MEASURING CONCENTRATION IN LESS-THAN-TRUCKLOAD NETWORKS

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ABSTRACT

An efficient and service-oriented transportation network is a necessary resource for successful less-than-truckload operations. The design, as well as the evaluation, of transportation networks is mainly driven by quantitative in particular cost-oriented measures, such as transport and transshipment costs. Spatial network centrality is often neglected in transportation network design, even though network centrality is at the root of many aspects of network performance, for instance schedule reliability and terminal congestion.
This paper suggests modifications of the Gini-based network concentration index as well as the hubbing concentration index from the passenger airline context to the less-than-truckload road transportation context. The modified indices assess the concentration of a less-than-truckload network and allow incorporating centrality in a structured way into transportation network design. They provide aggregated information on structural aspects of a network and are thus a starting point for network evaluation and further examination. This paper presents a comparison of network scenarios, which illustrates how the indices provide relevant information for network design decisions.
Key words: Network configuration, Network design, Spatial concentration, Centrality, Less-than-truckload transportation

1. INTRODUCTION

Less-than-truckload (LTL) transportation networks support the efficient transport of “individually labeled dry or staple goods from the industrial or consumer goods sectors in [palletized] consignments weighing between approximately 30 and 2,500 kg” (Klaus et al., 2009, p. 87). The market size for European LTL transports in 2008 accounts for 4% of the entire logistics market. This market segment continues to grow with harsh competition amongst the players. National and Europe-wide efficient transportation networks of high quality are the backbone and simultaneously the key success factor for this market. About 90% of the market is outsourced to logistics service providers (LSPs) who operate distinct networks (Klaus et al., 2009, p. 88). Their goal is to optimize network operations to achieve the best trade-off between minimum cost and maximum quality.

Optimal network design has been an important research field for many years; therefore optimal solution algorithms and good heuristics have been developed to solve a wide variety of problems. Wieberneit (2008), Crainic (2000) as well as Crainic and Laporte (1997) provide extensive overviews of network design for freight transportation. However, qualitative aspects such as spatial centrality, while critically important, are oftentimes neglected in transportation network design. Centrality is difficult to quantify. Even though it is of high relevance for the operations in a transportation network, it is rarely discussed in the context of LTL transportation network design.

LTL networks rely on transshipment terminals to exploit efficiencies and consolidation effects in their operations (Wieberneit, 2008). The more central the network the greater these effects will be. Then again, centrality in transportation networks usually leads to long additional transportation distances – hence additional transportation time – for the consignments as these are transferred to the central node before actually reaching their final destination. This illustrates that there is a direct relationship between the quantitative aspects efficiency, cost as well as transportation time and the qualitative concept of centrality. However, centrality itself is also relevant for network design. Networks with comparable costs may differ in their spatial centrality. Centralized networks are more exposed to challenges, e.g. hub congestion. Furthermore, centralized networks have a high service frequency, which relates to a targeted customer service level. Decentralized networks are known to have a high schedule reliability as delays do not spread over the entire network (Lederer and Nambimadom, 1998). It is therefore important to be aware of the degree of centrality of a given network. Expressive centrality measurements are needed to provide a structured information basis.

Borgatti and Everett (2006) lay out a topology of centrality measures. The authors conclude that all measures point at the involvement of a node in the network traffic. If a node is highly involved in the network, it is a central one. These central nodes will be labeled *hubs*.

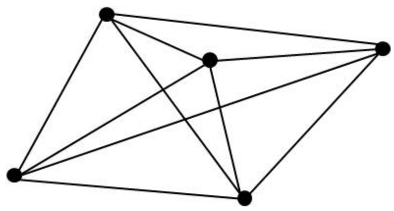

Figure 1 - Point-to-point network.

Following O’Kelly and Miller a hub is a “major sorting or switching center in a many-to-many distribution system” (O’Kelly and Miller, 1994, p. 32). A network often has several hubs. Examples of hubs are airports or LTL transshipment terminals. A *centralized network*, then, is a network with one or few hubs. A point-to-point network (see figure 1) is a decentralized network as opposed to a centralized hub-and-spoke network (see figure 2).

It is surprising that the literature lacks contributions concerning the measurement of centrality in LTL transportation networks. Hesse and Rodrigue (2004) highlight that the “spatial character” (Hesse and Rodrigue, 2004, p. 172) of transportation does not receive much attention neither in transportation science nor in business administration. This paper contributes to the filling of this gap by providing simple yet expressive measurements to assess network concentration in LTL networks. It suggests two indices to evaluate concentration in LTL transportation networks. These indices allow to incorporate concentration into network design and offer a new perspective in the decision making process. They are especially valuable to compare given networks – for example different scenarios – in the process of network design. By providing one value per network, they reveal differences in centrality between the configurations. This information may then serve as a starting point for further in-depth network comparison.

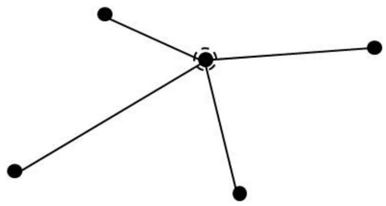

Figure 2 - Hub-and-spoken network.

