Article publicat / *Published paper*:

Klophaus, R.; Merkert, R.; Lordan, O. Mesh network as a competitive advantage for European LCCs: An alternative topology to hub-and-spoke for selling online connections. "Transport policy", Juny 2021, vol. 106, p. 196-204. DOI: 10.1016/j.tranpol.2021.04.012

Mesh Network as a Competitive Advantage for European LCCs: An Alternative Topology to Hub-and-Spoke for Selling Online Connections

Richard Klophaus[a], Rico Merkert[b], Oriol Lordan[c]

[a] Worms University of Applied Sciences, Competence Center Aviation Management, Erenburgerstraße 19, D-67549 Worms, Germany, klophaus@hs-worms.de

[b] Institute of Transport & Logistics Studies, The University of Sydney Business School, NSW, 2006, Sydney, Australia, rico.merkert@sydney.edu.au

[c] Universitat Politècnica de Catalunya - Barcelona Tech., Department of Management, Colom 11, TR6, 3.17, 08222 Terrassa, Spain, oriol.lordan@upc.edu

Abstract

We introduce mesh networks as an alternative topology to hub-and-spoke networks for low-cost carriers (LCCs) to sell online connections, i.e., indirect connections requiring a transfer between direct connections within a carrier's own operated network. While a common global practice, none of the large independent intra-European LCCs has fully deployed such a network strategy. We define a point-to-point with online connections (PPWOC) representation to establish potential mesh networks for the three largest independent LCCs in Europe. After providing airline and airport metrics to describe structural properties, we also discuss managerial implications of the mesh networks and conclude that investing into hub-and-spoke systems may no longer be necessary if LCCs can gain and maintain a competitive advantage with the mesh network strategy.

1. Introduction

Establishing a hub-and-spoke network with time-coordinated arrivals and departures adds complexity, costs and vulnerability to an airline's operation, particularly in networks that comprise one or multiple capacity constraint airports. Hence, a core element of the archetypical low-cost carrier (LCC) business model is the point-to-point paradigm (e.g., Doganis, 2019). This paper conceptualizes an alternative network topology to hub-and-spoke (HS) for LCCs to sell online connections which allow passengers to transfer between flights operated by the same LCC using a single ticket. A mesh network combines an existing set of point-to-point (PP) routes with permissible geographical detour factors and connection time window thresholds for passenger transfers allowing an LCC to market online connections (i.e., indirect connections with all legs operated by the same carrier). The notion of an online connection might be a little confusing at first. However, the term represents a conceptual standard in the airline industry established well before the appearance of the Internet to distinguish passenger transfers between flights involving a change of airlines (offline connections) from passenger transfers with no change of airlines (online connections).

While "base airport" and "hub airport" are both well-established concepts, so far no airline network topology has been proposed to study passenger traffic flows which connect via LCC bases and other intermediate points between origin and destination airports. Our research is further motivated by recent airline failures (e.g., Air Berlin, Germania) and observable changes in the business model of large LCCs in Europe. For example, Ryanair which used to be considered a prime example for a pure LCC has departed from the point-to-point paradigm of the archetypical LCC business model by trialing the provision of online connections, i.e., indirect connections within the carrier's own network, via at this stage three of its base airports, namely Bergamo (BGY), Rome (FCO), and Porto (OPO) (Ryanair 2018a). However, easyJet and Wizz Air, the second and third largest independent European LCCs based on seat capacity, do not offer online connections at all.

Airlines can no longer be easily labeled as either LCCs or full-service network carriers (FSNCs) (Klophaus & Fichert, 2019). Instead, many carriers are evolving towards a hybrid business model (e.g., Klophaus, Conrady & Fichert, 2012; Lohmann & Koo, 2013; Daft & Albers, 2015; Fageda, Suau-Sanchez & Mason, 2015; Azadian & Vasigh, 2019) while other LCCs have become part of airline groups that include FSNCs (Pearson & Merkert, 2014). Network design has been highlighted as "perhaps the most important core element" to differentiate airline business models (Mason & Morrison, 2008). However, when it comes to route networks as an essential component of any airline business model, the discussion focuses on the dichotomy between PP and HS even when other possible network structures are mentioned (e.g., Corbo, 2017; Urban et al., 2018). Such a dichotomous network categorization might no longer be appropriate for LCCs offering online connections within a mesh network. In this regard, our research relates to the recent work of Fu et al. (2019) who explored network effects in PP airline networks by examining the spatial entry pattern of Southwest Airlines, the world's largest LCC.

As short-haul low-cost air travel has matured in Europe, the stimulation of additional air travel demand through low fares is getting increasingly difficult. Hence, European LCCs are trying to develop new market segments. To this end, a significant issue is the prospect of LCC long-haul services (De Poret, O'Connell & Warnock-Smith, 2015; Soyk, Ringbeck & Spinler, 2017). The move towards primary airports to attract business travelers has also been highlighted in the extant literature (e.g., Dobruszkes, Givoni & Vowles, 2017). Another emerging issue is the role of LCCs as feeder airlines to support the mainline operations of large FSNCs (Reynolds-Feighan, 2018). Interestingly, financial problems and failures of a number of hybrid carriers have triggered the market entrance of ultra-low cost carriers (Bachwich & Wittman, 2017). Despite all these trends and increasingly larger route networks, European LCCs have to date held back in terms of systematically offering connecting flights, as they want to avoid adding complexity and costs (Fageda, Suau-Sanchez & Mason, 2015). Nevertheless, it has been noted that the substantial number of overlapping route end nodes has opened up transfer possibilities between LCC flights (Maertens, Pabst & Grimme, 2016). Even if connections are not actively offered by the respective carriers, passengers can choose to self-connect. This travel option comes with the inconvenience of additional check-ins and the risk of missed onward flights. In Europe, a few airports actively support and market self-connections (Zeigler et al., 2017). The present paper will neither consider self-connect possibilities nor offline connections between different carriers established by code-sharing agreements that typically require procedures related to schedule coordination and proration between the involved airlines (Fichert & Klophaus, 2016). Instead, we analyze the potential for LCC online connections within a mesh representation. We use the term mesh rather than grid or lattice, as the notion of a grid tends to imply a more rigid network structure such as a pattern of straight lines that cross over each other to form squares. Similarly, lattice networks often refer to networks where nodes are arranged in a regular lattice (Boccaletti et al., 2006).

We do not consider hub connectivity and competition for long-haul traffic. A considerable amount of literature has been published on this topic (e.g., Grosche & Klophaus, 2015; O'Connell & Bueno, 2018; Zhu et al., 2019). We also do not measure accessibility defined as the number of direct and indirect connections available to consumers from a certain airport as travel origin. That a small airport might achieve high accessibility with a single direct connection to a hub if this opens up numerous indirect connections (Burghouwt & Redondi, 2013) is related research to ours, however, it assumes a different network perspective.

How to offer a route network for connecting traffic without increasing turnaround times, lowering aircraft utilization, and compromising cost advantages, has become a managerial issue for large European LCCs. In May 2017, Ryanair first launched online connections via Rome Fiumicino (FCO) to test new opportunities for revenue generation. Allowing for online connections is a significant divergence from the traditional LCC model with stand-alone routes. However, it would be an even bigger step to establish hub airports with a temporal coordination of the flight schedule in a wave-system structure that aims to maximize the number of transfer options (Klophaus & Fichert, 2019). Mesh networks may be a cost-efficient alternative for the provision of online connections with a limited geographical scope (i.e., short-haul to short-haul connections only) based on an existing set of PP services. We argue that mesh networks rather than HS networks would be more in line with the original LCC business model built on the prime concept of stand-alone routes.

