An Evaluation of Network Competitiveness and the Effects of LCCs on South Korea’s Network Connectivity: Using Aviation Market Data

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Abstract: LCCs (low cost carriers) are expanding their routes, which is affecting airport network connectivity. The subsequent increases in market competition and the number of airlines operating in air network routes have made the centrality analysis more significant because it can be used to identify airport network connectivity competitiveness. This study analyzes the network connectivity competitiveness of South Korea among Asian airports using the MIDT (marketing information data transfer) dataset provided by OAG Traffic Analyser, which provides data collected from regional Asian airports since 2011. The network centrality of individual airports is estimated to compare network connectivity competitiveness in Asia. Measures for overall network centrality include degree, closeness and betweenness centrality. This network centrality analysis may be helpful for South Korean airports in identifying their network performance and competitive position in Asia and confirming the effects that LCCs have on airport network connectivity. The results indicate that South Korea’s aviation market needs to expand its network via a strategy that prioritizes the strengthening of airport connectivity and the pursuit of liberalization. In addition, LCC operations will support Korea’s network growth via the various strategies that they employ. Consequently, this in turn will bolster the overall market competitiveness of South Korean airports.

Key words: Air network connectivity competitiveness, network connectivity, centrality analysis, low-cost carrier effects.

1. Introduction

Recent increases in market competition and the number of airlines operating in air network routes have brought greater attention to the connectivity analysis because it can be used to identify airport network connectivity competitiveness. Connectivity analyses deliver the information necessary to design strategies to improve the competitive position of airports [1]. For example, these measures make it possible to demonstrate to what extent an airport plays a role as a connecting hub in a particular origin destination market in comparison to competing hubs [2].

Airport network connectivity is formed via the movement of products and people across a county. As such, it is a significant indicator of economic growth [2]. In addition, transportation networks are used as indicators to evaluate the socioeconomic development of countries or regions [3].

The air transport industry has experienced rapid growth, and air route networks are becoming increasingly complex. China’s air transport network has developed rapidly, and hub airports in East Asian countries are being extended to increase their competitiveness. Recently, the Asian aviation market has grown, and this growth has resulted in a high level of competition. In 2015, the Asian aviation market accounted for 34.1% of the global market share, and 24.6% of that traffic was international.

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In strategic airline management, both FSCs (full service carriers) and LCCs (low cost carriers) are significant factors that determine network structure [4]. South Korea has 16 regional airports, and LCCs now have more than 50% of the domestic market share. Moreover, because regional airports have increased the number of international routes operated by LCCs since 2011, LCCs have been able to boost their international market share from 3.5% in 2010 to 22.7% in 2015, as shown in Fig. 3.

Fig. 1  Market share of passenger traffic (international + domestic).
Source: ACI, 2015.

Fig. 2  Market share of passenger traffic (international).
Source: ACI, 2015.
LCCs have gradually changed their image in Korea. In the past, they were associated with low prices and short-distance routes. However, after recent developments such as the establishment of the Value Alliance in 2016, LCCs are increasingly recognized as long-distance options. Now, LCCs are striving to expand their routes, which will affect network connectivity in South Korea. Accordingly, big changes are expected with respect to the country’s network of airports. With that in mind, the present network centrality analysis may be helpful for South Korean airports to identify their network performance and competitive position in Asia, and to confirm the effects that LCCs are having with respect to airport network connectivity.

2. Background

Empirical studies have adopted the centrality perspective in order to evaluate the performance of airline hubs in a certain origin destination market in comparison to competing hubs [5, 6]. A number of studies have analyzed connectivity with a focus on specific countries such as the US and, more recently, China, as well as regions such as the EU. Wang et al. [7] studied the evolution and growth of the ATNC (air transport network of China) from 1930 to 2012. Their network analysis indicated that the ATNC improved its connectivity over time. Its network structure evolved
through six stages from scattered development to an emerging multi-airport system. Wang et al. [8] estimated both the network structure centrality, which included the degree distribution, average path length and clustering coefficient, and the centralities, which included the degree, closeness and betweenness of individual Chinese cities. The results showed that the structure of the ATNC was characterized by “small world” features. Jia et al. [3] analyzed the evolution of the US airport network from 1990 to 2010 from two perspectives—stable cities and new cities. They found that the US airport network preserved scale-free, small-world and disassortative mixing properties over time, and that stable cities showed regularity. Pere et al. [9] studied the role of London Heathrow and Southeast airports in providing connectivity for the UK. The authors relied on the MIDT (marketing information data transfer) dataset, and the results indicated that connectivity was dependent on foreign airlines, airports and governments.

