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# Spatial network configurations of cargo airlines

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## **Abstract**

The paper evaluates the spatial dimension of air cargo networks by means of concentration and centrality measures. Three groups of carriers are analyzed, namely combined carriers, their pure freighter operations and pure cargo airlines. Differences in their spatial network configuration are observed between the three groups. Combined carriers operate very centralized networks with high concentrations at a small number of airports. Hub-and-spoke schemes are their predominant network configuration. The freighter fleets of combined carriers have lower centrality and concentration scores but hub-and-spoke schemes are still the predominant network configuration. Pure cargo airlines operate the least concentrated and centralized networks. Round-trip configurations are wide spread among pure cargo airlines to cope with imbalances of demand.

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Keywords: Air cargo transport, network configuration, centrality, spatial network configuration.

## 1. Introduction

In the past decades air cargo volumes have strongly been linked to trade growth and have even outpaced the growth rate of worldwide GDP between 1.5 and 2 times. Freight tons transported by air rose between 1995 and 2007 by more than 5% annually. Major contributors to the increase in air cargo were the markets between Europe and Asia, Europe and North America as well as Latin America and North America.

Things changed dramatically in 2008. The worldwide production halt in various industries and a strong reduction of international trade has hit the entire logistics business but especially the air cargo industry. In December 2008 worldwide air cargo plunged by 22.6% compared with the same month of 2007, which was a sharper reduction than in September 2001, where most of the fleet stayed on ground for days (IATA, 2009). Airlines reacted differently to the crises: Tesis airlines went into insolvency by end of 2008, Atlas Air proposed the retirement of older aircrafts whereas Lufthansa Cargo grounded freighters and cut employee hours as it adapted to declining demand.

Independent from the business strategy of airlines, efficiency plays an increasing role in the aviation market under pressure. Efficiency can be interpreted in two ways, cost efficiency and price efficiency, which both affect overall efficiency of an airline. Price efficiency depends on the cost structure of the airline but is strongly influenced by the market's competition (exogenous factors). IATA price tables still exist but can only be charged in non-competitive markets (monopoly). However, cost efficiency can be influenced by the carrier endogenously. A key factor for efficiency is a cost minimizing network configuration for the airline.

Motivated by the under-researched state of cargo network structures, the (expected) long-term growth rates and the future challenges (e.g. over-capacities, reduced yields), this paper focuses on the spatial network configuration of non-integrated cargo carriers. It is organized as follows: After a short introduction to the research area, a literature review on network structures is given including an introduction to the indicators which will be applied to analyze network configurations. The third section discusses selected network structures and examines their impact on the chosen indicators. Section four explains the selection of carriers and describes the data sources. The core of the present paper is section five which analyzes the spatial network configuration of cargo carriers. Finally, the sixth section concludes the paper.

## 2. Network structure and its spatial concentration measures

Hub-and-spoke (H&S) network configurations require a concentration of air traffic in space and time (Reynolds-Feighan, 2001). Burghouwt and de Wit (2003) analyzed the spatial concentration of passenger airline networks by the level of traffic concentration at the airline's major airports. Summary measures, such as the Gini-Index, have been used to assess the spatial importance of single airports for the

entire network. Regarding temporal concentration, the existence of synchronized waves of flights through the airline's hubs is assessed (Graham, 1995; Reynolds-Feighan, 2000; Burghouwt et al., 2003). The more indirect connections at a hub exist, the higher is the temporal concentration of traffic at the hub. The aim of spatially and temporally concentrated networks is to optimize the number and quality of connections offered (Burghouwt, 2007). Research has so far been focused solely on networks of passenger airlines.

The paper at hand tries to fill this gap by analyzing cargo carrier's network configurations. Therefore, two families of indices are calculated, namely concentration and centrality measures. As concentration measures the Herfindahl-Index (HI), the concentration-ratio ( $CR_k$ ) and the Gini-Index (GI) are used whereas betweenness centrality ( $C_B$ ) is calculated as centrality index.

1. The *Herfindahl-Index* (HI) of an airline's network is computed as

$$HI = \sum_{i=1}^n s_i^2$$

where  $s_i$  is the share of air traffic at airport  $i$  in relation to the total traffic of the airline,  $n$  is the number of airports in the network.

The HI takes into account the relative size and the distribution of traffic in the market. It is size dependent and its minimum for a fixed number of actors is achieved in case of equal shares resulting in a value of  $1/n$ . Furthermore, the HI is sensitive for changes in the extremes, thus a property of the square-function which gives high weights to the largest airports. The HI is the most frequently used measure of market concentration. Since 1982, the index plays a central role in the US Justice Department's merger guidelines (e.g. Rhoades, 1993).

2. The *concentration-ratio* ( $CR_k$ ) is the fraction of the airline's network held by the largest  $k$  airports.

$$CR(k) = \sum_{i=1}^k s_i$$

The CR is a single point on the concentration curve, neglects the rest of the traffic distribution and has a range between 0 and 1 (Hall, 1967). Its value only changes when the largest  $k$  airports are affected.  $CR_1$  and  $CR_3$  are calculated in the paper to analyze the concentration of the major airports and their importance for the entire network.

3. The *Gini-Index* (GI) is a measure of inequality and is computed for an air carrier as

$$GI = \left( \frac{2 * \sum_{i=1}^n i * x_i}{n * \sum_{i=1}^n x_i} - \frac{(n+1)}{n} \right)$$

where airports are ranked according to their number of flights so that  $x_i$  is decreasing in  $i$ .