The remainder of this paper is set out as follows. Section 2 provides an introduction into our proposed point-to-point with online connections (PPWOC) representation of mesh networks including a comparison of this topology with PP and HS. Section 3 sets the scene for our empirical analysis with an overview of the provision of short-haul online connections by the 20 largest LCCs worldwide. Section 4 describes how to build and measure online connections offered in a scenario where the three largest independent European LCCs (Ryanair, easyJet and Wizz Air) would deploy our proposed PPWOC representation and hence start offering online connections across their respective route networks. Section 5 uses airline and airport metrics to assess and compare the resulting hypothetical mesh networks of the three carriers and outlines managerial implications of the introduction of mesh networks with special attention to lessons that can be learned from the Ryanair trial. This is followed by a concluding Section 6 that offers a summary of our key findings as well as recommendations for future research.

2. Point-to-point with online connections (PPWOC) representation of mesh networks

Since the pioneering work of Guimerá & Amaral (2004), airline networks have been examined with graph metrics that were previously used to analyze social networks. The extant literature (e.g., Alderighi et al., 2007; Burghouwt & Redondi, 2013; Dai, Lordan et al., 2016; Derudder & Liu, 2018, Malighetti et al., 2019) classifies airline networks in terms of spatial and temporal configuration and also provides different connectivity measures. Our paper extends this research by defining mesh networks as an alternative topology to HS networks for LCCs that aim to serve transfer passengers by selling online connections without the complexities and costs of operating hubs. An online connection is defined as an indirect connection allowing passengers to transfer between consecutive flights operated by the same airline. Online connections allow passengers to travel from origin *j* to destination *k* via the intermediate airport *i* on the same ticket instead of having to buy two separate tickets from j to *i* and from *i* to *k* which has several major shortcomings (Fichert & Klophaus, 2016). A third party selling indirect connections on separate tickets (i.e., with different booking reference numbers) does not constitute an online connection even if the legs are all operated by the same carrier as the tickets will still be issued separately.

Within a static set of air routes, we conceive airports as nodes and direct connections (i.e., scheduled nonstop flights) as links between them. To differentiate between node types in a PPWOC representation of mesh networks, we distinguish between feasible and actual online connections via a given airport (see Table 1). For simplicity reasons, we consider 1-stop indirect connections only.

Table 1: Scheduling attributes of online connections

Attribute	**Name**	**Description**
S.1	Feasible online connection	Indirect connection observing geographical detour factor and connection window threshold set by carrier
S.2	Actual online connection	Feasible online connection effectively offered by carrier

As further specified in Section 4, geographical detour is the total distance of the indirect connection divided by the straight distance between origin and destination airport pairs. The connection window results from a minimum connection time and a maximum connection time, both set by the carrier, the former not having to coincide with the minimum connection times published by airports. In Section 4, we assume a common connection window for all online connections irrespective of the specific transfer airport in line with Ryanair's trial at three airports. All feasible online connections (S.1) together constitute the largest mesh network possible for each of the three largest independent LCCs in Europe, while the set of actual online connections (S.2) at present is limited to Ryanair's trial offer. The difference between S.1 and S.2 can be considered to indicate an untapped market opportunity. The presence or absence of feasible and actual online connections allows a differentiation between three node types (see Table 2).

Table 2: Node types considering online connectivity

Type	Name	Description
T.1	End node	No feasible online connection via node exists (S.1 = 0 which implies S.2 = 0)
T.2	Non-activated (intermediate) node	Although feasible online connections exist (S.1 > 0), no actual online connection is offered (S.2 = 0)
T.3	Activated (intermediate) node	Node serves as transfer airport. At least one online connection is offered (S.2 > 0 which implies S.1 > 0)

Using these node types enables us to illustrate not only that an actual (potential) mesh network requires at least one activated (non-activated) intermediate node (as shown in Figure 1) but also what it takes to get there starting with stand-alone PP routes without overlapping nodes.

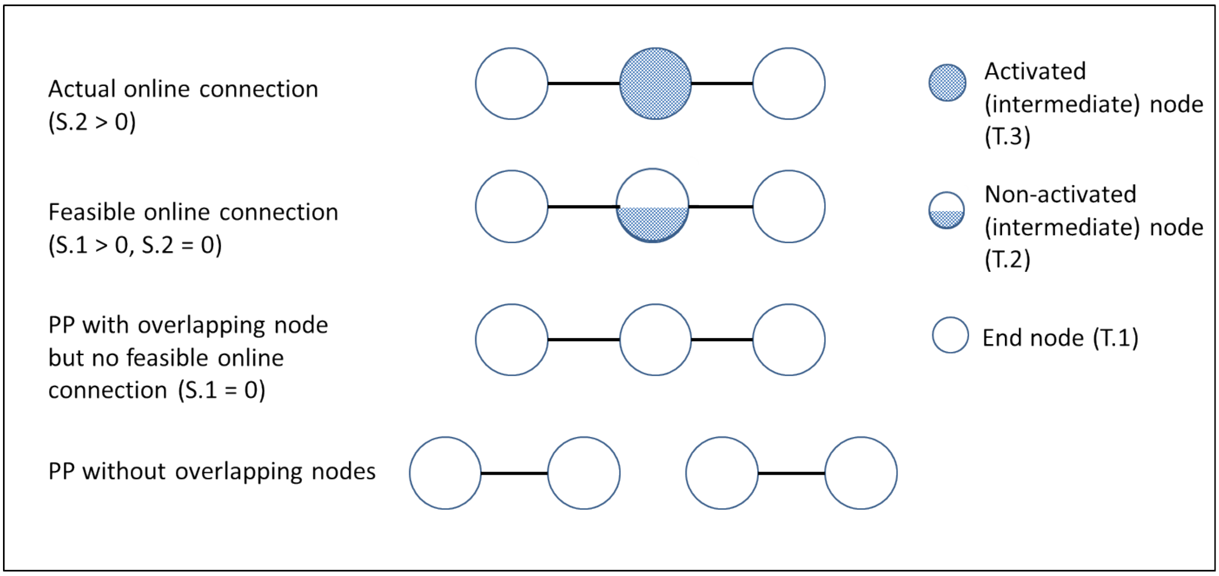


Figure 1. Mesh networks as PPWOC representation versus stand-alone PP routes

To illustrate the potential benefits of mesh networks, Table 3 which has been adapted from Klophaus & Fichert (2019, p. 65) compares the two topologies (HS versus mesh network) for providing online connections. "It does not account for differences in pricing (e.g., through fares), asset utilization (e.g., hub congestion), fleet requirements (e.g., heterogeneous fleet) or costs of operation which are influenced by the chosen network topology" (Klophaus & Fichert, 2019, p. 64). Although the use of a mesh network instead of an HS network for online connections might result in lower additional revenues from transfer passengers, this negative effect on revenues may be more than compensated by reduced operating costs. For example, in a decentralized mesh network with a large number of airports serving as intermediate nodes, longer turnaround times and lower aircraft utilization due to a centralized HS network might be avoided. Furthermore, the lack of a node hierarchy in a mesh network in principal enables each intermediate node to serve connecting passengers. While the potential for transfer passengers at every single intermediate node in a mesh network is rather small, online connections via many intermediate nodes might lead to a considerable number of transfer passengers. HS can be seen as an extreme type of mesh network, in which a central node (hub) is connected point-to-point to all other nodes (spokes) while there are no direct links between the other nodes (Klophaus & Fichert, 2019, p. 64). HS does not have intermediate nodes except for the hub as the single node in the route network of a given carrier that is activated by the carrier for actual online connections. Within a mesh network, certain airports are only connected to exactly one other airport while some airports are directly connected to two or more other airports.