As it will be demonstrated, airline networks and LTL transportation networks resemble each other in many ways. To the best of my knowledge, the aviation context provides the largest and most structured background on measuring centrality in transportation networks. Several perspectives on how to grasp spatial centrality in airline networks were developed in the past.
It is a logical step, therefore, to adapt existing airline network measurements to the context of land-based palletized cargo consignments in order to obtain centrality indices for LTL transportation networks.
The goal of this paper is to suggest valid measurements for LTL transportation network concentration. What is a valid measurement in the understanding of this paper? The intention is to highlight the importance of hubs for the network as well as for distinct origin-destination-markets. The role of hubs in the network helps to understand issues such as schedule reliability for the network. It is furthermore interesting to investigate the involvement of one or several hubs on single origin-destination-markets since the risk of congestion on hubs serving a market will directly influence the service for this market. Some authors in the airline context give axioms that the measures they use fulfill (Reynolds-Feighan, 1998, 2001; Wojahn, 2001), but these do not exactly cover the purpose of this paper.

1. This paper seeks to find measurements that allow the comparison of complete networks; i.e. cumulative measurements that provide one value per network instead of separate values for each arc or node. This idea follows Reynolds-Feighan's approach, in that she is interested in an aggregate measure for the entire network (Reynolds-Feighan, 1998).

2. It is dependent upon measurements that are invariant to the scale of the network. A change in the number of arcs and nodes in the network must not influence the indication on network concentration given by an index. This aspect is amongst those Wojahn (2001, p. 27) puts forth.

3. It relies on measures that are calculated based on data that is typically available to network operators, i.e. consignment information such as consingment routing and transport volume, as well as network information such as the location of terminals.

4. Finally, the paper targets at measures that are able to cope with 2-stop routings common in LTL transportation. This aspect has not been discussed explicitly by research in the airline context.

These four elements will guide the selection and modification of existing concentration measurements derived from the airline context.
The remainder of this paper is structured as follows: The next section outlines work previously done on measuring centrality in airline networks with a focus on the network concentration (NC) index and the hubbing concentration (HC) index. Section 3 develops suggestions on assessing LTL transportation network concentration. Similarities and differences between airline and LTL networks are highlighted, before the modifications to the two aforementioned indices are presented. An application to LTL networks that were simulated in the scope of a project in cooperation with an LSP is demonstrated to close this section. The paper ends with a summary in section 4.

2. INDICES TO MEASURE AIRLINE NETWORK CENTRALITY

Network centrality has been studied intensively in order to compare different airline networks. Many of these contributions are driven by the goal of highlighting changes that stem from the deregulation of the aviation industry (e.g. Burghouwt et al., 2003). But authors also compare different network scopes, such as a single airline's network vs. the airline's cooperation's network (e.g. Reggiani et al., 2009).

Table 1 - Scope of network topology measurements.

Contribution	**Main measurement**
Taaffe and Gauthier (1973)	Gamma index
Wojahn (2001)	Topological hubbing index
Bowen (2002)	Shimbel index
Alderighi et al. (2007)	Freeman centrality index
Reggiani et al. (2009)	Degree, closeness, betweenness, diameter, clustering coefficient, Freeman centrality index[1]

Centrality measurements in the aviation literature focus on two main aspects: The topology of the network on the one hand and the concentration of the network on the other hand. The former describes how the airline network is set up in terms of arcs and nodes. Table 1 gives a brief overview of some key contributions in this context.
The latter – measurements for the concentration of the network – are used to assess, how strongly the network's operations are focused on single or few hubs. These measurements rely on the traffic flows in the network. Concentration measures for LTL networks are the focus of this paper as they allow to evaluate the importance of transshipment points for the entire network.

[1] The authors see the Freeman centrality index as a measurement for concentration, however, in the light of our discussion it is rather perceived as a measure for topology in the spirit it was introduced by Alderighi et al. (2007).

Table 2 - Scope of network concentration measurements.

Contribution	**Main measurement**
McShan and Windle (1989)	McShan-Windle index
Borenstein (1992)	Hubness, Airport Herfindahl index
Saunders and Shepherd (1993)	Hirschman-Herfindahl index
Reynolds-Feighan (2001)	Gini index
Wojahn (2001)	Broad literature overview
Burghouwt et al. (2003)	Normalized Gini index
Martín and Voltes-Dorta (2008)	Hubbing concentration index
Derudder and Witlox (2009)	Entropy-based measurements
Huber (2009a, b)	Gini-based analysis
Martín and Voltes-Dorta (2009)	Hubbing concentration index
Papatheodorou and Arvanitis (2009)	Gini-based analysis
Reggiani et al. (2009)	Normalized Gini index, entropy index
Costa et al. (2010)	Modified Hirschman-Herfindahl index

Table 2 hints at the wide spectrum of concentration measures that are used in the literature to account for network concentration. Some are more prominent than others. Among these, the Hirschman-Herfindahl (HH) index and the Theil-type entropy measurements will not support the assessment of LTL network concentration. The HH index is used to underpin the concentration of an airline network. However, Wojahn (2001, p. 29) points out that the HH index is scale-dependent. The number of nodes in the network changes the value of the index, even if the network structure is unchanged. The HH index is therefore excluded from further investigation.

Similarly, the theoretically well-founded Theil index as a measure for inequality of income in a population (Theil, 1967) will be excluded from the analysis, even though Wojahn (2001) demonstrates how the Theil index can be modified to explain the degree of centrality in an airline network by interpreting inequality as centrality. Conçeicão and Ferreira (2000) highlight that the Theil entropy measure of inequality has one particular strength: The Theil index is superior to the Gini index (see below) in that it provides a much better understanding of the concentration that exists within a cluster of grouped individuals, which is a result from its decomposability. However, in the LTL context data quality is better than in social sciences where the Theil index is commonly used. Large databases that provide full information about all consignments and transshipment activities at all terminals, as well as all routings, are usually available. Thus, there is no need to aggregate individual data points into larger groups, and hence no concentration within these groups. This paper can therefore limit itself to the insight gained by Gini-type indices.

