Measuring Onward Connectivity with a Prescriptive Approach.

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Abstract

Although connectivity has been the focus of several topics in the research field, onward connectivity has received less attention, despite the fact that it can shed light on various issues; in the context of a mature air transport market and an increasingly dense airport network. We propose several ways to measure onward connectivity, some of which are based on connectivity literature whilst others are suggested in the light of a qualitative study on the needs and wants of a particular customer segment in the case study of Castellon airport. We apply our measures to this case to determine the best hub to connect to for this segment and provide the connection that maximises the demand catered for and could bring profitability. Our work opens new avenues for studying connectivity from a perspective based on market demand as well as using onward connectivity for prescriptive applications.

Keywords

air transport; connectivity; airport strategy; industrial cluster; hub and spoke

1.- Introduction

The demand for air transport has increased significantly during the last thirty years, except for short periods of economic downturn. Air traffic has more than doubled since the shock of the 11-S terrorist attacks in 2001, reaching 4.54bn passengers in 2019. The fleet of commercial aircraft with more than 100 seats and freighters capable of transporting more than 100 tonnes stood at around 20,500 units at the beginning of 2017, and the number of routes increased by 1,300 between 2017 and 2018, reaching a total of almost 22,000 (*IATA, 2019*). The COVID-19 pandemic has brought an abrupt halt to the last growth cycle, but vaccine proliferation suggests that 2019 levels will be recovered before 2024 (Eurocontrol, 2020). This article is based on pre-crisis data, and should be applied to a post-crisis situation.

Pre-pandemic growth in air traffic drove an increase in the number of airport infrastructures built and put into service. The number of airports affiliated to the Airports Council International (ACI) grew at a rate of approximately 40 new airports per year, reaching over 1,940 affiliated airports in 2017. To put these figures into perspective, a country like Spain has 52 airports, six of which have been built in this century.

These new airports are built to increase the air connectivity of the regions in which they are located. Even small airports can play an important role for travellers, reducing their travel times and costs (Redondi, Malighetti and Paleari, 2013), and attracting foreign direct investments (Bannò and Redondi, 2014). The context described above suggest that life should be easy for these new and small airports; however, it is not the case.

On one hand, many of these new airports serve sparsely populated regions. On the other, growth in the number of airports means the network is becoming too dense, and new airports are located too close to existing ones. In this context, the potential passengers located in the area of influence of the new airport do, in fact, consider these new options, although this does not mean they discard any pre-existing airport they have used. Consequently, new airports compete in a highly competitive market.

Accordingly, the scenario these airports face is one where pre-existing airports have a clear advantage, since they have probably been operating for years, possibly for decades, and consequently have developed favourable logics in the strategic scope, i.e. economies of scale, symbiotic relationships with suppliers, learning, etc. In short, the general competitive strategy theory (*Porter, 1985*) is applicable (Graham, 2010).

To tackle this challenge, new airports need to develop competitive skills, as well as strategic reach capabilities. These capabilities, once tailored to newcomers in a market, will help them find their niches. We are talking about capabilities such as knowledge about the passengers and potential passengers in the market they are

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attempting to break into, as well as knowledge about the operating standards of the industry in which they aim to provide a service: the airline industry.

Low-cost airlines have been growing constantly for decades, driven by the liberalisation of the airline sector. They initially captured the majority of the leisure segment, but then evolved to capture an increasing share of the business segment, as well as the visiting friends and relatives (VFR) segment, in a process of hybridisation which has already been studied in literature (Lohmann and Koo, 2013; Pereira and Caetano, 2015). These last two segments have always been the main audience of traditional airlines which offered a broad range of destinations, thanks to their hub and spoke networks.

New airports initially capture the interest of low-cost airlines and their ambitious growth strategies, therefore capturing leisure travellers, but this does not always mean they can break even. To be successful, new airports have to capture travellers from other local market segments. When the market is small, it is not time to focus, it is time to fill the segments (Rapp and Collins, 1992). How can this be achieved? How can they reach clients who want to travel to different destinations (but only a few to each of those destinations)? The answer is well documented: by linking to a hub. The question is, which hub? Which is the most suitable hub airport? Which one can capture a substantial part of the market (enough to make the route profitable)? Literature on connectivity has suggested the tool that can answer these questions: onward connectivity. As far as we know, the tool has not been developed, which justifies our research work. Our purpose is to propose methodologies to measure the connectivity of an airport through a hub (onward connectivity). To compare and draw conclusions about these measures, we applied them to a case study, Castellon airport, in Spain.