A mesh network appears to be most relevant for transfer networks with a limited geographical scope (i.e., short-haul to short-haul connections only). Once a carrier operates long-haul services, a mesh network approach to transfer traffic might no longer be appropriate as short-haul operations may form part of a feeder network for long-haul services. That is especially true for LCCs belonging to large airline groups (e.g., Eurowings as part of the Lufthansa Group). If the geographical scope of a route network includes long-haul traffic, a mesh network configuration to serve short-haul to short-haul transfer traffic is likely to omit the cost advantages of a centralized network such as those resulting from economies of density and scale (Klophaus & Fichert, 2019, p. 65).

Table 3. Comparison of HS network with mesh network

Attribute	**HS network**	**Mesh network**
Geographical scope	• Intercontinental (Directional hub) • Continental and intercontinental (Hinterland hub) • Short-haul to short-haul (Regional hub)	Regional only (domestic or continental)
Scope of network planning	Direct and connecting traffic	(Primarily) direct traffic
Types of nodes	• Single activated node (hub) • End nodes (spokes)	• Activated nodes • Non-activated nodes • End nodes
Type of topology	Centralized	Decentralized
No. of intermediate nodes	Hub only	Multiple
No. of connecting services per intermediate node	Larger	Smaller
Coordination requirement of arrival and departure times	Higher	Lower
Average seat load factor on short-haul flights	Lower	Higher
Average transfer time	Lower	Higher
Average geographical detour	Higher	Lower
Pre-dominant profitability metric	Network profitability	Route profitability

Source: Adapted from Klophaus & Fichert (2019).

Without further information about the relative importance of the links between the nodes, for example with regard to the number of flight frequencies or the assigned network function of a particular node, there is in principle no node hierarchy in a mesh network. End nodes are obviously excluded as intermediate points for connecting passengers. In contrast, HS revolves around a star node, i.e., the hub airport as a central connection point between the other nodes (spokes) (Klophaus & Fichert, 2019, p. 64). The functioning of the hub is of crucial importance for the entire flight operations of the airline. In an LCC route network, basically every node can perform as an LCC base (i.e., an airport at which the carrier permanently positions aircraft and crew and from where it operates routes). The typically higher load factors of LCCs (2018 on average 85.2%) compared to

FSNCs (2018 on average 80.7%; see for example IATA, 2019) lend themselves to generate passenger transfers at LCC bases activated as part of a mesh network. Intermediate nodes are of course more likely candidates for LCC bases than end nodes. In the context of airline networks, it has been shown that not only the spatial configuration matters but also the temporal configuration (Burghouwt, 2007). It is the temporal configuration that distinguishes LCC bases from FSNC hubs. While the spatial mapping of routes offered at a given LCC base might resemble the one of a hub, the temporal configuration of arriving and departing flights in a wave-like structure is absent.

PPWOC allows LCC network planning to continue with a strategy that maximizes route profitability on a stand-alone basis. In addition to direct traffic, the network planners of LCCs deploying the mesh network concept will of course consider transfer traffic flows which will lead to somewhat modified flight schedules over time (e.g., changes in arrival and departure times of certain flights). In principal, however, there is less coordination of arrival and departure times to attract connecting traffic (Klophaus & Fichert, 2019, p. 65). According to Table 3, a mesh network has a higher average seat load factor than an HS network. This seems to contradict the notion that hub carriers have higher load factors because they benefit from the consolidation of different origin-destination markets on a limited number of routes (Burghouwt & Redondi, 2013). In our view, this only applies to long-haul flights that are fed by short-haul flights ("Hinterland hub") or other long-haul flights ("Directional hub") while the proposed mesh network concept focuses on short-haul to short-haul connections to add transfer traffic to already established direct traffic flows. As shown in Table 3, the lack of temporal coordination of inbound and outbound flights in a mesh network tends to result in higher average transfer times. This limits the level of connectivity that a single node in a mesh network can achieve compared to a large hub with a wave-system structure that maximizes the number of transfer options. However, as a large mesh network contains multiple intermediate nodes to serve connecting passengers, this might more than compensate for the limited connectivity provided by a single node itself. The average geographical detour in a mesh network is usually significantly lower compared to an HS network since the former provides additional direct links and avoids routings via a hub. Mesh networks allow LCCs to offer online connections while they can continue to assess each route as individual profit center. Hence, route profitability which allocates costs and revenues to each route within the airline network can be maintained as key profitability metric while an HS network with significant shares of transfer traffic requires measuring network profitability, i.e., assessing the profitability of each route as part of the overall network beyond stand-alone routes.

Table 3 assumes an HS network with only one activated node, i.e., a single hub. The large European groupings of traditional network carriers (Lufthansa Group, International Airlines Group (IAG), Air France/KLM Group) today all operate multiple hubs. For example, the Lufthansa Group hubs are Frankfurt, Munich, Zurich, and Vienna. Multiple hubs might appear to be in-between the HS network and the mesh network as described in Table 3, e.g., with regard to the average number of connecting services per intermediate node. However, this is not true for the pre-dominant profitability metric in an HS network which remains network profitability rather than stand-alone route profitability. Further, hubs of the same airline grouping should not be located too close to each other. There is a geographical limit to a multi-hub strategy aiming to accommodate connecting traffic while distance is less critical for the potential number of activated intermediate nodes in a mesh network as the scope of network planning remains (primarily) direct traffic.

3. Provision of short-haul online connections by LCCs worldwide

Ryanair, easyJet and Wizz Air belong to the world's largest LCCs. Further, they are independent carriers, i.e., no subsidiaries of airline groups that also encompass FSNCs. In the context of this paper, it is interesting to what extent LCC subsidiaries of large European airline groups as well as LCCs in other regions of the world at present operate routes on a similar scale without selling online connections. To this end, Table 4 ranks the TOP20 LCCs worldwide based on seat capacity. According to the OAG carrier categorization, globally there are a total of 112 LCCs in operation. The TOP20 LCCs stand for approx. 64.3% of the 33.7m seats offered by LCCs in the week ending Sep. 09, 2018 (OAG, 2018). Eight of the TOP20 LCCs have their domicile in Europe, five in North America and Asia, respectively, and two in South America. In comparison, Jetstar Airways (Rank 21) is the largest LCC in Australia and Mango (Rank 70) in Africa.