Coming from income analyzes, GI has been adopted to other questions. In the air freight industry GI can be interpreted as follows: The smaller GI, the more equal the airline distributes its traffic to the airports. In other words, a large index means that the airline focuses on few airports only. The GI increases with the number of airports in a network and is therefore size dependent. Assuming that the total incoming flights equal the outgoing flights, the theoretical maximum value of GI (GI=1) can never be achieved and that no airport will have more than half the total traffic (Burghouwt et al., 2003). Therefore, the Gini index cannot reach its theoretical maximum value of 1 and comparisons between different airline networks are complicated and not intuitive.

The maximum value for GI in the airline sector is dependent on the market size and can be computed as (Burghouwt et al., 2003):

$$GI_{\max} = \frac{(n-2)}{n}$$

The standardized Gini-coefficient (GI\*) equals the observed Gini-Index (GI) divided by its maximum value (GI<sub>max</sub>). GI\* guarantees that the spatial concentration of airline networks independent of their sizes can be compared. GI\* ranges from 0 to 1.

4. *Betweenness-centrality* (C<sub>B</sub>): Airports (nodes) that are located between pairs of other airports (nodes) have a structural advantage as passengers and goods need to be transferred at such airports. Such airports are characterized as central airports. In the late 1970s Freeman introduced a family of network measures which are based on the concept of centrality.

In graph theory, the geodesic distance between two nodes is defined as the length of the shortest path between them whereas its length is defined as the number of intermediate stops (Alderighi, et al. 2007). The betweenness centrality C<sub>B</sub> of airport  $i$  requires the evaluation of all geodesic paths within the network and is calculated as follows:

$$C_B(i) = \sum_{j < k} \sum_{j < k} b_{jk}(i)$$

with

$$b_{jk}(i) = \frac{g_{jk}(i)}{g_{jk}}$$

where  $g_{jk}$  is the number of geodesics linking airport  $j$  with airport  $k$ , and  $g_{jk}(i)$  is the number of geodesics that pass by airport  $i$  (transfer airport). The centrality of airport  $i$  ( $C_B(i)$ ) is the sum of all  $b_{jk}$  values for all unordered pairs of points where  $j < k$  and  $i \neq j \neq k$ .

Freeman's centrality index of a network is defined as the average difference between the relative centrality of the most central airport  $C_B(i^*)$  and that of all other airports within the network ( $i^*: C_B(i^*) \geq C_B(i)$  for all  $i$ ).

$$C_B = \left( \frac{\sum_{i=1}^n [C_B(i^*) - C_B(i)]}{(n^3 - 4n^2 + 5n - 2)} \right)$$

Betweenness centrality measures the network configuration as a percentage of a perfect star network which is found in aviation by a perfect H&S network configuration. Therefore, the concept of betweenness has been chosen for analysis to measure the similarity of the airline's network to a perfect H&S configuration.

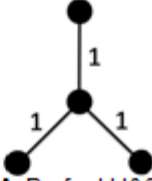
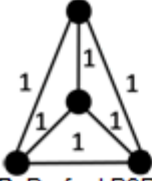
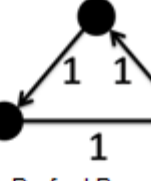
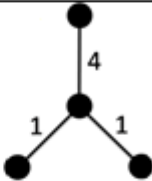
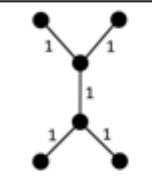
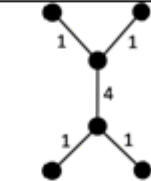
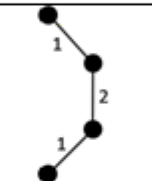
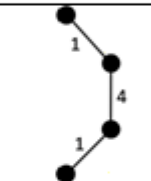
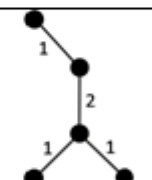
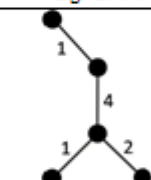
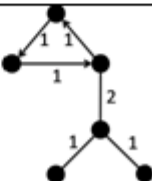
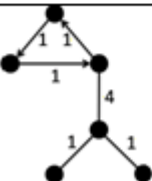
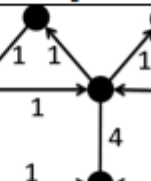
Freeman's measurement is based on the assumption that flows pass from one airport to another only along the shortest paths. Alderight et al. (2007) argue that the index is suitable when analyzing spatial economic behavior as it assigns a high centrality to airports that are more often visited by shortest paths. The airport which is best located within the airline's network has the minimum distances to the other airports and thus is more attractive to customers because shortest paths minimize network costs.

### 3. Network configurations in the airline industry

Since deregulation of the US airline industry in 1978, hub-and-spoke networks (H&S) emerged as the major network configuration of full-service passenger airlines. The advantage of a H&S structure is its efficiency for operating large networks by maximizing the number of destinations under the restrictions of the airline's capacity (TRB, 1991). This contrasts Point-to-Point (P2P) network configurations which became widespread with the entrant of low-cost carriers. Direct services are offered to reduce travel time for passengers. Beside these two perfect network structures, a large number of mixed structures exist especially in freight transport. Liedtke (2006) analyzed the behavior for road freight transport and found out that round-trips are the most common distribution structures.

Table 1 displays examples of network structures and demonstrates their performance concerning the above-mentioned indices.