The article continues as follows. Section 2 reviews the literature focusing on connectivity, presents our case study and delivers our initial proposal to measure onward connectivity. Section 3 applies these onward connectivity measures to our case study, presenting the main results obtained as well as the issues surrounding their application. It proposes alternatives to these problems and discusses the results. Section 4 offers conclusions and opens up further opportunities for this line of research.

2.- Material and methods

2.1.- Measuring connectivity

Connectivity is defined as a measure of the accessibility of a destination from all other destinations in the world (*Akça, 2018*), although it can also be viewed as the degree to which nodes in a network are connected to each other(Burghouwt and Redondi, 2013).

De Wit, Veldhuis, Burghouwt and Matsumoto (de Wit *et al.*, 2009) identified four types of connectivity: direct connectivity, indirect connectivity, onward connectivity and hub connectivity. Airports Council International (ACI, 2019) defined airport connectivity as a metric that takes into account both direct and indirect connectivity from the airport in question, understanding indirect connectivity as connectivity through one or more intermediate stopovers.

From a customer point of view, direct and indirect connectivity are not equally convenient. Taking this difference into account, Allroggen, Wittman and Malina introduced a qualifying variable named '*Directness of Routing'*, which was given the value 1 if it was a direct route, and was assigned a lower value when it was an indirect route (Allroggen, Wittman and Malina, 2015). Different functions have been proposed for this variable, mainly based on the delay that the indirectness of the route implies, as well as on passenger perceptions and behaviour.

These authors proposed a Global Connectivity Index for an airport in a specific year (Equation 1), based on previous models developed by Veldhuis (1997) and Burghouwt and de Wit (2005).

$$GCI_{a,t} = \sum_{r \in R_{a,t}} \alpha_{r,t}\, f_{r,t}\, Wd_{r,t}$$

Equation 1.- Global Connectivity Index

Where: $GCI_{a,t}$ is the Global Connectivity Index for an airport *a* during year *t*

$R_{a,t}$ is all the destination airports that can be reached from airport *a* in year *t*

$\alpha_{r,t}$ is the directness of routing *r* in year *t*

$f_{r,t}$ is the frequency of routing *r* in year *t*

$Wd_{r,t}$ is the destination quality (weight) of route r's destination airport d_r in year *t*

Variable $\alpha_{r,t}$ penalises all indirect flights, and hardly takes into account flights with two or more intermediate stopovers. In fact, not all the possible connections in an airport should be taken as available indirect flights. Two issues are relevant here, from a customer point of view. First, passengers avoid two-stop connections, particularly in the short-haul (Burghouwt and Redondi, 2013; Allroggen et al., 2015). Second, passengers avoid long connections. Consequently, connectivity measures should only consider the minimum connection time required to ensure boarding on the second flight and a maximum based on passenger perceptions. Authors have set the minimum connection time between 45 minutes (Veldhuis, 1997) and one hour (Burghouwt and Redondi, 2013). The maximum waiting time not only depends on passenger perceptions, it also depends on the total flight time. For instance, a passenger travelling on an intercontinental flight will be willing to factor in a longer stopover time than a passenger travelling within the same continent (Taafe, 1998; de Wit *et al.*, 2009). For a connection within Europe, authors have proposed a maximum connection time of between two hours (Danesi, 2006) and three hours (Bootsma, 1997; Burghouwt and Redondi, 2013). When one of the connecting flights is intercontinental the maximum waiting time is extended to three hours (Danesi, 2006) or five hours (Bootsma, 1997).

The algorithm proposed by Allroggen, Wittman and Malina (2015) for the calculation of $\alpha_{r,t}$ is based on the relationship between the total perceived time of the stopover flight and that of a theoretical direct flight (this relationship is called the 'detour factor'). The disutility of waiting time is introduced by doubling the waiting time, thus turning real time into perceived time. These authors also proposed a maximum detour factor that depends on the length of the theoretical direct flight (shown as a continuous line in Figure 1), and which has been estimated by comparing market share when direct and indirect flights are available for one route. $\alpha_{r,t}$ is equal to zero for routes that have a detour factor greater than the maximum detour factor. It is equal to 1 for direct flights and descends linearly between these two extreme cases (see Allroggen, Wittman and Malina, 2015, for more details).

