.5	12	407,541.5	11	410,785	12	102,496.5	3
Pleiku	150,358	12	37,406	18	206,803.5	14	319,155.5	14	320,190.5	14	169,832.5	2
Can Tho	138,593.5	13	58,961	16	83,842.5	18	253,126.5	15	290,890	15	152,296.5	2
Dong Hoi	58,734.5	16	77,799	14	130,349.5	16	217,623.5	16	261,184	16	202,449.5	0
Tuy Hoa	32,098.5	18	38,442.5	17	164,155	15	167,341	17	194,061	17	161,962.5	−1
Con Dao	93,639	14	104,198.5	13	112,053	17	137,430	18	164,433	18	70,794	4
Dien Bien	40,630	17	0	20	31,526	19	32,999.5	19	23,320.5	19	−17,309.5	2
Ca Mau	15,219	20	13,841	19	15,257.5	20	15,183.5	20	16,146.5	20	927.5	0

In contrast to those stable rankings, Chu Lai and Tho Xuan airports had significant shifts in rank, going from 19th to 13th place and from 15th to 11th place, respectively (Figure 1). Chu Lai and Tho Xuan operate only domestic flights, despite Chu Lai being an international airport, with Chu Lai airport having only two routes to Tan Son Nhat (1st) and Noi Bai (2nd) and Tho Xuan having only one route to Tan Son Nhat. These changes in rankings showed that the air traffic growth rates of these airports had been higher than those of other domestic airports over the same period, with Chu Lai airport leading in terms of growth with 28 times more traffic, and with Tho Xuan airport lying second with a fivefold traffic increase across 5 years. Can Tho ranked 13th in 2014 but dropped to 15th in 2018. The closure of the Phu Quoc route caused Can Tho to reduce its operation from three connections in 2014 to two connections in 2018. Furthermore, despite being connected (as was the case with Tho Xuan) to Tan Son Nhat, Ca Mau airport continued to rank the lowest in terms of traffic growth at 20th over 5 years, lower than Chu Lai (19th), Tuy Hoa (18th), and Dien Bien (17th). No notable changes occurred in relation to the other airports.