Table 1: Results of the indices for combined carriers

1. Category: Perfect configurations	 <p>A: Perfect H&amp;S GI*=0.5 HI=0.33 C<sub>B</sub>=1.0</p>	 <p>B: Perfect P2P GI*=0.0 HI=0.25 C<sub>B</sub>=0.0</p>	 <p>C: Perfect Round-trip GI*=0.0 HI=0.33 C<sub>B</sub>=0.0</p>
2. Category: H&S configurations	 <p>D: H&amp;S w concentration at one spoke GI*=0.75 HI=0.38 C<sub>B</sub>=1.0</p>	 <p>E: Multi-H&amp;S GI*=0.4 HI=0.22 C<sub>B</sub>=0.56</p>	 <p>F: Multi-H&amp;S w concentration between hubs GI*=0.63 HI=0.3 C<sub>B</sub>=0.56</p>
3. Category: Linear network configurations	 <p>G: Linear network GI*=0.5 HI=0.31 C<sub>B</sub>=0.44</p>		 <p>H: Linear network w concentration between hubs GI*=0.67 HI=0.36 C<sub>B</sub>=0.44</p>
4. Category: Mixed configurations of H&S and linear configurations	 <p>I: H&amp;S w linear component GI*=0.53 HI=0.28 C<sub>B</sub>=0.71</p>		 <p>K: H&amp;S w linear component and concentration at one spoke GI*=0.67 HI=0.31 C<sub>B</sub>=0.71</p>
5. Category: Mixed configuration of H&S and round-trip configurations	 <p>L: H&amp;S w round-trip at one hub GI*=0.48 HI=0.24 C<sub>B</sub>=0.49</p>	 <p>M: H&amp;S w round-trip at one hub and concentration between hubs GI*=0.62 HI=0.29 C<sub>B</sub>=0.49</p>	 <p>N: H&amp;S w round-trips at all spokes GI*=0.5 HI=0.2 C<sub>B</sub>=0.47</p>



Generally, the greater the index, the more concentrated, respectively centralized is the network configuration of the airline.  $GI^*$  as well as the centrality measure takes value 0 in case of a *perfect P2P* or in case of a *perfect round-trip* structure where all destinations are served equally. With a *perfect H&S*, the  $GI^*$  assumes the value 0.5 and 1.0 for the betweenness centrality index indicating a supreme central airport within the network, namely the hub.

*H&S* configurations have higher  $GI^*$  concentrations and also comparatively high HI values whereas the centrality score varies significantly between one hub and multi-hub configurations. In case of a pure single hub network all available relations pass by the hub whereas for a multi hub network, shortest paths exist where only one of the two hubs is used as transfer point. This leads to much lower centrality scores for multi-hub network structures. Both concentration indices illustrate the importance of the hub airport in a H&S network scheme with high concentration values.

*Linear network* configurations are characterized by smaller centrality scores than for the other network structures except the perfect P2P and the perfect round-trip structures. No hubbing activities are offered that concentrate and centralize flight activities at one airport. This results in lower scores than for most other network configurations.

*Mixed configurations* based on a H&S scheme with linear elements show their mixed natures also in the index scores. Centrality is less distinct than for most other H&S configurations because of the linear component of the network configuration whereas concentration measures signalize higher importance of major airports for the entire network.

*Round-trip configurations* can be characterized by comparatively low centrality as well as concentration values. The higher the importance of a single link within the network, the higher is the concentration level for the entire network ( $GI^*$  and HI). Centrality measure identifies the round-trip configuration but do not serve as a valuable indicator for detecting differences within the category.

Summarizing the observations from the examples and from the literature, some general conclusions can be drawn:

- the Gini index is more volatile than the Herfindahl index making the index sensitive to changes in the network traffic distribution,
- the Gini and the Herfindahl index are affected by the frequencies and their distribution within the network (see network G versus network H),
- the Gini index satisfies the axioms of monotonicity, of transfer and of relative equity as well as the ordinal weight axiom as shown by Reynolds-Feighan (2001) but the index fails to detect the spatial morphology of the network (see network B versus network C),
- the concentration ratio evaluates the importance of individual airports for the entire network,

- betweenness centrality measures the shape of the network (morphology) (Alderighi, 2007),
- reference configurations are the perfect P2P ( $C_B=0$ ) and the perfect H&S ( $C_B=1$ ) structure,
- all other configurations are measured as the degree of inequality with respect to the pure H&S network structure (Alderighi, 2007),
- betweenness centrality fails to measure the concentration of frequencies.

#### 4. Data and selection of cargo carriers

Data of the Official Airline Guide (OAG) for the year 2007 have been chosen for analysis. In contrast to other studies, flights over the whole year instead of one representative week are considered. Air cargo has a very high volatility during the year with demand peaks between November and March and much less demand in the rest of the year. Therefore, data of the entire year are analyzed to avoid data tilts.

The analysis focuses on the routes operated under the International Air Transport Association (IATA). This means that every flight with an official flight number is included in the sample. Flights with one (or more) en-route stops are recorded for each of the sector separately (e.g. LH8370 from FRA to ICN via TSE is recorded as FRA-TSE, TSE-ICN<sup>1</sup>). Variables include departure airport, destination airport, carrier code, service classification, flight period, days of operation and maximum possible freight tons.

Code-share flights have only been assigned to the operating airline to exclude double-counting. The analysis focuses on data where freight ton information of the flight is available and is unequal zero. This guarantees that only flights and airplanes which have the ability to transport cargo are considered for the analysis. Finally, Road Feeder Services (RFS) were excluded from the analysis because the paper focuses on the air side network structure of the airlines. Furthermore, data on RFS are incomplete in the database for some analyzed carriers which would lead to biased conclusions.

The present paper uses frequencies per year as the variable for air traffic of the airline's network. Burghouwt et al. (2003) suggest analyzing the number of seats per time instead of the frequencies. This could have been easily adapted to the cargo sector by choosing freight tons per time, hold volumes or a combination of both. Contrarily, Alderighi et al. (2007) recommends using the number of flights to reduce the impacts of passenger demand adaptation changes of the year. The author of the present paper also advocates using frequencies per time because of the dynamics of demand over the year which determines the optimal aircraft size. A change in demand may lead to an adaptation of the aircraft size, especially for passenger flights which determines belly capacity, but weekly frequencies usually remain fixed as slots are very valuable at major cargo airports worldwide.