Table 4: Short-haul online connections among TOP20 LCCs worldwide

Rank	Airline	IATA code	Domicile	Total seat capacity	Short-haul online connections	Airline subsidiary (parent)	Widebody seat capacity	Turboprop seat capacity	Codesharing as operating carrier	Codesharing as marketing carrier
1	Southwest Airlines	WN	North America/US	3,893,709	Yes	No	--	--	--	--
2	Ryanair	FR	Europe/EU	3,044,034	No*	No	--	--	--	--
3	easyJet	U2	Europe/EU	2,241,578	No	No	--	--	--	--
4	Indigo	6E	Asia/India	1,508,800	Yes	No	--	41,440	1,260	1,260
5	JetBlue Airways	B6	North America/US	982,054	Yes	No	--	--	1,549,847	345,240
6	Lion Air	JT	Asia/Indonesia	978,981	Yes	No	--	4,725	12,635	12,635
7	Vueling Airlines	VY	Europe/EU	920,818	Yes	Yes (IAG)	--	--	1,162,655	--
8	Wizz Air	W6	Europe/EU	820,740	No	No	--	--	--	--
9	Eurowings	EW	Europe/EU	804,114	Yes	Yes (LH)	31,100	57,478	127,356	144
10	GOL	G3	South America/Brazil	797,586	Yes	No	--	--	1,338,842	927,823
11	AirAsia	AK	Asia/Malaysia	746,640	No	No	--	--	--	--
12	Pegasus	PC	Europe/Turkey	722,820	Yes	No	--	--	111,441	30,870
13	Spirit Airlines	NK	North America/US	701,922	Yes	No	--	--	--	--
14	Westjet	WS	North America/Canada	616,178	Yes	No	10,480	178,904	770,642	1,015,290
15	Azul	AD	South America/Brazil	538,572	Yes	No	18,156	81,970	247,080	233,248
16	Norwegian Air Shuttle	DY	Europe/Norway	527,056	Yes	No	70,204	--	--	--
17	Thai AirAsia	FD	Asia/Thailand	467,580	No	No	--	--	--	--
18	Frontier Airlines	F9	North America/US	466,070	Yes	No	--	--	--	94,039
19	Spring Airlines	9C	Asia/PRC	445,680	Yes	No	--	--	--	--
20	Jet2.com	LS	Europe/EU	427,860	No	No	11,028	--	--	--

* Trial online connections are offered at Bergamo (BGY), Porto (OPO) and Rome (FCO) airports only.

Source: Own compilation with data from company websites and OAG; seat capacities for week ending Sep. 09, 2018.

From the eight TOP20 LCCs residing in Europe, Vueling is part of International Airlines Group (IAG) and Eurowings belongs to Lufthansa Group (LH). Interestingly, both subsidiaries offer short-haul online connections. Out of the six independent European LCCs, only Norwegian and Pegasus allow for transfers within their own route network. Norwegian provides comprehensive information about connecting flights with one booking reference number stating a general charge of 7.00 GBP per person and leg for connecting flights and 15.00 GBP per person and leg via London Gatwick (Norwegian, 2018). Noteworthy, all LCCs that offer long-haul services with widebody seat capacity support online connections. Jet2.com also employs widebody capacity in the summer season with a leased Airbus A330 but only from the UK to the Canary Islands and Mediterranean destinations in Southern Europe. LCC fleets commonly include narrowbody jetliner of the Airbus A320 family or the rival Boeing 737 family. Having a heterogeneous fleet by also operating turboprop capacity is a departure from the traditional LCC business model. Turboprop aircraft often provides feeder services which might explain why all LCCs shown in Table 4 with turboprop seat capacity provide short-haul connections. Further, all LCCs involved in codesharing agreements as operating and/or marketing carrier that allow for offline connections between two different carriers also sell short-haul online connections. This indicates that the necessity to feed widebody long-haul flights with short-haul flights, the use of turboprop aircraft, and the experience gained with offline connections all facilitate the provision of short-haul online connections. Without entries in the corresponding columns of Table 4 it comes as no surprise that Ryanair, easyJet and Wizz Air are not yet offering short-haul online connections. However, the proposed mesh network concept opens up the possibility for such connections even in the absence of the influencing factors just mentioned.

It is interesting that the majority of the large independent European LCCS only offer direct connections while all North and South American LCCs provide short-haul online connections. Large LCCs in Asia also offer online connections. Air Asia (AK) is selling its "Fly-Thru" bookings only via Kuala Lumpur and Bangkok (AirAsia, 2018), and emphasizes for the rest of its network that it is a point-to-point carrier, hence the "No" in Table 4 regarding the provision of short-haul online connections. Thai AirAsia, another member of the AirAsia Group, deploys a similar strategy. The case of AK illustrates that an LCC does not necessarily apply a mesh network concept with many intermediate airports for the provision of online connections but can also follow a more traditional HS approach. While Vueling established online connections as early as 2010, this offer is still limited to Barcelona El Prat (BCN) despite of the carrier's growing network of operational bases across Europe. In contrast, Southwest Airlines offers connecting flights via many intermediate airports in its extensive network and, hence, essentially operates a decentralized mesh network instead of a centralized HS network even if intermediate airports are referred to as hubs.

4. Framework for building and measurement of feasible LCC online connections

In order to analyze the structural properties of potential mesh networks of Ryanair, easyJet and Wizz Air, we start by considering the scheduling attributes of online connections (see Table 1). In this paper we only compute feasible online connections as these three LCCs do not yet offer online connections apart from Ryanair's tentative trial. As a result, we do not account for actual online connections but rather discuss which airports are candidates to become intermediate nodes based on feasible online connections.

We establish a scenario of potential mesh networks for Ryanair, easyJet and Wizz Air assuming these carriers would start with a large-scale implementation of 1-stop online connections within their route network. Direct connections as nonstop flights are available from the OAG flight schedule database. Online connections must be bookable on the same ticket within a given carrier's operated route network. The connections are constructed for a single day (Wed., May 16, 2018) considering all nonstop routes operated by Ryanair, easyJet and Wizz Air that depart and end in Europe with Europe being defined as IATA regions EU1 and EU2. We do not require return connections to exist on the same day. We build the networks of feasible online connections by applying the following conditions:

- Maximum geographical detour (gfact) = 4. The factor is defined as total distance divided by straight distance between origin and destination (O&D) airport pairs.

- Minimum connection time (minCT) = 2.5h. Minimal amount of time allowed between two flights.
- Maximum connection time (maxCT) = 6h. Maximal amount of time allowed between two flights.

In combination, minCT and maxCT define a connection window. We assume a connection window with minCT=2.5h and maxCT=6h for all online connections, irrespective of the specific transfer airport. This is the connection window currently applied by Ryanair at BGY, FCO, and OPO. The high minCT indicates a soft approach by Ryanair to market online connections. After gaining more experience with this new product offering, Ryanair might decide to lower its carrier-specific minCT to get closer to airport-specific minCT. Ryanair has not published a maximum geographical detour (max. gfact) for offered indirect connections. Clearly, the routing from Eindhoven (EIN) to Weeze (NRN) via Faro (FAO) with a straight distance (gKMs) of only 59 kilometers and gfact=69.48 is not in high demand. Generally speaking, the shorter gKM, the higher is gfact. According to Burghouwt & Redondi (2013), typical threshold values for detour factors found in the literature are between 1.2 and 1.5. We argue that such maximum values for gfact would be too restrictive for short-haul to short-haul online connections offered by Ryanair, easyJet and Wizz Air as intra-European LCCs. Instead, we assume max. gfact=4.0 which allows routings such as Copenhagen to Oslo via London to be included in the mesh network. The choice of max. gfact=4.0 may be justified considering a similar maximum time factor (total travel time of indirect connection / minimum travel time of direct connection) in the Ryanair mesh network. Being more (less) restrictive with the conditions would reduce (increase) the number of feasible online connections. For example, when using the index number 100 for the feasible online connections of Ryanair obtained from max gfact=4.0, the index numbers 59.8 (77.4) result for gfact=1.5 (gfact=2.0). Without max gfact, the index rises to 130.9. While geographical detour factors are commonly used to define feasible indirect connections, some authors (e.g., Alderighi et al., 2007) use total travel time to determine airline connectivity as it better reflects passengers' preference pattern. Even if we can understand this argument well, data availability led us to apply a spatial rather than a temporal approach to define detour.