Reynolds-Feighan (2001) argues that the Gini index can be seen as the superior index to capture concentration. Burghouwt et al. (2003) point out that the maximum of the Gini index depends on the number of airports in an airline network. The authors thus propose the network concentration index, which corrects the Gini index for its maximum. The NC index is invariant to changes in network size. Gini-based measurements are widely used in the literature (Cidell, 2010) and therefore provide a promising anchor point for the goal of measuring LTL network concentration.

Airline hubbing strategies may lead to a distorted picture when considering traffic at an airport. Passengers at the airport for initial departure are mixed with those switching planes to continue onward in their travels. Thus, traffic at an airport represents an ambiguous role of this airport as an origin and as a hub in the original sense (O'Connor, 2003). To be able to explain hubbing behavior expressively, Martín and Voltes-Dorta (2008) argue that one needs to distinguish between a hub and an important origin or destination in an airline network. The authors suggest the hubbing concentration index as a new concentration measurement that takes into account this difference. The aspect of separating hub transports from direct transports in an LTL network is just as relevant as for the airline context. A modification of the HC index will be presented as the second index for assessing LTL network concentration, but sections 2.1 and 2.2 will first depict the calculation of the NC and the HC index in the airline context.

2.1. Network concentration index

The NC index is a normalization of the Gini index (Burghouwt et al., 2003). The Gini index itself was firstly devised to measure the concentration of airline networks by Reynolds-Feighan (1998). It compares the traffic shares of all airports in the network. A network with strong differences in traffic is a concentrated network in the understanding of the Gini index. It is calculated as:

$$GI = \frac{1}{2N}\sum_i \sum_j \left|s_i - s_j\right| \tag{1}$$

where i and j are airports, N is the number of airports in the network, and s_i is the relative traffic share of airport i. The Gini index yields a value of 0 if traffic is evenly split between all airports in the network. It reaches its maximum in an airline network where all traffic is consolidated on a route (Burghouwt et al., 2003). However, the value of the maximum (GI_{max}) depends on the number of airports in the network.

$$GI_{\max} = 1 - \frac{2}{N} \tag{2}$$

The interpretation of the Gini index is therefore difficult when comparing networks of different sizes. Burghouwt et al. (2003) propose the NC index, which corrects the Gini index for network size.

$$NC = \frac{GI}{GI_{\max}} \tag{3}$$

In contrast to the Gini index, the NC index varies in the interval [0; 1], no matter what the network size. The NC index increases if the traffic becomes less evenly split across the network (Burghouwt et al., 2003). The lower the NC index, the less concentrated the network.

2.2. Hubbing concentration index

The HC index aims to fairly measure hubbing by identifying passengers connecting to their onward travels (Martín and Voltes-Dorta, 2008). It is an index that relates concentration to two major aspects: the importance of hubbing in the network and the concentration of hubbed traffic to few airports. As a first step, the hubbing behavior of the connecting passengers on a market *ij* needs to be calculated[2]:

$$H_{ij} = C_{ij} \sum_{k=1}^{N} s_{k,ij}^{2} \qquad (4)$$

where C_{ij} is the share of connecting passengers on the market *ij* and $s_{k;ij}$ equals the traffic share of airport *k* on the market *ij*.[3] The HC index is then calculated by weighting the hubbing behavior according to the relevance of this route for the airline. The relevance is expressed by the traffic on this route q_{ij} in relation to the overall traffic *Q*:

$$HC = \sum_{i} \sum_{j} \frac{q_{ij}}{Q} H_{ij} \qquad (5)$$

The HC index falls in the interval [0; 1]. A single hub-and-spoke network yields an HC index of 1 (Martín and Voltes-Dorta, 2008). An HC index equal to 0 represents inter alia a network where passengers do not connect at all to ongoing flights. Thus, a high HC index indicates that hubbing is important in the network and that it is done on a large share of the traffic.

3. ASSESSING LTL NETWORK CONCENTRATION

The indices given above are commonly used to evaluate the concentration of air passenger transportation networks. It is now necessary to show in what aspects airline networks and LTL networks are alike respectively differ from each other. The aforementioned concentration measures will then be modified to suit the LTL context before their application for the analysis of LTL networks is presented.

3.1. Airline networks vs. LTL networks

Airline networks are constructed from airports and flight routes. The literature on airline network centrality usually assumes traffic at one airport to be determined by passenger enplanements (Reynolds-Feighan, 2001). Therefore, passenger enplanements represent the intensity on a particular flight route.