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<sup>1</sup> IATA codes and their respective airports are displayed in Annex A.

In order to analyze network configurations in the air cargo sector, three groups of carriers have been distinguished, namely combined carriers (e.g. Lufthansa), their pure freighter fleet (cargo brands) and pure freighter airlines (e.g. Cargolux). *Table 2* displays the distinctive features of the three airline groups.

Table 2: Analyzed groups of air cargo carriers

	<b>Primary business</b>	<b>Fleet structure</b>	<b>Cargo capacity from</b>	<b>Selected carriers for analysis</b>
<b>Combined carriers</b>	Passenger transport	Very heterogeneous (pure freighters optionally)	Belly capacity of passenger aircrafts and optionally from pure freighter	Air France (AF), China Airlines (CI), Cathay Pacific (CX), Korean Air (KE), Lufthansa (LH), Singapore Airlines (SQ).
<b>Cargo brands</b> (Freighter fleet of combined carriers)	Cargo transport	Pure freighter aircrafts	Freighter fleet	Air France Cargo, China Airlines Cargo, Cathay Pacific Cargo, Korean Air Cargo, Lufthansa Cargo, Singapore Airlines Cargo.
<b>Pure freighter airlines</b>	Cargo transport	Pure freighter aircrafts	Freighter fleet	China Airlines (CK), CargoLux (CV), ABX Air (GB), Nippon Air Cargo (KZ), Varig Logistica (LC), Polar Air (PO).

The distinction between the three groups of cargo airlines has been made in order to analyze differences between the network configuration of pure freighter airlines and combined carriers where passenger business still plays the major role (highest priority). Therefore, the following questions will be answered: Is the network structure of the combined carrier also reflected in the network configuration of its cargo brand? Or is it similar to the configurations of pure freighter airlines? Statistical analyses are not possible with the existing dataset because of the small number of airlines within each airline category that conclusions are drawn from the differences in the analyzed indices.

## 5. Analysis of traffic distributions

### ***Combined carriers***

The results of the five indices for *combined carriers* are displayed in Figure 1. The Gini index (GI\*) varies between 0.70 (Singapore Airlines and Air France) and 0.81 (Korean Airlines) resulting in a mean value of 0.74. A high GI\* indicates an unequal

spread of traffic in the network. Such high scores are observed for hub-and-spoke schemes (H&S) with one (or a few) major airports (hubs) plus a large number of spoke airports connected to the hub.

The highest concentrations of traffic frequencies exist at the carriers' major passenger hubs (AF: 0.46 at CDG, SQ: 0.42 at SIN, CI: 0.37 at TPE). This result is not surprising as more than half of world air cargo is still transported as belly freight in passenger aircrafts.

The HI underlines the results of GI\* but with higher variations between the airlines. The average score is 0.16. Following the recommendations of the US Federal Trade Department, a market is concentrated when HI is above 0.18 which is true for AF (0.21) and SQ (0.19). An unconcentrated network structure ( $HI < 0.10$ ) exists only for LH (0.09) whereas CI (0.16), CX (0.17) and KE (0.11) indicate moderate concentrations ( $0.10 \leq HI \leq 0.18$ ). Within the category of combined airlines, AF and SQ have the highest shares of cargo traffic at their passenger hubs. Because of the square-function property of the HI, extensive weights are given to these airports resulting in a high HI for AF and SQ. LH and KE have only half the traffic shares as AF and SQ at their passenger hubs which explain the much lower HI.

CR3 is used as an index for analyzing the importance of the three largest airports within the network and to identify cargo hubs of the airline. The average fraction of the three largest airports for the combined carriers is 0.51 which denotes that 51% of the total flight activities are bundled at the three largest airports. The highest fraction can be observed for China Airlines (0.55) with its three major airports Taipei (TPE), Hong Kong (HKG) and Anchorage (ANC) whereas Lufthansa has the lowest fraction with 0.44 (FRA, MUC, DUS). The marginal difference between the largest and the three largest airports (CR3) within the network show that the focus for combined airlines is on their major airport (hub). Much lower shares can be observed for the second and third largest airport.

The betweenness approach expresses the degree of centrality of the network. This measure takes its maximum of 1 for a star structure which can be interpreted as a perfect H&S scheme in aviation. Its minimum of 0 is achieved for a complete graph which stands for a perfect P2P configuration. The betweenness centrality measure underlines the observation of the concentration indices: combined carriers operate H&S networks also for freight transport.

AF scores highest with 0.99 and detects CDG as its most central airport. CDG also scores 0.99, followed by the much smaller centrality value for BKK (0.04) which serves as a regional connecting node. Betweenness centrality reflects the idea that an airport has a structurally advantageous position when it falls between other airports within the network. In other words, the higher the centrality score, the more shortest-paths run through the airport. BKK solely connects Vietnam (HAN, SGN) with the rest of the AF network. Combined with direct connections from CDG, DXB and SIN, BKK serves as a well connected and therefore central airport of AF for South-East Asia.

The range of the betweenness centrality index for combined carriers varies from 0.99 (AF) to 0.75 (LH). Lufthansa has the least central network configuration and the most balanced scores for its two major airports. The low network centrality can be explained by LH's business model which is separated into two passenger hubs, namely FRA and MUC. Both airports serve as network hubs for LH which results in a lower overall centrality of the network (network is less compact).