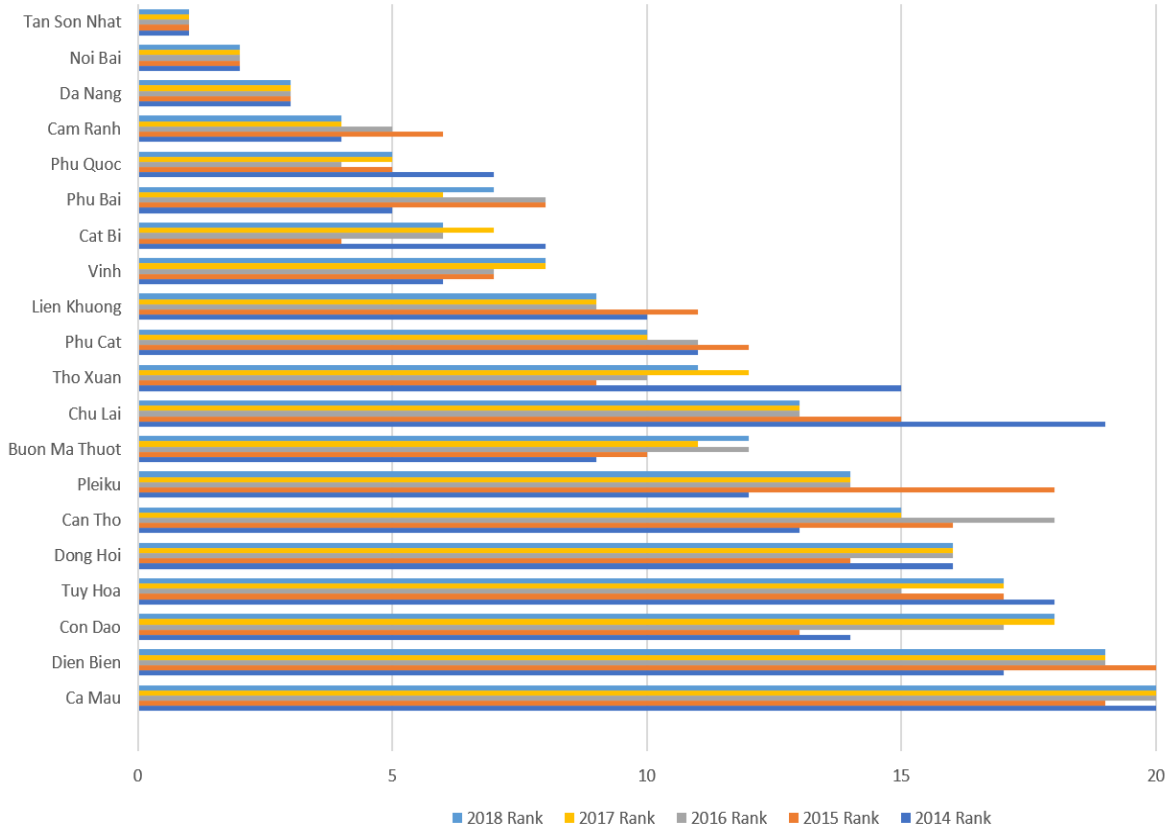

Figure 1. Degree centrality rank change of each airport in Vietnam.

4.2. Bonacich Beta Centrality

Bonacich centrality values concern the extent of associations within well-connected nodes, with a node having higher centrality when connected to a greater number of other central nodes. As Tan Son Nhat and Noi Bai were the most central airports (Table 2), other airports obtained higher scores if they were connected to these airports. All the airports had at least one connection to the three hub airports of Tan Son Nhat, Da Nang, and Noi Bai as at the end of 2018, apart from Rach Gia, Na San, and Van Don. Connections with major airports had a positive effect, as shown in terms of degree centrality (Figure 2). The two almost identical centrality rankings across 5 years indicate the leverage roles played by the three hub airports (Figures 1 and 2).

4.3. The Relationship between Centrality Indicators and Regional Growth Indicators

Degree centrality depends on traffic volume transfer among nodes, which is related to the number of routes at each airport and the traffic on each route. The more extensive the number of routes and the greater the traffic, the higher the Bonacich β centrality. As expected, the leading airports operated a large number of routes, with Tan Son Nhat operating the largest number of domestic routes (17 routes), followed by Noi Bai (15 routes).

However, this type of understanding appeared to be inadequate in explaining the change in ranking regarding several airports. When comparing changes between 2014 and 2018, we observed that Tho Xuan maintained only one connection with Tan Son Nhat, and Chu Lai still had only two connections with Tan Son Nhat and Noi Bai, whereas Phu Quoc reduced one connection with Can Tho and kept only two linkages with Tan Son Nhat and Noi Bai. Therefore, the number of connecting points could not satisfactorily explain the rise in centrality ranking for these airports, raising the question as to what caused the increase in traffic volume between certain node pairs (Chu Lai–Tan Son Nhat, Tho Xuan–Tan Son Nhat, and Phu Quoc–Tan Son Nhat). The answer appears to be a rise in traffic volume on existing connections. As discussed, the regional economy can be viewed as a major driver of air

travel demand. In addition, the aviation demand forecasting sector is well aware of the significance of population density, with more people increasing the potential travel demand. Therefore, this study assessed the correlation between the centrality measurements and GRDP values as well as population density. Figure 3 indicates the mapping of centrality results of each airport with population and GRDP of each province.

Table 2. Bonacich beta (positive) centrality and rank of each airport in Vietnam.