The study of air transport networks includes the topological analysis of global, regional, and airline alliance route networks (Klophaus & Lordan, 2018). We focus on individual airline networks conceptualizing each LCC route network as a directed graph that can be measured by airline and airport metrics. Airline metrics such as the number of intermediate and end nodes (airports) refer to the whole individual airline network and airport metrics to a single airport within this network. The metrics are used below to compare the mesh networks of Ryanair, easyJet and Wizz Air that would result if these LCCs decided to offer online connections throughout their respective short-haul route networks.

A basic airline metric is the number of direct connections (i.e., nonstop flights) between airports *i* and *j* for one day. Routes might be served with a single daily frequency or multiple frequencies. Unique direct connections only consider whether nodes are adjacent or not. Hence, the adjacency matrix *A* of the graph has values $a_{ij}=1$ when the LCC operates at least one direct connection between airports *i* and *j*, and zero otherwise. Non-unique direct connections separately capture multiple daily flight frequencies and, thus, allow for $a_{ij}>1$.

The number of online connections $g_{jk}(i)$ linking origin *j* and destination *k* via airport *i* is another airline metric. Indirect connections provided by the same carrier may have more than two legs, however, our analysis of transfer opportunities within mesh networks of intra-European LCCs does not consider multi-stop connections. Unique online connections require at least one online connection to exist, i.e., $g_{jk}(i)=1$ when the LCC operates has at least one online connection between airports *j* and *k* via airport *i*, and zero otherwise. With non-unique online connections all online connections on a given route are counted separately which allows for $g_{jk}(i)>1$.

Two basic airport metrics are degree and betweenness. The degree d_i of an airport *i* is the number of unique direct connections of this node for a given day:

$$d_i = \sum_j^n a_{ij}, \tag{1}$$

where the sum is over all nodes in the carrier's network. The degree score indicates the transfer potential of a single airport: The degree of an end node equals 1, large-degree nodes would commonly be referred to as hubs. A degree distribution *P(d)* captures how many nodes have each degree: P(*d*) = fraction of nodes in the graph with degree *d*.

Betweenness b_i of an airport *i* is the number of times the airport acts as a bridge for an online connection divided by all online connections in the carrier's network:

$$b_i = \sum_{j \neq k}^{n} \frac{g_{jk}(i)}{g_{jk}}. \tag{2}$$

5. Potential mesh networks of Ryanair, easyJet and Wizz Air

In the European Union (EU), carriers operate in a deregulated environment. LCCs with an Air Operator Certificate (AOC) registered in one EU Member State are free to operate on any route within the EU (Klein et al., 2015). Ryanair (FR), easyJet (U2), and Wizz Air (W6) took advantage of this by developing bases with significant destination coverage, many of them outside their home countries, providing potential for online connections. In the meantime, all three of them operate a comprehensive route network across Europe. However, most of their routes are still marketed on a stand-alone basis. Online connections are only offered by Ryanair as a trial via BGY, FCO and OPO. With the aim to show the commercial potential of mesh networks in the European LCC context, we deploy the specified parameter settings (minCT=2.5h, maxCT=6h, and max. gfact=4.0) to analyze and compare hypothetical mesh networks of Ryanair, easyJet, and Wizz Air that would result if these carriers decided to sell online connections throughout their respective route networks. Based on OAG schedule data, the eligible connections are built for operated flights on May 16, 2018. The resulting airline metrics of the individual potential mesh networks of our three case carriers (FR, U2 and W6) are shown in Table 5. These include the number of total nodes, intermediate nodes and end nodes. For example, the total number of nodes served by Ryanair was 170 of which 104 were intermediate nodes and 66 end nodes. The ratio of intermediate nodes to total nodes for Ryanair (61.2%) is greater than for easyJet (56.4%) and Wizz Air (39.6%). Ryanair operated around 85 bases with positioned aircraft and crew (Ryanair, 2018b). easyJet and Wizz Air had approximately 30 and 25 bases, respectively. While Ryanair operated a total of 2,336 direct connections (i.e., nonstop frequencies), Table 5 only shows the 2,158 of them that had a point of origin and a point of destination within Europe defined as IATA regions EU1 and EU2.

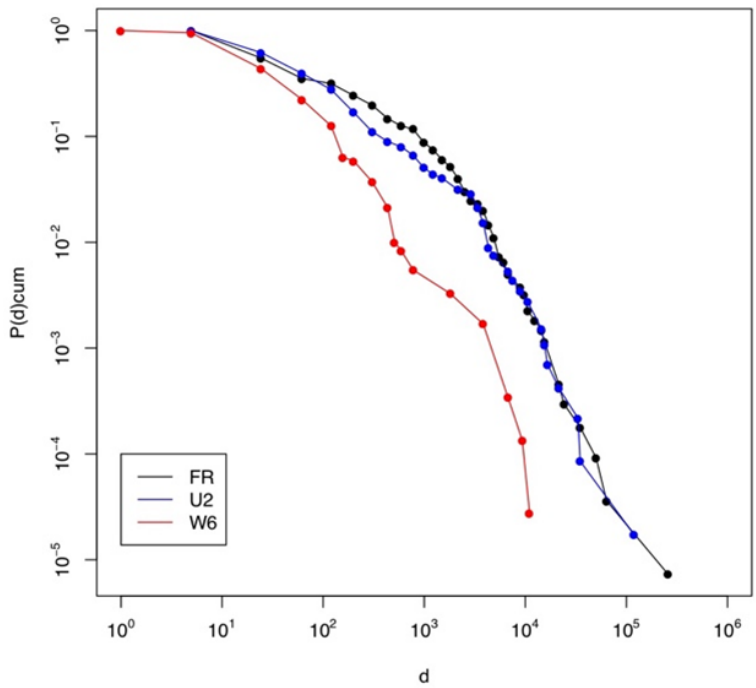
Different total seat capacities provided by these carriers (see Table 4) while operating similar-sized aircraft are reflected by different numbers of direct connections. Wizz Air has a much smaller total seat capacity than Ryanair and easyJet but serves relative to its seat capacity twice as many nodes. This already indicates that Wizz Air operates many of its routes with low frequency. The distinctive topology of the Wizz Air network is also shown by the lower ratio of intermediate nodes to total nodes. Table 5 further contains the total number of unique direct connections, i.e., the number of airport pairs served nonstop regardless of the frequency of service. The average frequency per airport pair is the number of direct connections divided by the number of unique direct connections. The ratio is greater for easyJet (1.60) than for Ryanair (1.29) and Wizz Air (1.12) which suggests that easyJet deploys a network strategy that aims to be more appealing to business travelers.

Table 5: Airline metrics for Ryanair, easyJet and Wizz Air within Europe on May 16, 2018

Airline metric	**Ryanair**	**easyJet**	**Wizz Air**
Total nodes	170	117	96
Non-activated intermediate nodes	101	66	38
Activated intermediate nodes	3	0	0
End nodes	66	51	58
Direct unique connections	1,670	1,034	429
Direct non-unique connections	2,158	1,652	479
Online connections (unique)	8,188	6,051	429
Online connections (non-unique)	9,060	7,427	437
Online connections / direct connections (unique)	4.90	5.85	1.00
Online connections / direct connections (non-unique)	4.20	4.50	0.91

As shown in Table 5, within our model scenario on May 16, 2018, the number of non-unique 1-stop online connections in the mesh network of Ryanair (easyJet) would have amounted to 9,060 (7,427). In comparison, the mesh network of Wizz Air would have allowed for 437 online connections only. Even when accounting for the different scale of operation, this is a significant finding which suggests that the present Wizz Air network does provide only limited scope for online connections based on our assumptions for connection building. We argue that this is a result of its flight schedule with relatively few route overlaps and a low average frequency per airport pair.