A number of studies have analyzed network connectivity with a focus on influence factors. The network structure depends on various factors, including the size of the origin destination market, carriers’ historical background, fleet composition, strategic airline management, hub capacity and the average stage length [4]. Pere et al. [9] studied the role of London Heathrow and Southeast airports as a way of measuring network connectivity, demonstrating that increases in liberalization and the intensity of hub competition can affect connectivity. Wang et al. [8] studied the network structure of China’s air transport network. They found that centrality indices were correlated with passenger volume, population and GRDP (gross regional domestic product). The open skies agreements in multi-airport regions have given air passengers more diverse flight networks [7]. The growth of new services has resulted in larger transportation networks, which has made the market more attractive [10]. Bourghouwt and Hakfoort [11] found that the route level and hub-and-spoke network structure had developed after deregulation, which indicated that deregulation policies affected network competition. Jimenez et al. [12] studied the effects of LCCs on airport networks in Lisbon, Faro and Porto. The results indicated that LCCs affected network size, and that for new airports, network concentration had even decreased after they began operations. Burghouwt [2] provided estimates for India’s domestic airport network using a weighted network analysis and proposed that the operation of LCCs and the addition of new airports would spur India’s network growth. Accordingly, LCC operation strategies affect transport networks.

Collectively, the literature offers numerous analyses on the network centrality of airports. These analyses have attempted to determine whether small-world and scale-free characteristics existed, and they have endeavored to estimate network positions and influence factors. The results of such studies allow policy makers, airports and airlines to identify and strengthen their network performance [1]. By understanding airport network evolution characteristics, industry decision makers and/or researchers can acquire beneficial information about their own potential as well insight into the competitive positions of their counterparts [3, 13].

The present study employs the MIDT dataset provided by OAG Traffic Analyser for Asian airports to analyze the airport network. The network centrality analysis is modeled as a weighted network with cities as nodes and airlines between cities as links. This paper studies the network connectivity competitiveness and the effects of LCCs on the network connectivity of South Korea.

3. Research Methodology

Small-world networks are characterized by a very small average shortest path length (L) and a high average clustering coefficient (C) [15, 16]. The average degree of a network is denoted as the average number of neighbors that a node has in the network.
The clustering coefficient of a node is indicated as the ratio of the number of links shared by neighboring nodes to the maximum number of possible links [17].

The centrality measure is the relative importance of a node within a network. This paper estimates the degree, closeness and betweenness centrality.

3.1 Degree Centrality

The degree is the number of edges that a node shares with other nodes, which reflects the importance of the current node [18].

In this paper, the node refers to the number of arrival airport routes having flights from current airports. \( g \) is the number of nodes in the network. This is written as

\[
C_D(n_i) = \frac{d(n_i)}{g-1} \tag{1}
\]

3.2 Weighted Degree Centrality

The number of passengers is considered to include information regarding the amount of traffic flow on the network as weighted centrality. This is written as

\[
C_{WD}(n_i) = \frac{\text{number of pax}(n_i)}{g-1} \tag{2}
\]

3.3 Closeness Centrality

Closeness is defined as how close a node is to all of the other nodes along the shortest path in the set of routes. A node is deemed central if it can quickly interact with all other nodes [18]. This is written as

\[
C_c(n_i) = (g - 1) \left[ \sum_{j=1}^{g} d_{ij} \right]^{-1} \tag{3}
\]