Airport	2014		2015		2016		2017		2018		2014–2018	
	Centrality	Rank	Centrality	Rank	Centrality	Rank	Centrality	Rank	Centrality	Rank	Centrality Change	Rank Change
Tan Son Nhat	6,459,327	1	4,531,344	1	6,444,682	1	11,012,848	1	11,519,483	1	5,060,156	0
Noi Bai	4,302,185	2	2,527,916	2	3,580,582	2	7,446,083	2	7,914,024	2	3,611,840	0
Da Nang	1,985,482	3	1,252,799	3	1,629,011	3	3,450,339.5	3	3,535,767	3	1,550,285	0
Cam Ranh	724,533.5	4	369,982	6	620,540.5	5	1,313,413	4	1,435,516	4	710,982	0
Phu Quoc	486,557.5	7	394,081	5	620,647.5	4	1,193,770.5	5	1,329,164	5	842,606.5	−2
Phu Bai	573,761.5	5	283,550.5	8	394,840	8	846,411.5	6	892,827	7	319,065.5	2
Cat Bi	464,808	8	410,472.5	4	585,827	6	834,299.5	7	955,200	6	490,392	−2
Vinh	535,428	6	363,863.5	7	520,689.5	7	780,170.5	8	774,976	8	239,548	2
Lien Khuong	298,806	10	185,369.5	11	365,107	9	610,637	9	605,597.5	9	306,791.5	−1
Phu Cat	209,674.5	11	149,672	12	308,799	11	555,924.5	10	595,432	10	385,757.5	−1
Tho Xuan	82,298	15	216,731.5	9	314,662	10	392,621	12	434,296.5	11	351,998.5	−4
Chu Lai	20,340.5	19	62,142	15	272,599.5	13	337,538	13	362,373.5	13	342,033	−6
Buon Ma Thuot	308,288.5	9	195,434.5	10	280,519.5	12	407,541.5	11	410,785	12	102,496.5	3
Pleiku	150,358	12	37,406	18	206,803.5	14	319,155.5	14	320,190.5	14	169,832.5	2
Can Tho	138,593.5	13	58,961	16	83,842.5	18	253,126.5	15	290,890	15	152,296.5	2
Dong Hoi	58,734.5	16	77,799	14	130,349.5	16	217,623.5	16	261,184	16	202,449.5	0
Tuy Hoa	32,098.5	18	38,442.5	17	164,155	15	167,341	17	194,061	17	161,962.5	−1
Con Dao	93,639	14	104,198.5	13	112,053	17	137,430	18	164,433	18	70,794	4
Dien Bien	40,630	17	0	20	31,526	19	32,999.5	19	23,320.5	19	−17,309.5	2
Ca Mau	15,219	20	13,841	19	15,257.5	20	15,183.5	20	16,146.5	20	927.5	0

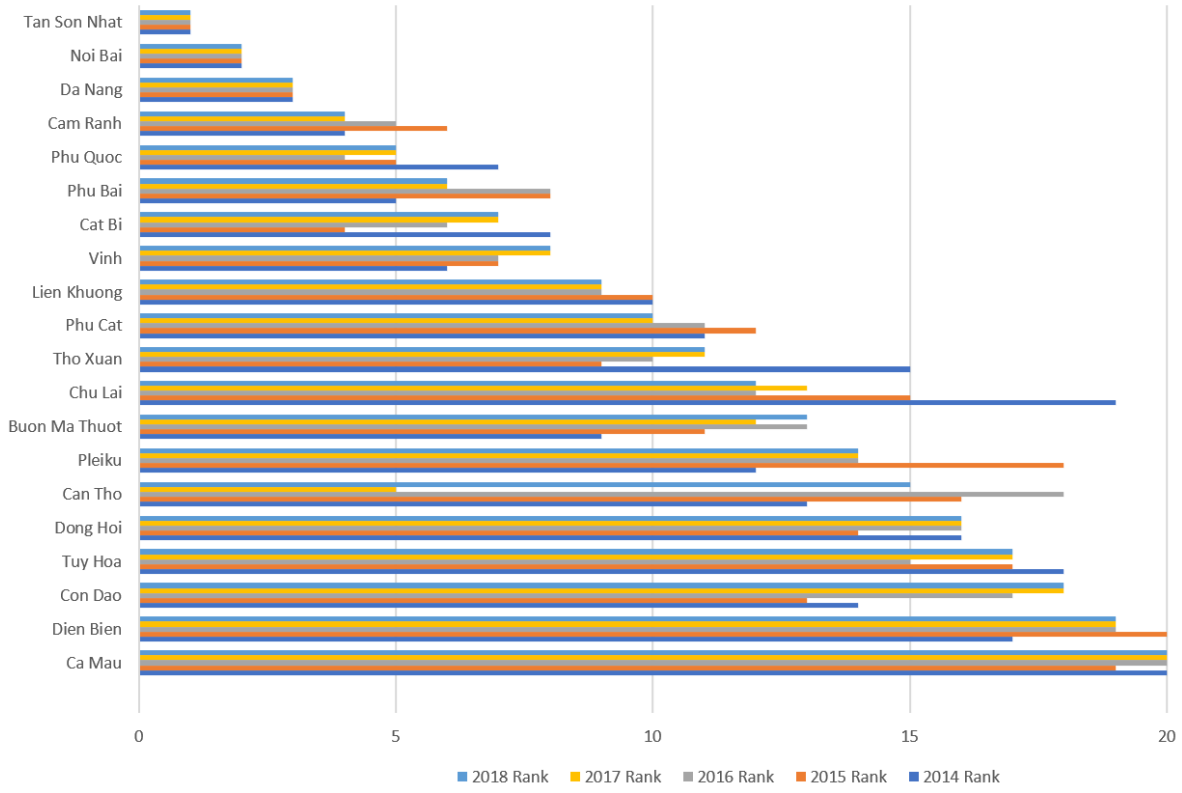

Figure 2. Bonacich (positive) centrality rank change of each airport in Vietnam.