From a structural point of view, airline networks can be placed in a continuum between point-to-point networks and hub-and-spoke networks (Wojahn, 2001, p. 23). Point-to-point networks are characterized by direct routes between nodes, as depicted in figure 1. Hub-and-spoke networks are the alternative at the other end of the scale. Their key feature is a central hub in the network as illustrated in figure 2. For an airline, this type of network leads to economies of density on the routes, and is usually attractive from an operating cost perspective (Delfmann, 2000). Many different network types between these two extremes exist in practice; Burghouwt (2007, p. 13) provides an illustrative overview. Derudder and Witlox (2009) emphasize that many airlines do not rely on one central hub but have several hubs in their network. Furthermore, the authors identify the current trend towards more point-to-point networks, which is on one hand driven by the recent rise of low-cost-carriers and on the other hand supported by the perception within the industry that customers prefer direct

[2] A market is the set of all possible flights (including direct flights and flights via a hub) to travel from an origin *i* to a destination *j*.
[3] Note that unlike the NC index, the HC index uses the share of traffic on a particular market and not the traffic share of an airport in the entire airline network.

flights. Multi-centered hybrid hub-and-spoke networks are a likely outcome of these trends, as depicted in figure 3.

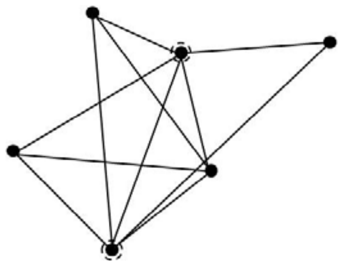

Figure 3 - Multi-centered hybrid hub-and-spoke network.

An LTL network consists of terminals and truck routes. The transported consignment volume or weight can be interpreted as the intensity on a route. The networks usually consist of two echelons: The end-of-line terminals for a city or region that are the bases for local pick-up and delivery trucks and transshipment facilities where consignments are consolidated and transshipped (Hall and Zhong, 2002; Cheung and Muralidharan, 2000; Powell, 1986). The network spanned by the end-of-line terminals and the transshipment facilities is set up similarly to an airline network and often takes the form of a multi-centered hybrid hub-and-spoke network. This paper focuses on this very network spanned by end-of-line and transshipment terminals: Local pick-up and delivery operations are out of the scope of research. Several operational routing schemes between end-of-line terminals are used in an LTL network, as seen in figure 4.[4] These four routing schemes are essential routings in European, network-based LTL operations. A stop is accounted for only when the truck stops at a hub or end-of-line terminal to transship consignments. A direct transport link, as depicted in scheme (i), is implemented if the volume of consignments between origin and destination is sufficiently high (Cheung and Muralidharan, 2000). Schemes (ii) and (iii) make use of one transshipment facility either near the origin or the departure terminal. It is also possible to route consignments through two transshipment facilities (iv) to increase the loads on the trucks by consolidating consignments further. This routing is also referred to as 2-stop routing, as it involves two stops at transshipment facilities.

The volume or weight of consignments from an origin to a destination will determine the routing scheme that is used. All of these routing schemes are routinely implemented in LTL networks.

Airline and LTL networks clearly have many characteristics in common. Their structural similarities have just been illustrated. Furthermore, both are characterized as many-to-many networks and operate in highly competitive market environments. High quality, high speed, and low prices are important factors for success in the LTL market (Crainic, 2000) just as in the aviation sector (Doganis, 2002, p. 25). Hence, LTL networks need to be designed for efficiency and customer orientation.

That said, there are key differences between these networks as well. In general, LTL networks tend to have far more direct routes between end-of-line terminals than in a full-service-carrier airline network. This is due to the different types of goods transported through the network: passengers and consignments. As airline passengers are sensitive to waiting

[4] Pick-up and delivery of consignments are omitted from figure 4 for the sake of simplicity; all consignments are treated as if they had their origin respectively destination at an end-of-line terminal.

time and expect high service frequencies, airlines are forced to make use of hubbing. Palletized consignments, however, can often be consolidated over time so that higher consignment volumes are accumulated which allows for direct transport links in LTL networks.

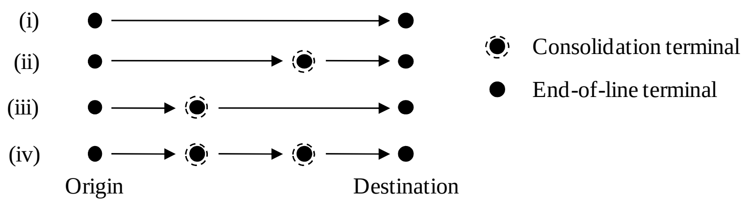

Figure 4 - Routing schemes in an LTL network.

Another important difference that stems from transporting passengers rather than consignments is that passengers have individual preferences whereas consignments do not. Thus, passengers may choose certain routings on their air journey for a variety of personal reasons. Consignments in an LTL network should always be routed according to predefined planning.

Furthermore, passenger traffic flows are usually assumed to be balanced, as most passengers return home after their trip. Hence, incoming and outgoing passenger traffic flows are equal (Burghouwt et al., 2003). This is a major difference when compared to air cargo (Doganis, 2002, p. 312), as well as cargo in general, such as LTL consignments. Such traffic flows are characterized by high imbalances of traffic.

Airline and LTL networks share many properties, which suggests to use similar indices to measure their concentration. However, as the networks differ in some aspects, modifications to the above presented NC and HC indices are necessary.