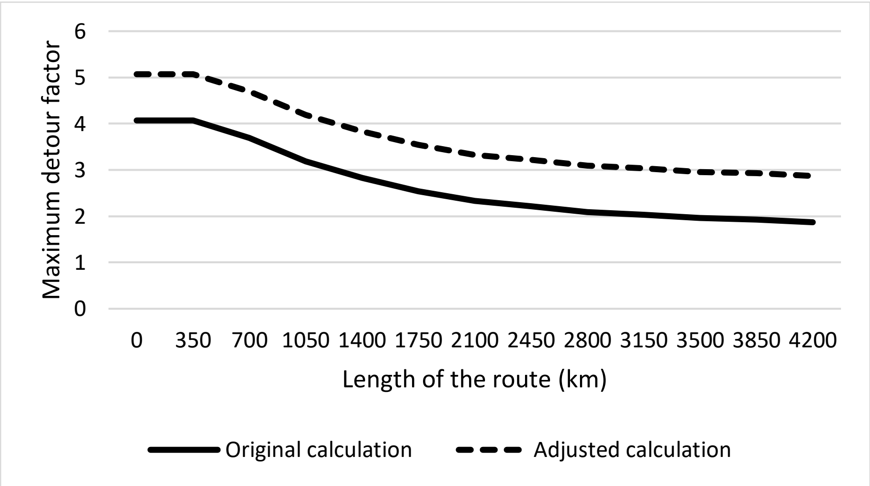

Figure 1.- Maximum detour factor depending on the length of the route

Several approaches have been proposed for the weighting factor in Equation 1. The World Economic Forum Connectivity Index evaluates connectivity based on available seats per week, not on weighting routes, whereas the IATA Connectivity Index weights the routes by the size of the destination airport, in terms of number of passengers handled each year, as a proxy of the regional potential (*PricewaterhouseCoopers, 2014*). Other connectivity measures use weighting indicators that are directly related to regional economic potential, such as Gross Domestic Product (Malighetti, Paleari and Redondi, 2008). In fact, the relationship between connectivity and economic growth has been proven (Smyth and Pearce, 2007).

Páez, Scott and Morency introduced an accessibility measure (connectivity) based on the perspective of an individual (Páez, Scott and Morency, 2012). See Equation 2.

$$A_{ik}^{p} = \sum_{j} g(W_{jk})\, f(c_{ij}^{p})$$

Equation 2.- Accessibility measure from an individual perspective

Where: A_{ik}^{p} is accessibility (connectivity) from the standpoint of the departure location *i* to opportunities of type k, from the perspective of individual p

W_{jk} is the number of opportunities of type *k* at destination *j*

c_{ij}^{p} is the cost of moving between *i* and *j* as perceived/experienced by person *p*

Nevertheless, in Páez, Scott and Morency's article, the formulation of the number of opportunities at a destination does not depend on the perspective of individual *p* (Páez, Scott and Morency, 2012). In fact, to our knowledge there are no connectivity measures in the literature that understand the potential of a destination according to personal perspectives.

In a recent article, Redondi, Birolini, Morlotti and Paleari (2021) proposed a new measure for the utility of alternative itineraries. This utility is approached by three variables: connecting time (CT), flight time (FT) and directness of the itinerary (DIR). They also used monthly market shares, in a six-month period in Europe, to estimate the coefficients that weighted each of the three variables. These coefficients are shown in Equation 3. The market share of each itinerary is approached by an exponential model (Equation 4).

$$V_i = -0.0034CT_i - 0.0037DT_i + 2.8805DIR_i$$

Equation 3.- Utility calculation estimated by Redondi *et al.* (2021)

Where: V_i is the utility of the itinerary i

CT_i is the connecting time for itinerary i

FT_i is the flying time for itinerary i

DIR_i is the directness of the itinerary i

$$MS_i = \frac{\psi_i e^{V_i}}{\sum_j \psi_j e^{V_j}}$$

Equation 4.- New index model, by Redondi *et al.* (2021)

Where: MS_i is the market share of the itinerary i

ψ_i is the monthly frequency of the itinerary i

V_i is the utility of the itinerary i

DIR_i is the directness of the itinerary i

2.2.- Case study: Castellon airport

Initially promoted by the provincial government of Castellon, Castellon airport received financial support for its construction from public entities at different levels. It was officially opened in 2011, though it did not receive its flight permits until late 2014, and only began to operate in 2015.

It currently offers a limited number of flights, mainly focused on the vacational segment, as well as on serving numerous colonies of immigrants from Eastern European countries such as Romania, Bulgaria and Hungary who live in the surrounding towns and cities. Hence, current flights link Castellon with Eastern European destinations such as Bucharest, Sofia, Budapest and Katowice. All these flights are operated solely by low-cost companies such as Ryanair and WizzAir.

The airport's operator and its public owners are highly interested in increasing the flight schedule, given that with the current number of destinations and their frequencies, the airport is far from breaking even.

Promotional efforts made by managers and owners have centred on establishing more routes focused on holiday and VFR purposes, run by the companies that currently fly from Castellon or others. However, they do also understand that there is a potential customer base the airport could also cater for, i.e. business passengers.