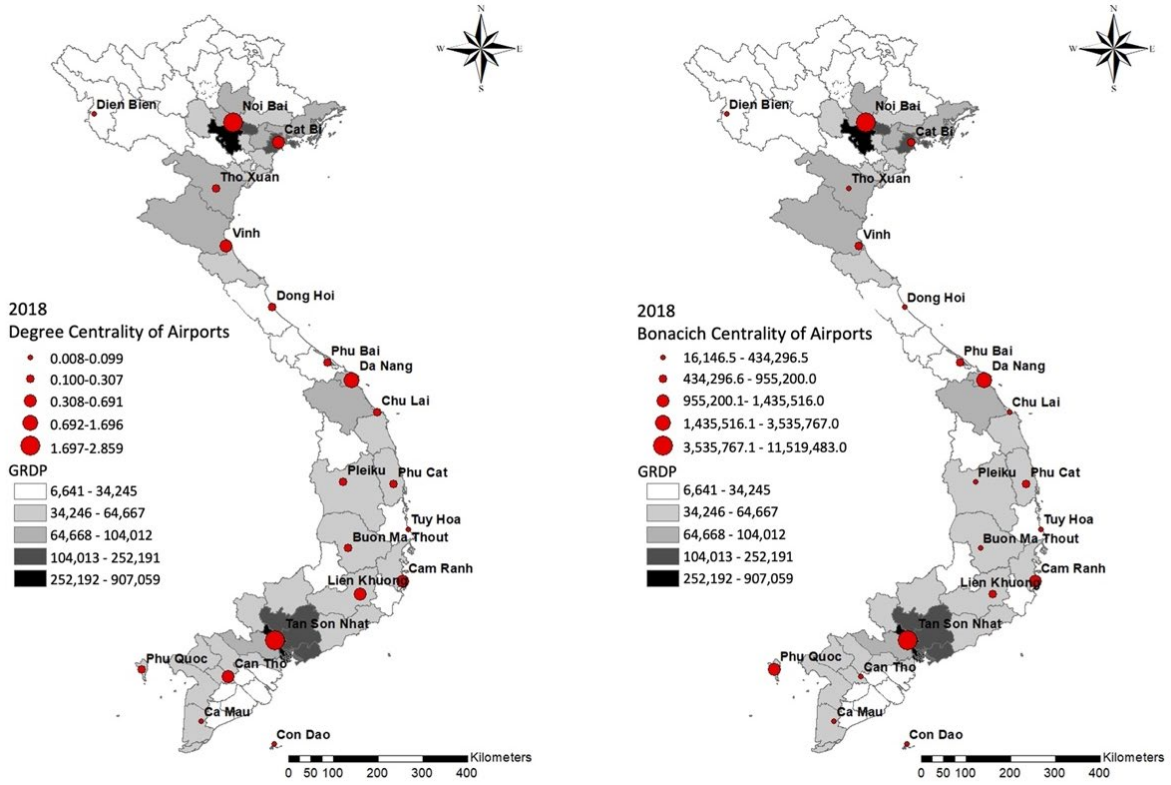

Figure 3. Mapping of centrality results of each airport with population and GRDP in 2018.

The results of the correlation tests shown in Table 3 depict a strong correlation between population density and GRDP and both centrality indicators. This also indicates a clear positive relationship between population density and economic development of an area, such as FDI, industrial products, enterprise, employment, and tourism, in relation to airport centrality.

Table 3. The correlation analysis among centralities and regional growth indicators.

	Degree Centrality	Bonacich Centrality	Population	GRDP	FDI	Industrial Product	Enterprise	Employment	Tourism
Degree Centrality	1								
Bonacich Centrality	0.960 **	1							
Population	0.901 **	0.841 **	1						
GDRP	0.965 **	0.917 **	0.961 **	1					
FDI	0.827 **	0.773 **	0.850 **	0.932 **	1				
Industrial Product	(−)0.095	(−)0.064	00.139	(−)0.076	00.139	1			
Enterprise	0.977 **	0.905 **	0.938 **	0.973 **	0.887 **	(−)0.056	1		
Employment	0.868 **	0.805 **	0.995 **	0.905 **	0.883 **	(−)0.203	0.909 **	1	
Tourism	0.952 **	0.850 **	0.876 **	0.919 **	0.848 **	(−)0.093	0.978 **	0.805 **	1

Note: ** Correlation is significant at the 0.01 level (2-tailed).