3.2. Adapted network concentration index

Measuring traffic is a first step before the NC index can be calculated. As mentioned above, airline traffic is usually measured in terms of enplanements. The Federal Aviation Administration (FAA) uses the term *enplanement* in the meaning of “revenue passenger boarding” (FAA, 2009). Most studies use outgoing traffic flows for their purpose (e.g. Debbage and Delk, 2001; Toh and Higgins, 1985; Reynolds-Feighan, 2001; Martín and Voltes-Dorta, 2008). Rare examples (e.g. Hensher, 2002) consider incoming and outgoing movements to assess traffic. Borenstein (1991, p. 1262) highlights that some statistics on airport traffic report only enplanements whereas others distinctly report en- and deplanements at airports. The idea to measure only outgoing flows is valid as passenger air transport traffic flows are usually assumed to be balanced. The LTL context, however, shows strong imbalances of traffic so that *traffic* at an LTL terminal is defined for the purpose of this paper as the sum of incoming and outgoing consignments. More operatively, consignments in the study are measured in terms of *payable weight*. Payable weight is the real weight for most consignments but may be a corrected measure for special cases such as odd-shaped consignments. An LSP usually collects this information for billing purposes.

The maximum of the Gini index (equation 2) for airline networks is limited due to the balanced traffic flows: No airport commands more than half the traffic in the network

(Burghouwt et al., 2003); otherwise, incoming and outgoing flows could not equal out. This argument is not valid for the LTL case. However, since traffic in the LTL case is counted at the outbound terminal as well as at the inbound terminal, there are always two terminals that share that traffic. This is true for any routing scheme. Therefore, any single terminal can accumulate at most half of the total traffic in the network. This leads to the same conclusion as derived for the airline case, namely that the Gini index will never reach its theoretical maximum and the NC index should be used instead in order to simplify the interpretation.

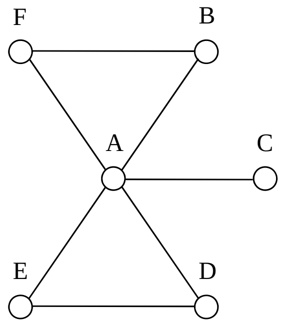

Figure 5 – Exemplary network.

Figure 5 shows a network that will serve to illustrate some values of the NC index. Nodes A - F represent LTL terminals. They send and receive consignments. Flow is counted in both directions. The arcs represent routes between the terminals. Table 3 displays the consignments sent on each route. The traffic share related to each terminal as well as the NC index value of the situation is shown in table 4.

Table 3 - Consignments on arcs.

Case	AB	AC	AD	AE	AF	FB	ED
I	0	1	0	0	0	1	1
II	1	1	1	1	1	0	0
III	1	1	1	1	1	1	0
IV	0	0	0	0	0	1	0
V	1	1	1	1	1	10	0
VI	1	10	1	1	1	11	11

The cases I - IV in tables 3 and 4 show some extreme NC values for the given network. The NC index is equal to 0 if all nodes have the same traffic in the network; this is the case of an unconcentrated network. An NC index value of 0.5 is related to a perfect star network (as case II displays), but other situations may lead to the same NC index value as well; case III is such an example. A network where all traffic is shared between two terminals while all other terminals have no traffic at all will lead to an NC index value of 1: a concentrated network. Cases V and VI underline how some aspects in a network may outweigh others. Case V is a star with one strong arc and is therefore characterized by an NC index value between these two types. Further, case VI possesses three strong routes with some additional star-type traffic, therefore the NC index value of this network is very small.

2-stop routings (figure 4 (iv)) are often used in the airline context, as most travelers will agree. Nevertheless, they are explicitly mentioned neither by Burghouwt et al. (2003) nor by Reynolds-Feighan (2001). This may be related to the datasets used by the authors; it would be surprising if they held the necessary information. To take 2-stop routings into account for the NC index, the additional transshipment is treated as another unloading and loading operation at the second transshipment terminal; it therefore increases the total traffic in the network.

Table 4 - Traffic of nodes and NC index values.

Case	A	B	C	D	E	F	NC index
I	1/6	1/6	1/6	1/6	1/6	1/6	0
II	1/2	1/10	1/10	1/10	1/10	1/10	1/2
III	5/12	1/6	1/12	1/12	1/12	1/6	1/2
IV	0	1/2	0	0	0	1/2	1
V	5/30	11/30	1/30	1/30	1/30	11/30	7/10
VI	7/36	1/6	5/36	1/6	1/6	1/6	5/108

3.3. Adapted hubbing concentration index

Measuring traffic is easier for the calculation of the HC index than for the NC index since the focus of the HC index is always market-oriented. It is sufficient to identify for each origin-destination-market the share of traffic that flows on any possible routing option. To do so, it is important to know the initial origin of any consignment and its final destination. In passenger airline networks it is often difficult to keep track of overall flight itineraries, but for the LTL context this data is usually available to the LSPs.
The key modification to the HC index is related to 2-stop routings, which are important in LTL networks. Martín and Voltes-Dorta (2008, p. 179) give meaningful examples on the intuition behind and the calculation of the HC index for 1-stop cases, but do not explicitly refer to 2-stop routings. 2-stop routings are incorporated into the modified HC index with the help of virtual hubs.