3.4 Betweenness Centrality

Betweenness is the ratio of the nodes passing through the shortest paths. A node tends to be more powerful if it is on the shortest paths connecting many node-pairs. This indicates that the node may be in a position to broker or mediate connections between these pairs [8]. This is written as

\[
C_B(n_i) = \frac{\sum_{j,k} \left( \frac{d_{jk}(i)}{d_{jk}} \right)}{\left[ (g-1)(g-2)/2 \right]} \tag{4}
\]

4. Centrality Analysis Results of Asian Airports

This study analyzes the network connectivity competitiveness of Asian airports using the MIDT dataset provided by OAG Traffic Analyser. In particular, the dataset is mined for one-way data on Asian and South Korean airports from 2011 to 2015. Measures for the overall network centrality include degree, weighted degree, closeness and betweenness centrality. The network centrality of individual airports is estimated to compare the network competitiveness in Asia by using NetMiner 4 software.

In Table 1, the node changes, average density and clustering coefficient indicate that the network of Asian airports has increased in size since 2011.

4.1 Degree Centrality

Degree centrality is defined as the number of nodes directly pointed at by the current node [4]. In 2015, the top five Asian airports ranked by network degree centrality were SIN (Singapore Changi International Airport), BKK (Suvarnabhumi International Airport), NRT (Narita International Airport), HKG (Hong Kong International Airport), ICN (Incheon International Airport) and MLN (Manila Ninoy Aquino International Airport), in that order.

In terms of international network degree centrality, SIN and BKK were ranked lower than HKG despite the fact that SIN and BKK appeared higher than HKG on the list of total network degree centrality rankings. This suggests that the Southeast Asian airport market achieved a large amount of latent competitiveness after developing its international network.

4.2 Weighted Degree Centrality

The weighted centrality index includes information on the amount of traffic flow in the network, indicated by the thickness of the link. In general, because the number of passengers is not reflected in the degree centrality index, airports operating smaller numbers of
routes rank lower even if they process large numbers of passengers. Bagler [19] constructed a weighted network that considered the number of flights that defined the strengths of the links. Bagler’s network also represented each airport’s connectivity architecture. In 2015, PEK ranked first on the total network weighted degree centrality index, which was influenced by the number of passengers (90 million in 2015). PEK’s domestic market share was higher than its international market share. Thus, on the international weighted degree centrality index, PEK ranked ninth. It is assumed that at present, PEK’s ranking in terms of the weighted degree centrality index has improved due to China’s efforts to increase its international network. For HKG and SIN, on the other hand, 100% of the air traffic is international, and this is reflected in their rankings for the weighted degree centrality index.

4.3 Closeness Centrality

The closeness centrality index focuses on how short the distance is between the self-node and all of the other nodes. However, it also lists the SPL (shortest path length). This value represents the minimum number of steps needed to connect nodes [20]. In 2015, in terms of the total network closeness centrality rankings, the top six airports were SIN, BKK, NRT, HJK, ICN and MNL. This shows that SIN, NRT, BKK and HKG have a geographical advantage, enabling easier connections with other countries.

4.4 Betweenness Centrality

The betweenness centrality index indicates the degree of power that an airport wields to broker or mediate connections between the shortest paths connecting node-pairs. In 2015, in terms of the total
network betweenness centrality rankings, the top six airports were NRT, BKK, SIN, MNL, DEL and ICN. From 2011 to 2015, MNL climbed the rankings because more passengers were flying in and out of the country.

This paper also conducts a correlation analysis between the number of transfer passengers and centralities by using data on the domestic and international transfer passengers at NRT, BKK, SIN, BKK, ICN, HKG and other airports. The results indicate that the correlation between the number of transfer passengers and centrality, including degree, closeness and betweenness, is statistically significant in the positive (+) direction, as shown in Table 6. In particular, among these parameters, the betweenness centrality has the strongest correlation with the number of transfer passengers.

Accordingly, the competition to improve betweenness centrality increased between 2011 and 2015. In other words, the trend indicates that the competition among airports in Asia will increase significantly. The Japanese and Chinese governments intend to extend their international connection networks to serve as Asian hubs. Therefore, it is necessary for ICN to make efforts to strengthen the competitiveness of Korean airports.