However, while Table 5 suggests that it might not be a commercially fitting network strategy for Wizz Air to allow for every intermediate node in its network to serve connecting passengers, it might still be an option for some intermediate nodes with a high number of direct connections to other nodes. To this end, Figure 2 depicts the cumulative degree and betweenness distributions of Ryanair, EasyJet and Wizz Air as double-logarithmic graphs. Ryanair and easyJet have similar distributions with a low initial gradient and are concave in shape. Both carriers have more uniform distributions than Wizz Air, i.e., Wizz Air has a more centralized network in terms of degree and betweenness.



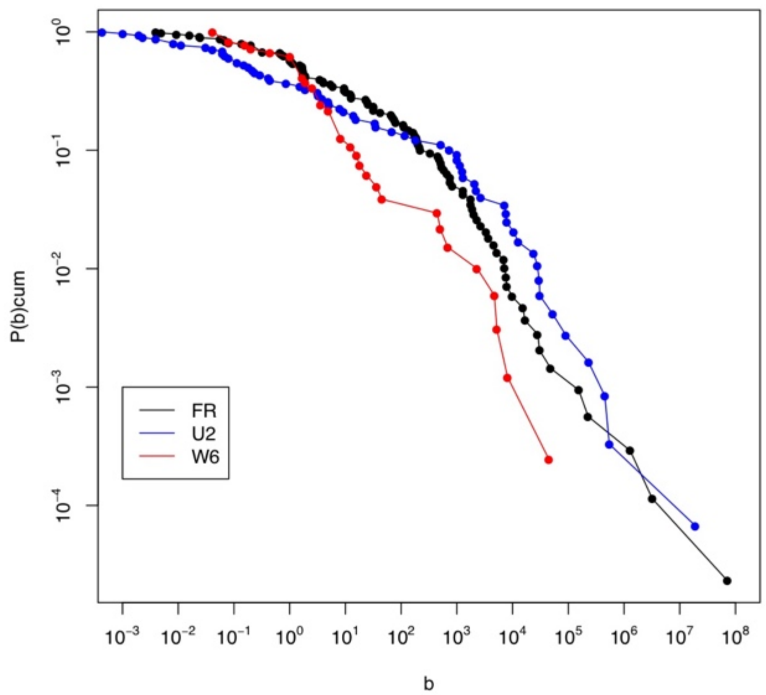


Figure 2. Cumulative degree and betweenness distributions for Ryanair, easyJet and Wizzair

Evaluating the networks at the individual airport level, Table 6 ranks the airports of Ryanair, easyJet and Wizz Air based on their degree scores. The scores of the airports with the highest degrees (highest betweenness) in the respective networks are 224 (2,578) and 160 (1,461) for Ryanair and easyJet, respectively. Such scores allow for a relatively large number of connecting services. In comparison, the maximum degree of 57 as well as the maximum betweenness of 105 within the Wizz Air network is relatively small. However, although the majority of nodes served by Wizz Air have only very limited potential for online connections, this assertion might not hold for the eight out of a total of 96 airports within the network of Wizz Air that have degree scores (betweenness scores) of 26 (17) or above. In comparison, at least 20 direct connections exist among 30% (20%) of all Ryanair (easyJet) airports which represent 51 (23) airports served.

Table 6: TOP 20 airports of Ryanair, easyJet and Wizz Air based on degree scores

Rank	Ryanair				easyJet				Wizz Air			
	Airport		d_i	b_i	Airport		d_i	b_i	Airport		d_i	b_i
1	London Stansted	STN	224	2578	London Gatwick	LGW	160	1461	London Luton	LTN	57	50
2	Dublin	DUB	122	669	Geneva	GVA	94	310	Budapest	BUD	53	105
3	Bergamo	BGY	110	450	London Luton	LTN	92	213	Bucharest	OTP	46	41
4	Brussels Charleroi	CRL	94	179	Milan Malpensa	MXP	76	286	Gdansk	GDN	36	39
5	Barcelona El Prat	BCN	80	212	Basel	BSL	68	112	Sofia	SOF	36	15
6	Madrid	MAD	76	109	Bristol	BRS	66	89	Warsaw	WAW	36	29
7	Alicante	ALC	66	49	Berlin Schoenefeld	SXF	64	88	Cluj-Napoca	CLJ	26	14
8	Palma de Mallorca	PMI	66	89	Amsterdam	AMS	56	80	Katowice	KTW	26	17
9	Berlin Schoenefeld	SXF	66	86	Manchester	MAN	56	49	Bergamo	BGY	18	3
10	Malaga	AGP	64	39	Paris Ch. de Gaulle	CDG	52	85	Dortmund	DTM	18	2
11	Manchester	MAN	60	68	Nice	NCE	48	61	Eindhoven	EIN	16	5
12	Rome Ciampino	CIA	56	66	Edinburgh	EDI	46	48	Skopje	SKP	16	1
13	Krakow	KRK	54	49	Lyon	LYS	40	47	Barcelona El Prat	BCN	15	0
14	Porto	OPO	54	54	Berlin Tegel	TXL	40	143	Athens	ATH	14	5
15	Bologna	BLQ	52	46	Belfast	BFS	38	56	Bologna	BLQ	14	1
16	Frankfurt	FRA	46	16	Bordeaux	BOD	36	22	Paris Beauvais	BVA	14	1
17	Valencia	VLC	46	26	Naples	NAP	36	23	Kiev	IEV	14	3
18	Faro	FAO	44	7	Palma de Mallorca	PMI	36	28	Malmo	MMX	14	4
19	Pisa	PSA	44	47	Toulouse	TLS	36	29	Belgrade	BEG	12	2
20	Budapest	BUD	42	19	Malaga	AGP	34	8	Berlin Schoenefeld	SXF	12	4

Table 6 shows that in each of the three LCC networks an airport from the London metropolitan area (STN, LGW, LTN) has the highest degree (d_i), i.e., the highest number of direct connections to other nodes, which translates into opportunities for online connections. High degree scores at least partially explain why Ryanair picked Bergamo (BGY), Porto (OPO) and Rome (FCO) for its trial to provide online connections (see Section 6). BGY and OPO belong to the TOP 20 airports of Ryanair based on degree scores and FCO follows immediately on one of the following ranks from a total set of 170 airports served by the carrier. easyJet's degree and betweenness scores in Table 6 suggest that the carrier has a similar perspective for implementing the mesh network concept as Ryanair. Figure 3 shows the relation between betweenness (b_i) and degree (d_i) in the Ryanair network. There is a positive exponential relationship between them. The three Ryanair airports with the highest degree also have the highest betweenness. We consider both metrics to indicate a business opportunity for Ryanair to implement a mesh network with many airports. A similar assertion holds for easyJet and for the highest ranked airports in the Wizz Air network.