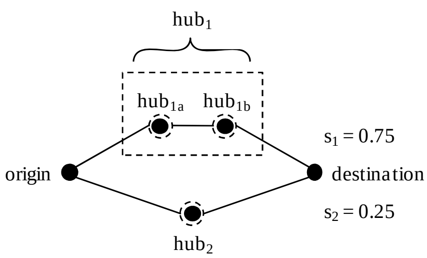

Figure 6 - 2-stop routing example

In the context of the LTL network in question, the 2-stop routing is the least common routing scheme but still cannot be neglected. Figure 6 shows an example of how 2-stop routings are accounted for. Whenever there is a consignment that uses two consolidation terminals on its way, these two terminals are treated as one *virtual hub*. Thus, hubs hub_{1a} and hub_{1b} together make up the virtual hub hub_1 for the path from origin to destination, and together account for a traffic share of 75%. Further calculation of the HC index then strictly follows the procedure provided by Martín and Voltes-Dorta. The idea of virtual hubs is easily extended to x-stop

cases: One virtual hub represents one possible path that consignments take from origin to destination. This further extension was, however, not necessary for the purpose of this study.
One needs to be aware that the suggested modification has one major drawback: Once two hubs are grouped together as a *virtual hub*, it is not possible to assess the importance of a single hub. Figure 7 presents a slightly modified version of the situation in figure 6. Hub_1 and hub_2 now both are virtual hubs and share the common gray terminal in the upper left corner. Hub_1 and hub_2 have a traffic share of 0.75 and 0.25 respectively. Thus, the hubbing behavior H for this case is $H = 1*(0.75^2 + 0.25^2) = 0.625$. However, all the traffic from origin to destination is channeled through the gray hub and one could argue that there are reasons to expect H to be equal to 1. Therefore, the modification with virtual hubs could also be interpreted as misleading.

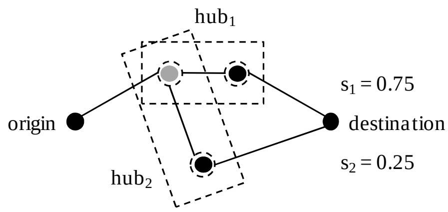

Figure 7 - 2-stop routing example with double involvement.

Nevertheless, we believe that this modification extends the HC index in an acceptable manner. The HC index was not formulated to compare the relevance of certain hubs in a given network; it was designed to provide a measure of the relevance of hubbing in a network and the modification follows that concept.

3.4. Application to LTL network data

The modified indices were used in a project with a large European logistics service provider aiming to reconfigure its LTL network. A number of network scenarios were developed and evaluated based on different performance indicators. These indicators included inter alia monetary and service aspects. Network concentration is included in the indicators.
The network scenarios are based on data provided by the LSP. It operates 154 terminals in its European network. The data reflects consignments from a representative four week period. The routing structure for each single consignment, which is included in the data, is always one of the four cases illustrated in figure 4. Based on this information, the indices were calculated with the previously described modifications for the situation prior to the project. In the initial situation 79 terminals are used for transshipment purposes.
The provided data was the starting point for simulations to compare scenarios with a varying number of hubs. The consignments in the network remain the same over all scenarios. The scenarios differ in their network configuration, but all of them are based on a heuristic to construct efficient networks while respecting service constraints. The general goal of the scenario analysis was to concentrate the hub usage to few, currently already important terminals in the network. It is thus favorable in the light of the project if the simulated networks are more concentrated than the initial network sample.
The usage of the indices will be presented with the values obtained for the initial situation that was found prior to the project, as well as for three scenarios: scenario A (SA), scenario B

(SB) and scenario C (SC). These three selected scenarios are very similar in terms of cost but differ in the number of employed hubs: Scenario A possesses the fewest hubs whereas scenario C has most hubs in this sample, yet significantly less hubs than in the initial LTL network. It is therefore interesting to highlight the differences in concentration amongst them.
The base case is the situation of transporting all consignments in the network without any hubbing. It gives an idea of the concentration of the initial customer demand. It was calculated for the NC index; the HC index of the base case would be 0 since no hubbing takes place in the network. The base case gives an NC index of 0.650. This signifies that the demand for transportation by itself already is somewhat concentrated. The initial LTL network yields a NC index of 0.678. The NC index values for the simulated networks score higher the fewer hubs are relevant for the scenario. Table 5 provides an overview of the index values. Given that the network consists of 154 terminals and direct routes between many of them, the values highlight that the network has some arcs with high traffic and others with low traffic. The relevance of some highly utilized arcs increases even further as fewer hubs are available in the simulated networks. However, the difference between all index values is surprisingly small. This can be easily explained by the LTL context: All routes that have a high customer demand for transportation are routed directly from origin to destination. The impact of choosing a certain hub and routing traffic through that hub, is of minor importance for the concentration of the network. Nevertheless, an increase in concentration can be achieved. From the point of view of the project, this is the intended situation. Lowly utilized origin-destination-routes are suppressed and their demand is consolidated to transports via a hub.
The adapted NC index seems to depict mainly the imbalance in the market demand. It thus appears likely that its expressiveness in transportation contexts that are characterized by an imbalance in traffic flows is limited.

Table 5 - NC index values.

	NC index
Base case concentration	0.650
Initial LTL network sample	0.678
Simulated LTL network SA	0.730
Simulated LTL network SB	0.725
Simulated LTL network SC	0.706

The modified hubbing concentration index as well as the overall share of transshipped consignments in the network was calculated. Table 6 depicts the calculated values. It further lists the ratio of HC index over the transshipment share in order to see the relation of the two others.

Table 6 - HC index values.