### Table 3  Top 10 airports by weighted degree centrality index.

| Rank | Total (Inter. + Dom.) network | International network |
|------|-------------------------------|-----------------------|
|      | 2011                          | 2015                  | 2011                          | 2015                  |
|      | Airport | Weighted degree centrality index | Airport | Weighted degree centrality index | Airport | Weighted degree centrality index | Airport | Weighted degree centrality index |
| 1    | PEK     | 22,490                          | PEK     | 27,563                          | HKG     | 11,765                          | HKG     | 15,357                          |
| 2    | HND     | 17,851                          | HND     | 19,931                          | SIN     | 10,950                          | SIN     | 13,859                          |
| 3    | CGK     | 15,301                          | CGK     | 18,226                          | ICN     | 8,830                           | ICN     | 12,901                          |
| 4    | CAN     | 13,678                          | PVG     | 17,419                          | BKK     | 8,031                           | TPE     | 11,299                          |
| 5    | HKG     | 13,425                          | CAN     | 16,530                          | TPE     | 7,555                           | BKK     | 10,766                          |
| 6    | SIN     | 12,494                          | HKG     | 15,173                          | KUL     | 5,993                           | KUL     | 8,627                           |
| 7    | BKK     | 12,285                          | SIN     | 13,693                          | NRT     | 5,772                           | PVG     | 8,044                           |
| 8    | PVG     | 11,937                          | SZX     | 13,353                          | PVG     | 5,110                           | NRT     | 6,924                           |
| 9    | SHA     | 11,042                          | SHA     | 13,144                          | PEK     | 4,128                           | PEK     | 5,668                           |
| 10   | DEL     | 10,735                          | CTU     | 12,963                          | MNL     | 3,386                           | KIX     | 5,176                           |

### Table 4  Top 10 airports by closeness centrality index.

| Rank | Total (Inter. + Dom.) network | International network |
|------|-------------------------------|-----------------------|
|      | 2011                          | 2015                  | 2011                          | 2015                  |
|      | Airport | Closeness centrality index | Airport | Closeness centrality index | Airport | Closeness centrality index | Airport | Closeness centrality index |
| 1    | HKG     | 0.7028                          | SIN     | 0.700                          | HKG     | 0.597                          | SIN     | 0.694                          |
| 2    | PEK     | 0.6892                          | BKK     | 0.700                          | SIN     | 0.584                          | BKK     | 0.689                          |
| 3    | BKK     | 0.6888                          | NRT     | 0.696                          | BKK     | 0.579                          | HKG     | 0.687                          |
| 4    | SIN     | 0.6878                          | HKG     | 0.695                          | NRT     | 0.575                          | ICN     | 0.681                          |
| 5    | NRT     | 0.6860                          | ICN     | 0.690                          | ICN     | 0.574                          | NRT     | 0.679                          |
| 6    | ICN     | 0.6791                          | MNL     | 0.687                          | PEK     | 0.556                          | MNL     | 0.671                          |
| 7    | PVG     | 0.6487                          | PEK     | 0.675                          | DEL     | 0.528                          | DEL     | 0.648                          |
| 8    | DEL     | 0.6449                          | PVG     | 0.674                          | PVG     | 0.522                          | KUL     | 0.643                          |
| 9    | BOM     | 0.6247                          | DEL     | 0.673                          | KUL     | 0.517                          | PEK     | 0.630                          |
| 10   | KUL     | 0.6203                          | KUL     | 0.656                          | BOM     | 0.510                          | PVG     | 0.630                          |
Table 5  Top 10 airports by betweenness centrality index.