The Spanish province of Castellon, where the airport is located, has intense industrial activity concentrated in one specific sector: tile manufacturing. More than one hundred tile manufacturing companies make Castellon a real industrial cluster, which is complemented by several subsectors which are important in terms of revenue and worldwide competitiveness. These subsectors are focused on manufacturing raw materials and components (frits, glazes, ceramic inks), designing and manufacturing equipment for the ceramic sector (ovens, mills, printers, etc.), as well as other complementary and satellite subsectors dedicated to engineering, the design of promotional material, stands for fairs, training for the sector and others. Overall, the industry constitutes a dynamic and competitive group of companies that export their products and services to a large number of countries. The cluster exported ceramic materials with a value of €2.64 bn in 2019 (*DataComEx*[1]*, 2019*) to 185 countries of the 194 that exist in the world. This accounts for 33.60% of the total value exported by the province and over[2] 90% of the total ceramic products exported by Spain (*ASCER*[3]*, 2019*).

Unlike other sectors, which promote their international sales directly over the Internet, the ceramic sector travels extensively to visit its clients and distributors around the world, in order to establish and maintain profitable trade relationships, promote sales, provide technical support and train their partners' staff. Additionally, a significant number of customers and distributors visit Castellon to see the manufacturers' premises and meet their managers and sales-force.

It is important to understand the needs of this type of passenger who travels for professional purposes. In fact, the business passengers' needs are completely opposite to those of leisure travellers (*Shaw, 2016*). Hence, we can synthetically describe the leisure passenger as one whose main interest in a flight ticket lies in the price, who will be more flexible when it comes to comfort, convenience of departure times and even destination. On the other hand, passengers travelling for business purposes are not flexible in terms of destination, since they have to fly to wherever their work takes them, although they may be flexible with the tariff. Furthermore, the latter are more demanding when it comes to comfort and departure times and dates.

In our case study, these latent business travellers rely on flights departing from airports which are farther away than Castellon airport. Their main choice is Valencia airport, which is located 104 km from the city of Castellon. It is evident that there is not enough demand for direct flights from Castellon to all the destinations these people travel to, but bringing this demand together in a flight to a convenient hub could cater for this demand and, presumably, make the flight profitable for the airline. The key here would be to connect to the hub with the greatest onward connectivity. A previous question then emerges: how can onward connectivity be measured with this specific purpose in mind?

2.3.- Measuring onward connectivity

Airlines, and legacy carriers in particular, centralise their operations in selected airports (hubs) in order to maximise possible connections, thus basing their strategy on hub and spoke networks. These airlines can then offer multi-stop connections. Additionally, the growth of new distribution channels on the Internet and the hybridisation of low-cost carriers, generate new customer options such as self-connecting routes, and reinforce the role of hubs (Fichert and Klophaus, 2016). ACI defines hub connectivity as the number of connecting flights that can be facilitated by the hub airport, taking into account a minimum and maximum connecting time, and weighting the quality of the connections by the detour involved and connecting times (ACI, 2019).

Onward connectivity for an airport can be defined as the indirect connectivity channelled through a connection with an airport or hub (ACI, 2019; *Akça, 2018*). The concept has been used by some authors to compare the competitive position of airline networks (Veldhuis, 1997), to identify air connectivity gaps in a region (*PricewaterhouseCoopers, 2014*), to show the connectivity effects of public service obligations in terms of air

[2] *http://datacomex.comercio.es/principal_comex_es.aspx accessed 25/04/20*
[3] *https://www.ascer.es/sectorDatos.aspx?lang=es-ES accessed 25/04/20*

transport in some countries (Wittman, Allroggen and Malina, 2016), as well as to measure connectivity in the air freight industry (Boonekamp and Burghouwt, 2017). Our goal is to use the concept to assess available opportunities for new airports.

Most of the connectivity measures proposed by the literature pursue a descriptive goal. Consequently, they use cumulative data, in other words, the measures are related to extended periods of time (e.g. one year). However, our goal is prescriptive. We aim to help people in charge of airlines and airports to make decisions about, for instance, which hub to connect to (Figure 2). Onward connectivity appears to be a good tool to help out in this situation, given that it can measure which hub offers more connectivity to a particular airport in a given period of time. Nevertheless, this period can be reduced to its lowest limit, in order to measure the onward connectivity offered by a single flight from the airport in question arriving at the hub at a specific point in time. This enables a comparison to be made, not only by the onward connectivity provided by several competitive hubs, but also by different days and times throughout a day.