	Transshipment share	**HC index**	**Ratio**
Initial LTL network sample	0.204	0.169	0.828
Simulated LTL network SA	0.283	0.277	0.979
Simulated LTL network SB	0.278	0.273	0.982
Simulated LTL network SC	0.257	0.254	0.988

Martín and Voltes-Dorta (2009) point out, that the share of connecting passengers is highly correlated with the HC index. The calculations for the scenarios support this finding. The results on the HC index hint at a low relevance of hubbing in the initial LTL sample as well as all the simulated networks. Only 20% (initial sample) to 28% (scenario A) of the payable weight of the consignments in the network is transshipped. This is – again – due to the fact that origin-destination-markets with high demand for the transportation of consignments are served directly. The decrease in transshipment share as the number of hubs increases in the simulations stems from the hub choice: as the hubs have much origin- and destination-demand themselves, the more hubs exist in the network, the fewer transshipments are necessary as the origin- and destination-traffic to these terminals is combined with consolidated flows for transshipment to these locations. The decrease in the HC index is of course also related to this. The HC index represents the variety of routings for a single origin-destination-market. It expresses how many different routing options are used on one market. The ratio of the HC index over the transshipment share is significantly closer to one for the simulated networks that in the initial network, which indicates that for almost all markets in the network, there is only one highly used routing option. This is a major point for the project. It indicates that the number of different routing options on the markets is relevantly lower than in the initial situation. Without going into detail on the routing schemes used for the scenarios, this is an important element for the project goal to focus the operations to few central nodes.

The scenario results show the different perspectives the NC index and the HC index take on network concentration. The NC index highlights that the considered LTL networks are concentrated because the index perceives concentration as the imbalance in traffic shares, and this imbalance is rather high for the LTL cases. This is related to the demand the LSP serves and only partially influenced by the network design. However, the HC index clearly points out that hubbing is of minor importance in the networks. One could interpret this as a low concentration. These two perspectives give relevant insights on an aggregated level into the network structure. The obtained information serves as a first comparison between networks and may guide further examination of the networks.

In the data example, the concentration shown by the NC index is in large shares externally driven due to the imbalance of demand and the relevance of certain markets for the LSP. The HC index was especially important for the project. It indicates that in the network scenarios hubbing is only relevant to a certain extent but by comparing the transshipment share and the HC index, it becomes obvious that the routing is always concentrated to few hubs. Whilst this is intended in the project, there are operating downsides of this: The hubs in question will experience extremely high transshipment volumes. Loading facilities and handling equipment must be available at the hubs. This may require investments for the LSP but is crucial to avoid congestion challenges. Furthermore, if for whatever reason one of these hubs will not be able to perform the transshipment tasks, there is no other option to route consignments. The LSP will need to set up emergency routines and/or come up with solutions to bypass the specific hub in such a situation. It should finally not be neglected that, even though the networks are comparable in terms of costs, their differences in the NC index and in HC index are higher. Both concentration indices are able to add yet another perspective for the overall task of network design.

4. SUMMARY

This paper shows how indices commonly used to measure spatial concentration of airline networks can be adapted to express the spatial concentration of LTL networks. It is demonstrated that the network concentration index and the hubbing concentration index can be applied to LTL networks with some minor modifications. The main issue for the network concentration index is the definition of traffic in the LTL context as incoming plus outgoing flows. The challenge in the modification of the hubbing concentration index is to take 2-stop routings into account, which is achieved by virtual hubs. The general expressiveness of the adapted NC index seems to be impacted by the imbalance in traffic flows in the LTL network. Future research should search for further applications to networks with imbalances in traffic to verify if this is - indeed - a general deficit of the (adapted) NC index in these types of networks.
In the scope of a project to redesign an LTL network with a large LSP, the indices allowed to compare different network scenarios. They provided a new perspective for this comparison. The NC index highlights strong imbalances of traffic in the network, which reveals that some high-volume origin-destination-markets are served by the LSP directly and independently from the network. The hubbing concentration index, however, gives some more information on the transports that actually involve transshipment operations. It highlights that the network scenarios highly depend on very few hubs. This is a significant indicator for the relevance of these hubs and the importance for the LSP to ensure their function and prepare emergency plans. In this sense, the concentration measures add a facet to the effective design of LTL networks and create transparency in the process of network design.

REFERENCES

Alderighi, M., A. Cento, P. Nijkamp and P. Rietveld (2007). Assessment of New Hub-and-Spoke and Point-to-Point Airline Network Configurations. Transport Reviews, 27 (5), 529-549.

Borenstein, S. (1991). The Dominant-Firm Advantage in Multiproduct Industries: Evidence from the U. S. Airlines. The Quarterly Journal of Economics, 106 (4), 1237-1266.

Borenstein, S. (1992). The Evolution of U.S. Airline Competition. The Journal of Economic Perspectives, 6 (2), 45-73.

Borgatti, S. P. and M. G. Everett (2006). A Graph-theoretic perspective on centrality. Social Networks, 28 (4), 466-484.

Bowen, J. (2002). Network Change, Deregulation, and Access in the Global Airline Industry. Economic Geography, 78 (4), 425-439.

Burghouwt, G. (2007). Airline Network Development in Europe and its Implications for Airport Planning. Ashgate, Aldershot, Hampshire, England, Burlington, VT.

Burghouwt, G., J. Hakfoort and J. Ritsema van Eck (2003). The spatial configuration of airline networks in Europe. Journal of Air Transport Management, 9 (5), 309-323.

Cheung, R. K. and B. Muralidharan (2000). Dynamic Routing for Priority Shipments in LTL Service Networks. Transportation Science, 34 (1), 86-98.

Cidell, J. (2010). Concentration and decentralization: The new geography of freight distribution in us metropolitan areas. Journal of Transport Geography 18 (3), 363-371.

Conçeicão, P. and P. Ferreira (2000). The Young Person's Guide to the Theil Index: Suggesting Intuitive Interpretations and Exploring Analytical Applications. Tech. rep., UTIP Working Paper.