| Rank | Total (Inter. + Dom.) network | International network |
|------|-----------------------------|----------------------|
|      | 2011 | 2015 | Betweenness centrality | 2011 | 2015 | Betweenness centrality |
|      | 2011 | 2015 | index | 2011 | 2015 | index |
| 1    | HKG  | 0.099| NRT  | 0.069| HKG  | 0.078| NRT  | 0.057|
| 2    | PEK  | 0.086| BKK  | 0.058| NRT  | 0.062| SIN  | 0.054|
| 3    | NRT  | 0.083| SIN  | 0.056| BKK  | 0.061| BKK  | 0.051|
| 4    | BKK  | 0.082| MNL  | 0.051| SIN  | 0.056| ICN  | 0.044|
| 5    | SIN  | 0.070| DEL  | 0.050| PEK  | 0.054| HKG  | 0.043|
| 6    | ICN  | 0.065| ICN  | 0.050| ICN  | 0.050| MNL  | 0.041|
| 7    | DEL  | 0.058| HKG  | 0.047| DEL  | 0.041| DEL  | 0.040|
| 8    | BOM  | 0.048| BOM  | 0.037| BOM  | 0.032| BOM  | 0.029|
| 9    | PVG  | 0.035| PEK  | 0.036| PVG  | 0.022| PEK  | 0.025|
| 10   | KUL  | 0.030| PVG  | 0.035| KUL  | 0.022| PVG  | 0.025|

Table 6  Correlation analysis results.

|                  | Number of transfer passengers | Degree centrality | Closeness centrality | Betweenness centrality |
|------------------|-------------------------------|-------------------|----------------------|------------------------|
| Number of transfer passengers | 1    | .803** | .800** | .873** |
| Degree centrality   | 0.803** | 1    | 0.966** | 0.855** |
| Closeness centrality | 0.800** | 0.966** | 1    | 0.863** |
| Betweenness centrality | 0.873** | 0.855** | 0.863** | 1    |

Source: OAG Traffic Analyser, 2014.
* p < 0.05, ** p < 0.01, *** p < 0.001.

5. Discussion

5.1 Centrality Analysis Results of South Korean Airports

In South Korea, there are 16 airports. Regional airports in the country have been increasing the number of international routes operated by LCCs since 2011. LCCs are striving to expand their routes, which affects Korea’s airport network connectivity, as shown in Fig. 5. Accordingly, big changes are expected for Korea’s airport network. In this paper, the centralities are estimated to compare the network competitiveness of individual airports in South Korea with cities as nodes. The effects of LCCs on airport network connectivity are also estimated. The centrality analysis, including the degree, weighted degree, closeness and betweenness centrality of airports, is estimated to compare network competitiveness.

The emergence of LCCs has resulted in route level changes in South Korean airports, with LCCs taking on more domestic and international routes. As a result, airports are being influenced by LCC market strategies. Recently, regional airports such as PUS, TAE and CJU have begun operating more international routes. In terms of network degree centrality, these three airports, as well as other South Korean airports, have increased their total route numbers based on the extension of LCC routes, and this has affected the node characteristics of each airport, as shown in Table 7.

The closeness centrality rankings prioritize airports based on the shortest paths connecting node-pairs. The betweenness centrality ranking indicates nodes that are in a position to broker or mediate connections between network pairs. As the number of routes in an airport increases, their nodes close in on other nodes and pass through shorter paths. Accordingly, it is possible for each airport to increase its closeness centrality and betweenness centrality rankings. For instance, CJU and TAE operate short routes between
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Fig. 5 LCC market share of regional airports for international routes.
Source: OAG Traffic Analyser, 2011-2015.

Table 7 Degree centrality ranking of South Korean airports.

| Airport | 2011 | 2015 | △Ranking | 2011 | 2015 | △Ranking |
|---------|------|------|----------|------|------|----------|
| ICN     | 6    | 5    | 1        | ICN  | 5    | 0        |
| PUS     | 35   | 24   | 11       | PUS  | 32   | 9        |
| GMP     | 107  | 109  | -2       | GMP  | 80   | -14      |
| CJU     | 133  | 98   | 35       | CJU  | 108  | 86       |
| TAE     | 165  | 99   | 66       | TAE  | 134  | 51       |
self-nodes and other nodes operated by LCCs.

5.2 Effects of LCCs on the Network of South Korean Airports

Since 2011, airports have opened more LCC-operated international routes, and thus, the total number of LCC routes has increased, as shown in Table 10. At ICN, LCC-operated routes increased in number from 124 in 2011 to 181 in 2015 (an increase of 57 routes). CJU and TAE added 23 and 33 routes, respectively, over the same time period. However, GMP added just one route because its decision-making in this regard was influenced by government policy.