The results of the indices are quite homogeneous within the group. For all carriers except LH single H&S network schemes are identified. Especially the network configuration of AF is depicted as a clear H&S structure. A very high betweenness centrality combined with a high concentration measure (Gini and Herfindahl) characterizes an H&S scheme with concentrations on some major destinations and on one hub. This scheme is mostly operated by combined carriers.

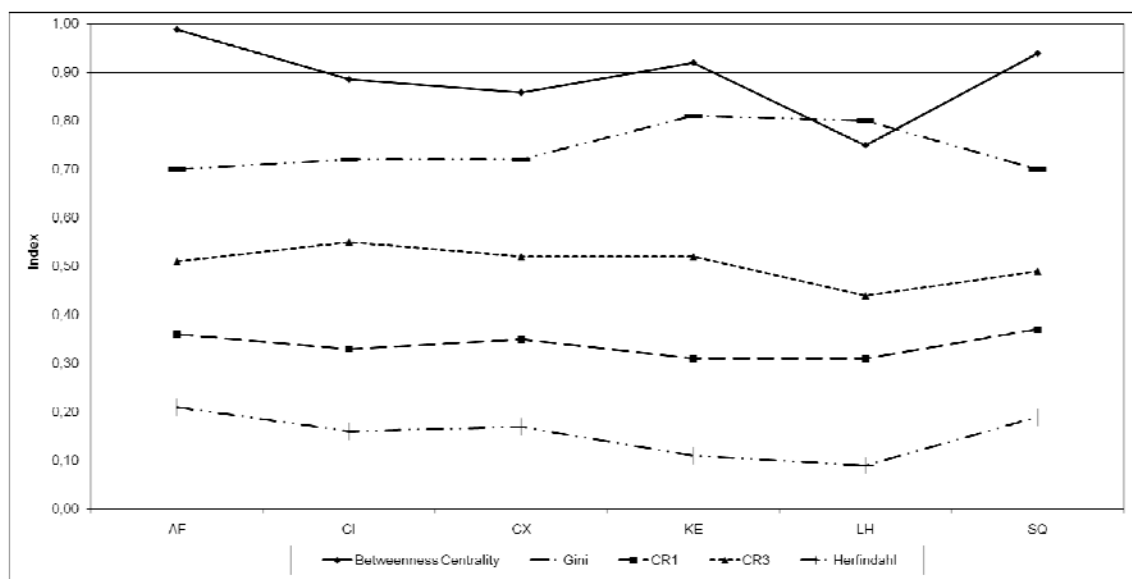


Figure 1: Results of the indices for combined carriers

### **Cargo brands of combined carriers**

The category of the *cargo brands* of combined carriers, the freighter fleet, shows similar tendencies as for the group of combined carriers, however, with lower absolute values (see Figure 2). GI\* detects lower concentrations for the cargo brands (0.62) than for their parent companies (0.74). A homogeneous category exists with small differences between the carriers (min. 0.56 SQ Cargo, max. 0.67 CX Cargo). As for the combined carriers, the major passenger hubs are also the main airports in the networks of the cargo brands but with lower concentration values (lower inequality). Secondary passenger airports play a significant role for cargo carriers. For all Asian carriers, Anchorage (ANC) was ranked second in 2007. Anchorage plays an unusual role for the cargo industry. It is solely important because of intermediacy rather than for any local origin and destination traffic. Anchorage is used as a hub by many cargo airlines, it is fed by domestic traffic from North America (Bowen, 2004).

The HI shows moderate concentration levels for AF Cargo (0.12), CI Cargo (0.14), CX Cargo (0.13) and KE Cargo (0.16). LH Cargo (0.08) and SQ Cargo (0.07) operate

unconcentrated networks. As for  $GI^*$  lower absolute levels are observed also for HI. The result of KE needs further interpretations as it differs significantly from the rest of the category. As seen before, the parent company of KE Cargo shows very moderate concentration levels ( $HI=0.11$ ). For all other airlines HI decreases for the cargo brand whereas the HI of KE Cargo increases significantly to 0.16. The reason for this unusual trend lies in political decisions in South Korea. The major airport for KE Cargo is ICN with a traffic share of 38% followed by ANC (10%) which reflects the major market for KE Cargo (Asia - North America). The government of Korea supports a long-term strategy to become a cargo gateway to and from East Asia (especially Japan and China) and to establish world's number one air cargo hub at Incheon airport (ICN). Therefore, ICN as well as KE Cargo are boosted by the Korean government and freight is focused on ICN, a relatively new airport, to achieve its long-term objective (Bowen, 2004).

Betweenness centrality is on average much lower for the cargo brands ( $C_B$  Cargo=0.76) compared to the combined carriers ( $C_B$  Combined=0.89). Based on this index AF Cargo operates the most central network ( $C_B$  Cargo=0.89) with CDG as its most central airport. More than 90% of all shortest paths of AF Cargo run through CDG. Contrary to AF Cargo is the network of LH Cargo with a betweenness centrality of only 0.58 indicating moderate H&S activities. Beside FRA as its major hub, further airports exist with lower but still important flight frequencies, namely CGN<sup>2</sup>, TSE, SHJ, NBO, DEL and ORD. Especially TSE<sup>3</sup> and SHJ serve as major airports for their regions where freight is bundled and flight activities are concentrated to ship cargo to the core markets of LH Cargo.