Costa, T. F. G., G. Lohmann and A. V. M. Oliveira (2010). A model to identify airport hubs and their importance to tourism in Brazil. Research in Transportation Economics, 26 (1), 3-11.

Crainic, T. G. (2000). Service network design in freight transportation. European Journal of Operational Research, 122 (2), 272-288.

Crainic, T. G. and G. Laporte (1997). Planning models for freight transportation. European Journal of Operational Research, 97 (3), 409-438.

Debbage, K. G. and D. Delk (2001). The geography of air passenger volume and local employment patterns by US metropolitan core area: 1973–1996. Journal of Air Transport Management, 7 (3), 159-167.

Delfmann, W. (2000). Hub-and-Spoke-Systeme. In: Klaus, P., Krieger, W. (Eds.), Gabler Lexikon Logistik, 2nd Edition. Gabler, Wiesbaden, pp. 189-190.

Derudder, B. and F. Witlox (2009). The impact of progressive liberalization on the spatiality of airline networks: a measurement framework based on the assessment of hierarchical differentiation. Journal of Transport Geography, 17 (4), 276-284.

Doganis, R. (2002). Flying off Course: The economics of international airlines, 3rd Edition. Routledge, London ; New York.

FAA (2009). Federal Aviation Administration, www.faa.gov (last accessed: Dec 09, 2009).

Hall, R. W. and H. Zhong (2002). Decentralized inventory control policies for equipment management in a many-to-many network. Transportation Research Part A: Policy and Practice, 36 (10), 849-865.

Hensher, D. A. (2002). Determining passenger potential for a regional airline hub at Canberra International Airport. Journal of Air Transport Management, 8 (5), 301-311.

Hesse, M. and J.-P. Rodrigue (2004). The transport geography of logistics and freight distribution. Journal of Transport Geography, 12 (3), 171-184.

Huber, H. (2009a). Comparing spatial concentration and assessing relative market structure in air traffic. Journal of Air Transport Management, 15 (4), 184-194.

Huber, H. (2009b). Spatial structure and network behaviour of strategic airline groups: A comparison between Europe and the United States. Transport Policy 16 (4), 151-162.

Klaus, P., Hartmann, E., Kille, C. (2009). TOP 100 in European Transport and Logistics Services. Deutscher Verkehrs-Verlag, Hamburg.

Lederer, P. J. and R. S. Nambimadom (1998). Airline Network Design. Operations Research, 46 (6), 785-804.

Martín, J. and A. Voltes-Dorta (2008). Theoretical Evidence of Existing Pitfalls in Measuring Hubbing Practices in Airline Networks. Networks & Spatial Economics, 8 (2/3), 161-181.

Martín, J. C. and A. Voltes-Dorta (2009). A note on how to measure hubbing practices in airline networks. Transportation Research Part E: Logistics and Transportation Review, 45 (1), 250-254.

McShan, S. and, R. Windle (1989). The implications of hub-and-spoke routing for airline costs and competitiveness. Logistics and Transportation Review, 25 (3), 209-230.

O'Connor, K. (2003). Global air travel: toward concentration or dispersal? Journal of Transport Geography, 11 (2), 83-92.

O'Kelly, M. E. and H. J. Miller (1994). The hub network design problem: A review and synthesis. Journal of Transport Geography, 2 (1), 31-40.

Papatheodorou, A. and P. Arvanitis (2009). Spatial evolution of airport traffic and air transport liberalisation: the case of Greece. Journal of Transport Geography, 17 (5), 402-412.

Powell, W. B. (1986). A Local Improvement Heuristic for the Design of Less-than-Truckload Motor Carrier Networks. Transportation Science, 20 (4), 246-257.

Reggiani, A., S. Signoretti, P. Nijkamp and A. Cento (2009). Network measures in civil air transport: A case study of Lufthansa. In: Naimzada, A. K., Stefani, S., Torriero, A. (Eds.), Networks, Topology and Dynamics: Theory and Applications to Economics and Social Systems. Vol. 613 of Lecture Notes in Economics and Mathematical Systems. Springer, Berlin, Heidelberg, pp. 257-282.

Reynolds-Feighan, A. (2001). Traffic distribution in low-cost and full-service carrier networks in the US air transportation market. Journal of Air Transport Management, 7 (5), 265-275.

Reynolds-Feighan, A. J. (1998). The Impact of US Airline Deregulation on Airport Traffic Patterns. Geographical Analysis, 30 (3), 234-253.

Saunders, L. F. and W. G. Shepherd (1993). Airlines: Setting constraints on hub dominance. Logistics and Transportation Review, 29 (3), 201-220.

Taaffe, E. J. and H. L. Gauthier (1973). Geography of transportation. PrenticeHall foundations of economic geography series. Prentice-Hall, Englewood Cliffs, N.J.

Theil, H. (1967). Economics and information theory. Vol. 7 of Studies in mathematical and managerial economics. North-Holland Pub. Co.; Rand McNally, Amsterdam, Chicago.

Toh, R. S. and R. G. Higgins (1985). The impact of hub and spoke network centralization and route monopoly on domestic airline profitability. Transportation Journal, 24 (4), 16-27.

Wieberneit, N. (2008). Service network design for freight transportation: a review. OR Spectrum, 30 (1), 77-112.

Wojahn, O. W. (2001). Airline Networks. Volkswirtschaftliche Analysen. Peter Lang, Frankfurt am Main et al.