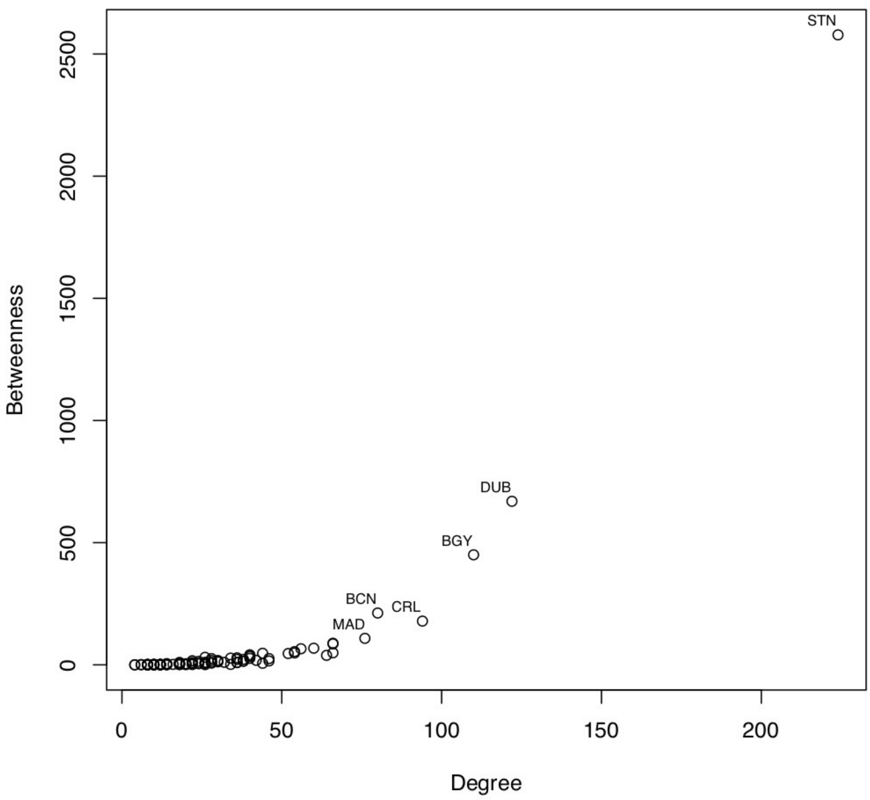


Figure 3. Betweenness and degree scores of the airports in the Ryanair network

We established (potential) mesh networks for Ryanair, easyJet and Wizz Air assuming these carriers would effectively offer all feasible online connections within their respective route networks. Among these three LCCs, the present route network of Wizz Air is the least suitable for actual online connections. Wizz Air operates routes with lower frequency and also has a much higher share of end nodes which cannot serve as transfer points for connecting traffic. However, this does not rule out that Wizz Air could select several airports with relatively high degree scores to serve as transit points for connecting traffic.

Unlike easyJet and Wizz Air, Ryanair is trialing online connections. Although London Stansted (STN) is Ryanair's airport with the highest degree and betweenness scores (see Table 6) , the carrier does not yet provide online connections via STN and instead decided for actual online connections via Bergamo (BGY), Rome Fiumicino (FCO), and Porto (OPO) which are also important Ryanair bases. Ryanair applies a connection window with minCT=2.5h and maxCT=6h and the offered online connections include airside transfer between connecting flights, checked-in baggage transfer through to the final destination, and the issuance of one booking reference for both flights. Ryanair also takes some responsibility for delays and cancellations stating on its website that: "If you've booked a connecting flight with us (one reservation number) and you miss your connection because your first flight is cancelled or delayed, we'll make sure you're transferred to our next available flight to your final destination. Alternatively, you may be entitled to a flight back to your original destination and to a refund" (Ryanair, 2018c). It should be noted that this offer is mandatory under the EU regulation on passenger rights.

Porto became the latest airport at which Ryanair offers online connections. The case of connecting flights by Ryanair via Porto has been investigated by Klophaus & Fichert (2019). These connecting flights as announced in January 2018 covered 12 European origins and four Portuguese destinations. They are shown on the Ryanair website as "1 stop" connections. Klophaus & Fichert (2019) found several rather surprising inbound/outbound relations. For example, the Ryanair offer of eight weekly connections from Madrid to Lisbon, but none in the other direction. Unbalanced frequencies or even completely missing connections in one direction are likely to reduce overall demand by transfer passengers in the long term due to the bi-directional causal relationship between supply and demand (e.g., Baker et al., 2015). In the short term this unsatisfied demand would either chose another airline, other modes of transport or not travel at all.

The provision of online connections does not necessarily imply a move towards integrated hub operations with schedule-coordinated inbound and outbound flights which would tend to result in slower turnaround times, lower aircraft utilization, and, hence, higher operating costs. Ryanair has not changed its schedule of arriving and departing flights in Porto to accommodate connecting passengers between the summer schedules 2017 and 2018, i.e., there has been no observable reorganization of the flight schedule towards a wave-system structure to maximize the number of connecting opportunities (Klophaus & Fichert, 2019). Passenger charges at hub airports for transfer passengers are typically lower than for originating passengers. The airport charge for transfer passengers in Porto is also below the charge for originating passengers (Klophaus & Fichert, 2019). Further, missed connections cause additional costs for the carrier. Given the rather generous minCT=2.5h set by Ryanair, the number of missed connections should be relatively low. Consequently, the cost difference between a passenger with a 1-stop connection and two passengers flying the itinerary's legs separately should be rather small.

Ryanair still builds its business around stand-alone routes, but has taken first steps to make use of its large route network with many intermediate nodes to grow its passenger numbers beyond direct traffic by offering booking options for transfer traffic. It is not yet clear whether the carrier will allow for more online connections in the future. However, the provision of short-haul to short-haul online connections within mesh networks might enable LCCs to achieve and maintain a competitive advantage over FSNCs. While the costs of implementing a mesh network should be lower than those of an HS network, there will still be some additional cost-causing processes (e.g., luggage transfers) due to connecting services. We argue that these costs will be more than offset by traffic and revenue increases.

6. Conclusions

Network strategy is a critical component of any airline business model. This paper has introduced the concept of a mesh network as a conceivable future network topology for European LCCs. As the mesh network topology can be considered to be the middle ground between point-to-point and hub-and-spoke, we would like to think that it offers a further perspective and contribution to the academic and managerial discussion on how to create competitive advantage in the context of LCCs serving connecting passengers with a limited geographical scope, i.e., short-haul to short-haul connections only.

At the core of the original business model of the largest independent European LCCs (Ryanair, easyJet and Wizz Air) is the concept of stand-alone routes. If these LCCs start to offer (or are considering) online connections within their route network, they can choose between two basic strategic approaches (Klophaus & Fichert, 2019, p. 73): "1) To establish a spatial network structure with spokes linked to a single (or a few) hub airport(s) together with a temporal coordination of inbound and outbound flights, or 2) to make use of their mesh network and offer online connections at many intermediate nodes based on already existing flight schedules." The first option would further blur the line between LCCs and FSNCs. Carriers that set up or operate an HS network may not even be called "hybrids" anymore. In contrast, the second option would be more in line with the original LCC business model with stand-alone routes. In our view, since there are two strategic options for actual online connections, one should be careful to refer to HS as the evolving network typology for large LCCs. Our analysis has shown that online connections can be provided via multiple intermediate points of LCC route networks, and our findings suggest that the commercial potential for both Ryanair and easyJet would be substantial should they decide to partially or fully implement a mesh network strategy using our proposed point-to-point with online connections (PPWOC) representation. In comparison, the present Wizz Air network provides only limited scope for online connections.

An integrated hub-and-spoke system increases the operational complexity and vulnerability of an airline compared to operating independent point-to-point routes. It requires a departure from the LCC business model. In comparison, we believe that using a mesh network to offer online connections is less risky and less complex. It appears to be the more cost-efficient topology for LCCs to offer short-haul to short-haul online connections. The implementation of a mesh network concept does not require LCCs to change their schedules. The scope of network planning could remain on direct traffic but LCCs could generate additional revenue from offering online connections.

For further research, the weighting of links by frequency, seat capacity, etc. would add another dimension of heterogeneity within the network beyond the basic topology. It might be worthwhile to study whether the move of Lufthansa as the largest FSNC grouping in Europe from a single hub strategy to a multi-hub strategy over the last decade might have been influenced by similar cost considerations. Should Ryanair maintain or even expand its offer of online connections in the future, it might also be worthwhile to conduct in-depth research on the correlation with fare variations in line with the analysis done by Cattaneo et al. (2018).