Summarizing the findings for the cargo brands it becomes obvious that H&S structures are also the dominant network configuration. Particularly AF Cargo, as its parent company operates a one hub network strategy as indicated by the indices. A very high betweenness centrality score stands for the central role of the hub in the network. The moderate concentration indices and especially the parameter-value of  $GI^*$  ( $GI^*=0.57$ ,  $HI=0.12$ ) underline the hypothesis that traffic is more equally distributed within the network but with a clear focus on one hub airport. LH Cargo's network structure differs from the AF Cargo network. Betweenness centrality is much lower ( $C_B=0.58$ ) which points towards a multi-hub network configuration. FRA ( $C_B=0.60$ ) and CGN ( $C_B=0.24$ ) serve as hubs for LH Cargo in 2007. The Gini index ( $GI^*=0.65$ ) detects LH Cargo as having a comparatively high network concentration compared with, for example, AF Cargo. Based on these results the network configuration of LH Cargo can be classified as a multi-hub-and-spoke structure with a concentration of flight activities at few destinations (e.g. FRA-TSE).

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<sup>2</sup> CGN was replaced by LHJ as second hub for LH Cargo in late 2007

<sup>3</sup> TSE will be replaced by Yemelyanovo Airport (KJA) in Krasnoyarsk (Russia) by the end of March 2009 and its regional importance will be assigned to KJA

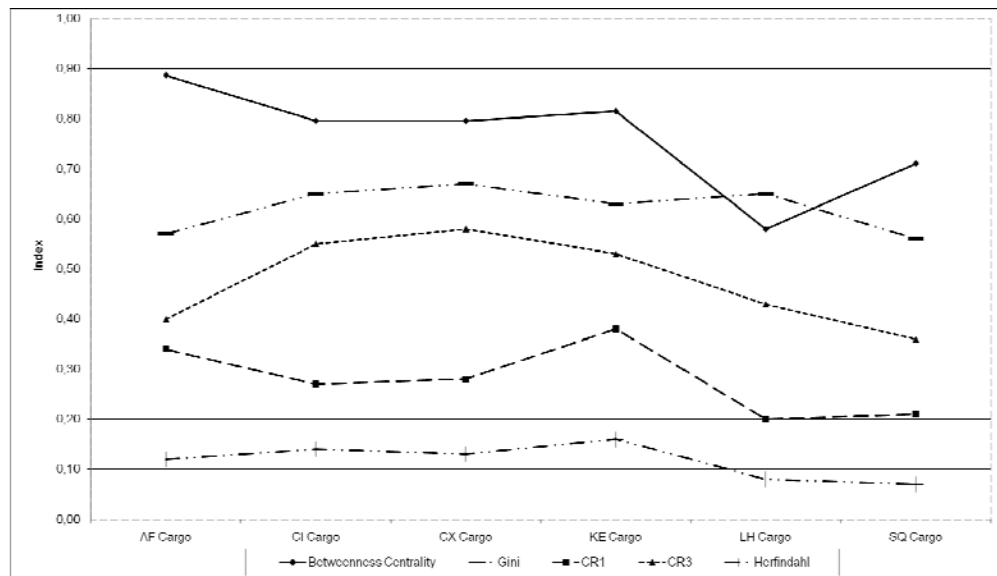


Figure 2: Results of the indices for the cargo brands of combined carriers

### **Pure cargo airlines**

*Pure cargo carriers* have the lowest Gini coefficients (average value of 0.54) and therefore the lowest network asymmetries (see Figure 3). A homogeneous category exists with a  $GI^*$  ranging from 0.49 (KZ) to 0.58 (LC). Concerning the routing behavior of pure cargo carriers, significant differences can be observed. Pure cargo airlines operate round-trips to cope with imbalances of demand. Polar Air Cargo, for example, operates the route PVG-ANC-LAX-PVG and scores 0.57 in  $GI^*$ . Caused by en-route stops and one-way vectored traffic flows, lower concentration can be observed for single airports resulting in a lower network concentration. Similar characteristics are found for other cargo airlines. Nippon Air Cargo (KZ) has a business focus on inter-continental flights connecting the major cargo markets with Asia and especially with Japan its country of origin. NRT serves as its major airport (traffic share 26%) closely followed by ANC (18%) which shows tendencies of a second major airport for KZ. The traffic shares of the following airports, such as KIX (9%), HKG (6%), AMS (6%) and SFO (6%) underline the importance of inter-continental connections for KZ.

The range of the HI varies from 0.08 (CV) to 0.14 (CK) which is around the same size as for the cargo brands of combined carriers. China Cargo Airlines (CK) focuses more than half of its business on three airports with PVG (28%) being the largest airport in its network followed by PEK (16%) and ANC (13%). This leads to a concentration ratio (CR3) of 57%. In total, 15 airports are operated by CK but other airports than the three largest play only minor roles (< 6%). The concentrated network activities at few airports lead to a comparably high HI caused by the square-function characteristic of the indicator.

Contrary to the small network size of CK is the network of Cargolux (CV) with around 60 destinations. Flights are distributed more equally among the airports with most airports having a traffic share between 1.0 and 2.5%. The three largest airports (CR3) combine 42% of traffic (LUX= 23%, GYD=14% and HKG=5%) which leads to a

much smaller HI compared to the other carriers within and especially compared to the other groups.

Analyzing the results of the betweenness centrality index, the outcomes of the former indices are validated: Pure freighter carriers operate less compact and more evenly distributed networks. Betweenness centrality of the pure freighter category is 0.66 compared to 0.76 (cargo brands) and 0.89 (combined carriers). As the heterogeneity of centrality values within the category is high, different network configurations are applied for pure freighter airlines. GI\* detects Nippon Air Cargo (KZ) as having the least concentrated network amongst the pure freighter carriers (GI\*=0.49). In combination with a low centrality value ( $C_B=0.49$ ) the network can be characterized as a H&S network with round-trips originating from the two major airports (NRT and ANC). Flights are concentrated on one major relation which is the relation NRT – ANC combining 15% of total flights. Round-trips are operated from NRT (e.g. NRT-KIX-SIN-BKK-NRT) as well as from ANC (e.g. ANC-ORD-JFK-ANC) to feed the inter-continental flights between KZ's major markets of Asia and North America.