Tho Xuan retained its connection only with Tan Son Nhat, as well as the strength of the Tan Son Nhat node, indicating that attention should be paid to the relationship between Tan Son Nhat and Tho Xuan. The GRDP of Thanh Hoa (Tho Xuan airport) is more than 2.5 times more than that of Ca Mau and 9 times more than Dien Bien [59]. Excluding Ho Chi Minh City, Ha Noi, and Hai Phong, Thanh Hoa is a leading city in terms of GRDP and population. This factor is likely the reason for Tho Xuan showing a remarkable change in its ranking importance, whereas Ca Mau and Dien Bien had low centrality values and

maintained their lower rankings over the years, despite Tho Xuan operating only one route to one of the two major airports in Hanoi and Ho Chi Minh City. Moreover, although most airports were connected to the three busiest airports, Tho Xuan consistently improved its score across all three centrality indicators. These findings highlight the importance of considering passenger transfer flows between nodes in terms of population density and economic development factors. In relation to Chu Lai, Quang Nam is a province with a substantially higher GRDP and population density with economic growth factors compared to other provinces. This explained why Chu Lai showed a remarkable rise in centrality rankings, while Tuy Hoa, Phu Cat, Dong Hoi, and Vinh showed no significant changes, although Chu Lai only operated two routes to Tan Son Nhat and Noi Bai. This suggests that an airport can promote its central role in terms of positively increasing traffic volume and airline service usage because of the advantages deriving from high local population density and regional development.

5. Conclusions

This study investigated whether an air transport node in terms of its centrality could be an important indicator of where economic development needs to be better integrated with key transport infrastructures. Using centrality analysis based on O–D data concerning domestic air traffic in Vietnam from to 2014 to 2018, the following conclusions were derived.

First, SNA was found to be a reliable method in identifying the three most central airports of the domestic air traffic network in Vietnam, namely Tan Son Nhat, Noi Bai, and Da Nang, over the study period of 5 years, using centrality measurements. The consistent results in terms of the leading positions retained by these airports can be explained through their locations in the three most important economic centers and tourist hubs of Vietnam. As Vietnam's aviation industry continues to develop, aviation O–D data and SNA methods can provide key information to effectively identify not only airport centrality but also city centrality. Although India's airport network analysis depicts that airports with high centrality scores are not necessarily the ones with the highest traffic volume or the closest distances to other airports [47], the other two studies support this study's results [40,48]. The assessment of the airport network in Australia shows the high centrality of the three major Australian airports—Sydney, Brisbane, and Melbourne [40]. This outcome is similar to the study of the airport network in China, which is consistent with the network in emerging countries. The centrality approach also delivers the outstanding rankings of the three largest Chinese airports, namely Beijing, Shanghai, and Guangzhou [48]. Second, the airport network in Vietnam was found to be a reciprocal system, meaning that the actors in the system tended to operate collaboratively rather than competitively. The Vietnamese aviation industry has grown extensively—not only in certain airports over a study period of 5 years but also overall—because of the benefits deriving from the three network leaders, Tan Son Nhat, Noi Bai, and Da Nang, promoting improvement throughout the domestic network. This finding corroborates that of a recent study of air transport in Vietnam [60]. Hub airports, as Saleena et al. [38] state, are engines of economic growth because they control routes to spoke airports and generate increasing traffic flows. Third, this study clarified the relationship between air transport mobility and regional characteristics. Airports in areas of high-density population and economic development values were highly ranked and retained their rankings. Economic and residential spatial organization were linked to the spatial distribution of important airports in the national aviation network. Notably, in terms of improving rankings for certain airports, these factors need to be considered in terms of future investment because there is a " ... burgeoning demand between Tier Two cities" [60]. Cátells and Sole'-Olles [3] demonstrated the relationship between the distribution of infrastructure investment by region, emphasizing the influence of population, regional product per capita and primary and secondary sectors, and other political factors. This study reckons that localities with stable high-ranking airports are those with large populations, strong regional economies, and prioritized public investment allocation. Therefore, policymakers can optimize their

decision-making processes in relation to sustainable regional development by considering air transport mobility and network in addition to conventional socioeconomic criteria.

A limitation of this study is that it analyzes only passenger flow data, but the flow of goods may also be meaningful in understanding the dynamic growth of airports and its influence on socioeconomic factors. Therefore, future studies can include more dynamic networks by integrating logistical information concerning the flow of goods, as well as passenger flows, so that regional economic development can also be influenced through greater awareness of such diverse types of information.

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