References

AirAsia (2018). Connecting flights. Available at: https://www.airasia.com/my/en/our-connections/connecting-flights.page. [Accessed 1 November 2018].

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

Azadian, F., Vasigh, B. (2019). The blurring lines between full-service network carriers and low-cost carriers: A financial perspective on business model convergence, *Transport Policy*, 75, 19-26.

Bachwich, A. R., Wittman, M. D. (2017). The emergence and effects of the ultra-low cost carrier (ULCC) business model in the U.S. airline industry, *Journal of Air Transport Management*, 62, 155-164.

Baker, D., Merkert, R. and Kamruzzaman, M. (2015): Regional aviation and economic growth: cointegration and causality analysis in Australia, *Journal of Transport Geography*, 43, 140-150.

Boccaletti, S., Latora, V., Morenod, Y., Chavez, M., Hwang, D.-U. (2006). Complex networks: Structure and dynamics, Physics Reports, 424, 175-308.

Burghouwt, G. (2007). Airline Network Development in Europe and its Implications for Airport Planning, Routledge.

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

Cattaneo, M., Malighetti, P., Redondi, R., Salanti, A. (2018). Changes in frequencies and price variations on point-to-point routes: The case of EasyJet, *Transportation Research Part A: Policy and Practice*, 112, 60-70.

Corbo, L. (2017). In search of business model configurations that work: Lessons from the hybridization of Air Berlin and JetBlue, *Journal of Air Transport Management*, 64, 139-150.

Daft, J., Albers, S. (2015). An empirical analysis of airline business model convergence, *Journal of Air Transport Management*, 46, 3-11.

Dai, L., Derudder B., Liu, X. (2018). The evolving structure of the Southeast Asian air transport network through the lens of complex networks, 1979–2012, *Journal of Transport Geography*, 68 (2018) 67–77.

De Poret, M., O'Connell, J. F., Warnock-Smith, D. (2015). The economic viability of longhaul low cost operations: Evidence from the transatlantic market, *Journal of Air Transport Management*, 42, 272-281.

Dobruszkes, F., Givoni, M., Vowles, T. (2017). Hello major airports, goodbye regional airports? Recent changes in European and US low-cost airline airport choice, *Journal of Air Transport Management*, 59, 50-62.

Doganis, R. (2019). Flying Off Course, 5th ed., Routledge.

Fageda, X., Suau-Sanchez, P., Mason, K. J. (2015). The evolving low-cost business model: Network implications of fare bundling and connecting flights in Europe, *Journal of Air Transport Management*, 42, 289-296.

Fichert, F., Klophaus, R. (2016). Self-connecting, codesharing and hubbing among LCCs: From point-to-point to connections? *Research in Transportation Business & Management*, 19, 94-98.

Fu., X., Jin, H., Liu, S., Oum, T. H., Yan, J. (2019). Exploring network effects of point-to-point networks: An investigation of the spatial patterns of Southwest Airlines' network, *Transport Policy*, 76, 36-45.

Grosche, T., Klophaus, R. (2015). Hubs at risk: Exposure of Europe's largest hubs to competition on transfer city pairs. *Transport Policy*, 43, 55-60.

Guimerá, R., Amaral, L. A. N. (2004). Modeling the world-wide airport network, *The European Physical Journal B*, 38, 381-385.

IATA (2019). World Air Transport Statistics 2019, Montreal-Geneva.

Klein, K., Albers, S., Allroggen, F., Malina, R. (2015). Serving vs. settling: What drives the establishment of low-cost carriers' foreign bases? *Transportation Research Part A: Policy and Practice*, 79, 17-30.

Klophaus, R., Conrady, R., Fichert, F. (2012). Low cost carriers going hybrid: Evidence from Europe, *Journal of Air Transport Management*, 23, 54-58.

Klophaus, R., Fichert, F. (2019). From Low-cost Carriers to Network Carriers without Legacy? Evolving Airline Business Models in Europe. In: Cullinane, K. (Ed.): Airline Economics in Europe (Advances in Airline Economics, Vol. 8), Emerald Publishing, 57-76.

Klophaus, R., Lordan, O. (2018). Codesharing network vulnerability of global airline alliances. *Transportation Research Part A: Policy and Practice*, 111, 1-10.

Lohmann, G., Koo, T. T. R. (2013). The airline business model spectrum, *Journal of Air Transport Management*, 31, 7-9.

Lordan, O., Sallan, J. M., Escorihuela, N., & Gonzalez-Prieto, D. (2016). Robustness of airline route networks, *Physica A: Statistical Mechanics and its Applications*, 445, 18-26.

Maertens, S., Pabst, H., Grimme, W. (2016). The scope for low-cost connecting services in Europe - Is self-hubbing only the beginning? *Research in Transportation Business & Management*, 21, 84-93.

Malighetti, P., Martini, G., Redondi, R., Scotti, D. (2019). Air transport networks of global integrators in the more liberalized Asian air cargo industry, *Transport Policy*, 80, 12-23.

Mason, K. J., Morrison, W. G. (2008). Towards a means of consistently comparing airline business models with an application to the 'low cost' airline sector, *Research in Transportation Economics*, 24, 75-84.

Norwegian (2018). Connecting flights. Available at: https://www.norwegian.com/uk/booking/booking-information/connecting-flights. [Accessed 1 November 2018].

OAG (2018). Schedules Analyser, https://www.oag.com/hubfs/Product_Sheets/Analyser%20Product%20Sheets/SchedulesAnalyser-PS-Mar2018.pdf

O'Connell, J. F., Bueno, O. E (2018). A study into the hub performance Emirates, Etihad Airways and Qatar Airways and their competitive position against the major European hubbing airlines, *Journal of Air Transport Management*, 69, 257-268.

Pearson, J., Merkert, R. (2014). Airlines-within-airlines: a business model moving East, *Journal of Air Transport Management*, 39, 21-26.

Reynolds-Feighan, A. (2018). US feeder airlines: Industry structure, networks and performance, *Transportation Research Part A: Policy and Practice*, 117, 142-157.

Ryanair (2018a). Connecting Flights At Porto Now Live. Press release, 03 Jan 2018.

Ryanair (2018b). Our Network. Available at: https://corporate.ryanair.com/network. [Accessed 7 November 2018].

Ryanair (2018c). Connecting Flights. Available at: https://www.ryanair.com/gb/en/useful-info/help-centre/faq-overview/Making-a-reservation/Connecting-flights. [Accessed 3 August 2018].

Soyk, C., Ringbeck, J., Spinler, S. (2017). Long-haul low cost airlines: Characteristics of the business model and sustainability of its cost advantages. *Transportation Research Part A: Policy and Practice*, 106, 215-234.

Urban, M., Klemm, M., Ploetner, K. O., Hornung, M. (2018). Airline categorisation by applying the business model canvas and clustering algorithms, *Journal of Air Transport Management*, 71, 175-192.

Zeigler, P., Pagliari, R., Suau-Sanchez, P., Malighetti, P., Redondi, R. (2017). Low-cost carrier entry at small European airports: Low-cost carrier effects on network connectivity and self-transfer potential, *Journal of Transport Geography*, 60, 68-79.

Zhu, Z., Zhang, A., Zhang, Y., Huang, Z., Xu, S. (2019). Measuring air connectivity between China and Australia, *Journal of Transport Geography*, 74, 359-370.