The network shape of Cargolux (CV) differs significantly from the KZ network with a GI\*=0.56 and  $C_B=0.75$  indicating a more concentrated and centralized network. Such characteristics exist for mixed networks of linear and H&S configurations. CV operates two hubs which are LUX and GYD. More than 10% of total flights are operated between these two hubs. Other single relations are much less frequently operated. The connections to the spokes are arranged through bi-directional flights as well as round-trips whereas the most important airports are connected directly to the hubs. These connections are LUX-MXP, LUX-PIK, GYD-PVG and GYD-HKG and account for 17% of the remaining flights (excluding LUX-GYD).

The case of ABX Air (GB) shows some interesting issues. While its primary airport ILN has a traffic share of 33% (CR1), CR3 is only 38%. In total, more than 90 destinations have shares of up to 2.5% which results in an unconcentrated network configuration, even though a major airport for GB exists. The very high betweenness score underlines the importance of the major airport for the entire network. 97% of all connections run through ILN. In combination with a moderate Gini index (GI\*=0.50), the premises for a pure H&S configuration are fulfilled.

Comparing the results for pure cargo carriers with those of the two other groups it comes out that network configuration of cargo carriers are much more diverse than those of combined carriers and their cargo brands. Especially the round-trip structure of routes is a characteristic of cargo carriers which is not applied in passenger transport. This structure can also be observed for road freight transport where trips are organized and operated as round-trips to cope with imbalances of demand (efficient resource allocation) (Liedtke, 2006). The importance of single airports for the entire network of pure freighters is much smaller. Average CR1 is 27% and CR3 45% indicate a greater importance of the remaining airports and a less concentrated network configuration. The results can be underlined by smaller average concentration levels (GI\* and HI) and less centralized network configurations.



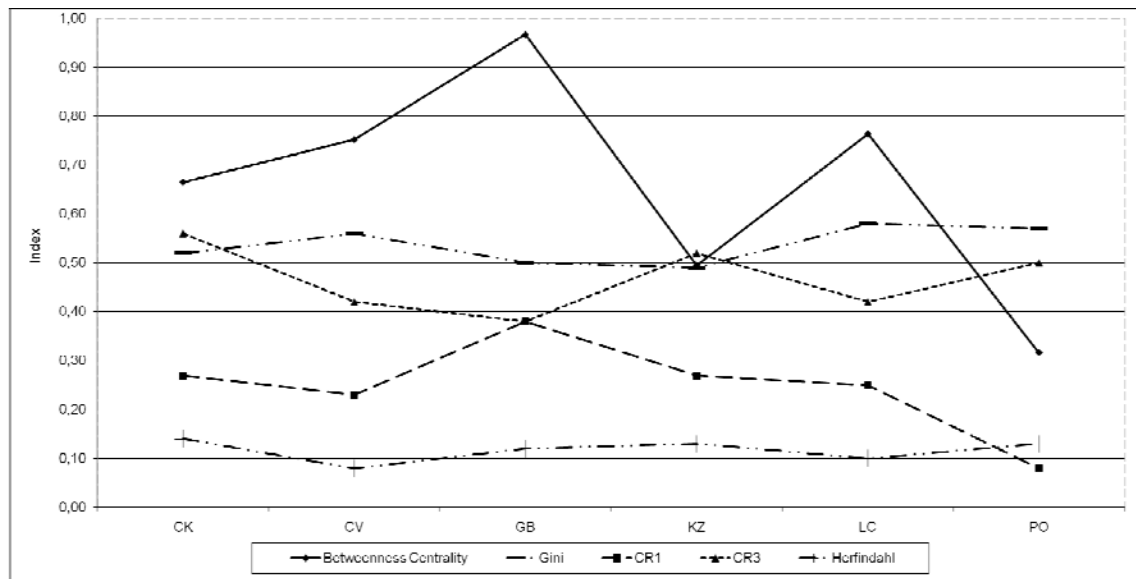


Figure 3: Results of the indices for pure freighter airlines

## 6. Conclusions

This paper has explored the characteristics of spatial network configurations in the air freight industry. Common measures of spatial concentration have been applied to account for differences in network configuration between the groups of combined carriers, their cargo brands and of pure cargo operators. The carriers have been chosen based on their RTK ranking in 2007 and only cargo flights have been included in the analysis. The paper evaluated the spatial dimension of cargo networks by means of the Gini index, the Herfindahl index, the concentration ratio and the betweenness centrality. It was argued that none of the indices dominates the others but that only the variety of indices permits a classification of the networks.

The results show that structural differences exist in network design (see Figure 4). Combined carriers operate very centralized networks with concentrations at a small number of airports (more than half of air cargo is still transported by passenger aircrafts as belly freight that the network structure for combined carriers is determined by the behavior of passengers). Combined carriers route and schedule their networks based on the convenience of the passengers and in particular on business travelers. Passengers minimize en-route stops which can be achieved most efficiently in large networks by operating H&S schemes. AF operates the most concentrated network with CDG as its hub. The other analyzed combined carriers operate analogue network configurations but less stringent. Only Lufthansa operates a multi-H&S network with its two hubs at FRA and MUC.