The penetration of LCCs into the South Korean market resulted in a change at the route level, as shown in Fig. 6. The total network and international network had expanded significantly by 2015. This expansion was influenced by the route strategies of the LCCs, including point-to-point flights, new destinations and low price strategies in regional airports, which propelled growth in terms of network size [12]. In addition, it has been shown that LCCs contribute significantly to increases in passenger latency in a given region [21]. Therefore, it is reasonable to assume that liberalization is necessary in order to attract greater numbers of latent passengers.

The network structure depends on various factors, including the size of the origin destination market, carriers’ historical background, fleet composition, strategic airline management, hub capacity and the average stage length [4]. This study is limited in its reliance on factor effects in the centrality analysis. For example, centrality rankings are analyzed without considering additional factors. This point should be considered in future studies.

Table 8  Closeness centrality ranking of South Korean airports.

| Airport | 2011 | 2015 | △Ranking | Airport | 2011 | 2015 | △Ranking |
|---------|------|------|----------|---------|------|------|----------|
| ICN     | 6    | 5    | 1        | ICN     | 5    | 4    | 1        |
| PUS     | 35   | 24   | 11       | PUS     | 35   | 23   | 12       |
| GMP     | 123  | 115  | 8        | GMP     | 87   | 94   | -7       |
| CJU     | 148  | 95   | 53       | CJU     | 113  | 85   | 28       |
| TAE     | 186  | 100  | 86       | TAE     | 152  | 86   | 66       |

Table 9  Betweeness centrality ranking of South Korean airports.

| Airport | 2011 | 2015 | △Ranking | Airport | 2011 | 2015 | △Ranking |
|---------|------|------|----------|---------|------|------|----------|
| ICN     | 6    | 6    | 0        | ICN     | 6    | 4    | 2        |
| PUS     | 65   | 32   | 33       | PUS     | 44   | 26   | 18       |
| GMP     | 168  | 171  | -3       | GMP     | 128  | 100  | 28       |
| CJU     | 189  | 158  | 31       | CJU     | 135  | 134  | 1        |
| TAE     | 305  | 172  | 133      | TAE     | 205  | 127  | 78       |

Table 10  Route development of LCCs in South Korean airports.

| Airport | 2011 | 2015 |
|---------|------|------|
| ICN     | 124  | ICN  | 181  |
| PUS     | 125  | PUS  | 139  |
| GMP     | 31   | GMP  | 32   |
| CJU     | 51   | CJU  | 74   |
| TAE     | 10   | TAE  | 43   |
6. Conclusion

This study analyzed the network competitiveness of airports in Asia using OAG data for regional Asian airports between 2011 and 2015. The network centrality of individual airports was estimated to investigate network competitiveness in Asia. The network centrality measure allows policy makers and industry professionals to benchmark and monitor the network performance against that of other airports and airline networks [1, 3]. Furthermore, the results of the centrality measures will allow policy makers, airports and airlines to monitor and maintain or enhance network performance over time [1]. Such analyses may be helpful for South Korean airports to identify their network performance and competitive position in Asia and to confirm the effects that LCCs have on airport network connectivity in the evolution of the network over time.

The results of the present analysis indicated that the weighted centrality reflected real traffic flows. In terms of total weighted centrality, PEK and HND were highly ranked in spite of other centralities achieving lower rankings. This indicated that they possessed large latent competitiveness in terms of network centrality, as evidenced by their efforts to extend their international
networks. In addition, in terms of network centrality, ICN was competing with SIN, BKK, HKG, NRT, MNL and PEK. This made it clear that South Korea’s aviation market also needs to expand its network via a strategy that prioritizes the strengthening of airport connectivity and the pursuit of liberalization. In addition, LCC operations will further spur the growth of Korea’s network via the variety of strategies that they employ. Consequently, this in turn will bolster the overall market competitiveness of South Korean airports.

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