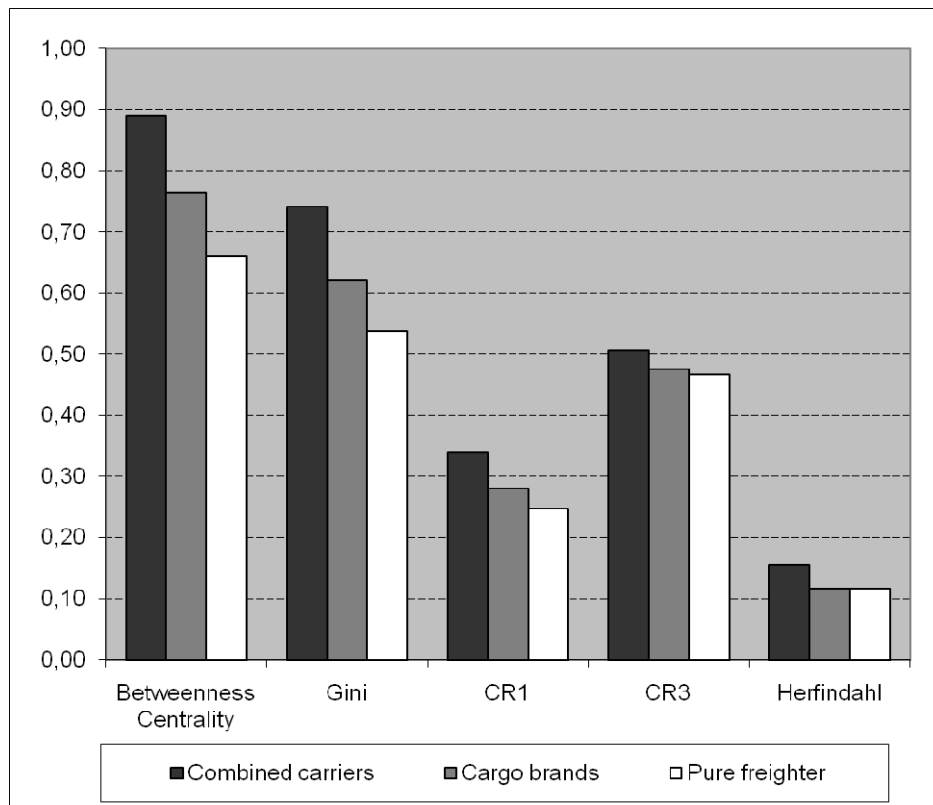


Figure 4: Comparison of the results of the three groups

In addition, the results for the cargo brands reveal that the freighter fleets of combined carriers have lower centrality and concentration scores. Typical values for the Gini coefficient are between 0.1 and 0.15 lower than for their parent companies. The same tendency can be observed for the Herfindahl index, the concentration ratios and for the betweenness centrality index. Combining the results for the cargo brands, H&S schemes are still the predominant network configurations. Again Lufthansa Cargo operates a different network scheme which shows characteristics of a multi-H&S network but with CGN as its second hub beside FRA for its freighter fleet in 2007.

Pure freighter airlines operate moderate perfect star networks and differ significantly from the two other groups. Concentration indices, such as Gini and Herfindahl index show little variation within the category and underline that a more equal distribution of flight frequencies is common for cargo carriers. A different picture exists for centrality which ranges from 32% to 97% indicating that no uniform network configuration exists. Three major configurations have been observed, namely perfect H&S scheme, mixed scheme of H&S and linear connections and H&S schemes with round-trips at the hubs. A distinctive feature of cargo carriers are round-trip structures. Contrary to passenger transport they are operated in the cargo industry to cope with imbalances of demand.

**Appendix A: IATA airport codes**

<b>ANC</b>	Anchorage (US) - Ted Stevens International Airport	<b>LUX</b>	Luxembourg (LU) – Findel
<b>BKK</b>	Bangkok (TH) - Suvarnabhumi International	<b>MUC</b>	Munich (DE) – Franz Josef Strauss
<b>CDG</b>	Paris (FR) - Charles De Gaulle	<b>MPX</b>	Milan (IT) - Malpensa
<b>CGN</b>	Cologne (DE) – Köln/Bonn	<b>NBO</b>	Nairobi (KE) - Jomo Kenyatta International
<b>DEL</b>	New Delhi (IN) - Indira Gandhi International	<b>NRT</b>	Tokyo (JN) – Tokyo Narita International Airport
<b>DUS</b>	Düsseldorf (DE) – Düsseldorf International Airport	<b>ORD</b>	Chicago (US) - Chicago O'hare International
<b>DXB</b>	Dubai (AE) – Dubai International Airport	<b>PEK</b>	Beijing (CH) - Beijing Capital International
<b>FRA</b>	Frankfurt (DE) – Frankfurt International Airport	<b>PIK</b>	Glasgow (GB) – Glasgow-Prestwick
<b>GYD</b>	Baku (AZ) - Heydar Aliyev International	<b>PVG</b>	Shanghai (CN) – Pu Dong
<b>HAN</b>	Hanoi (VN) - Noibai International	<b>SFO</b>	San Francisco (US) – San Francisco International
<b>HKG</b>	Hong Kong (HK) – Hong Kong International	<b>SGN</b>	Hi Chi Min City (VN) - Tan Son Nhat International
<b>ICN</b>	Seoul (KR) – Incheon International	<b>SHJ</b>	Sharjah (AE) – Sharjah International
<b>JFK</b>	New York (US) - John F. Kennedy International	<b>SIN</b>	Singapore (SG) – Changi International
<b>KIX</b>	Osaka (JP) - Kansai International	<b>TPE</b>	Taipei (TW) - Taiwan Taoyuan International
<b>LAX</b>	Los Angeles (US) – Los Angeles International	<b>TSE</b>	Astana (KZ) - Astana

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