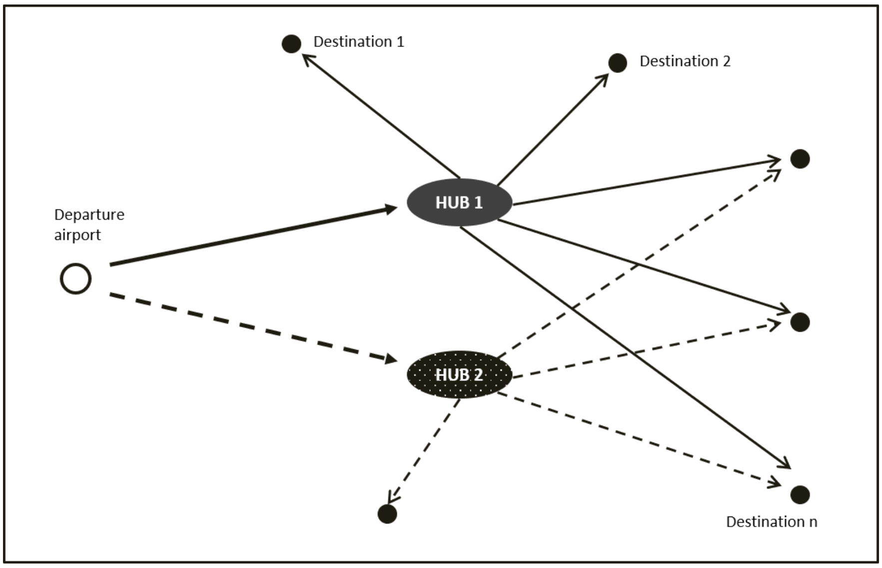

Figure 2.- View of two alternative connecting hubs

Equation 5 reveals an initial simple way to measure the onward connectivity provided by a hub *i*. It is based on the recommendations put forward by the literature, and is related to a specific moment *t*. It is important to understand that *t* is not related here to a time period, but to a moment in time.

$$OC_{i,t} = \sum_{r \in RC_i} N_{r,t}\alpha_r$$

Equation 5.- Onward Connectivity

Where:

$OC_{i,t}$ is the Onward Connectivity provided by Hub *i* at time *t*

RC_i is all the *r* routes currently departing from Hub *i*.

$N_{r,t}$ is the number of flights on route ***r*** taking off from the hub between t+1 hours and t+3 hours when the route is continental and between t+1 hours and t+5 hours when the route is intercontinental

α_r is the current directness of route *r*.

This measure coincides with the number of flights departing from the hub in the specified intervals, when α_r is equal to 1 for all the routes.

Our prescriptive view forces us to introduce the customer perspective. Not all routes are equally as interesting for potential passengers. We have to balance the connectivity offered by each route with a measure of the interest of the route for potential passengers. This measure could be directly provided by a survey if this were available. Otherwise, this could be replaced by indirect indicators such as those suggested by literature sources (GDP, size of the destination airport, etc.). Nevertheless, we put forward indicators that really proxy the interest of our target, such as the volume of exports to the route's destination.

Equation 6 offers our general formula for measuring Weighted Onward Connectivity (WOC) provided by a hub *i* at a moment *t*.

$$WOC_{i,t} = \sum_{r \in RC_i} N_{r,t} \alpha_r W_{r,t}$$

Equation 6.- Weighted onward connectivity

Where:

$WOC_{i,t}$ is the Weighted Onward Connectivity provided by Hub *i* at time *t*

RC_i is all the routes *r* currently departing from Hub *i*.

$N_{r,t}$ is the number of flights on route ***r*** taking off from the hub between t+1 hours and t+3 hours when the route is continental and between t+1 hours and t+5 hours when the route is intercontinental.

α_r is the current directness of route *r*.

$W_{r,t}$ is a measure or indicator of the interest in route *r* of potential passengers at time *t*.

It is interesting to point out that this measure is a direct application of the GCI methodology proposed by Allroggen et al. (2015), if we use their algorithm to calculate $\alpha_{r,t}$.

There is an intrinsic issue in both of the onward connectivity measures we have proposed. We can better highlight this issue by using an example with the first one. Imagine a hub that provides a direct flight to each of three different destinations, and another one that provides three flights to a unique destination. The onward connectivity would be the same for both hubs, but the usefulness to customers would not be the same. Business passengers would probably prefer the first one, because they would have direct flights to different destinations, whilst the second one offers different options to one of the three destinations. This problem is also present to a certain extent in our second measure, Weighted Onward Connectivity (WOC).

In order to avoid this issue, we propose a third measure for onward connectivity, initially entitled Radical weighted onward connectivity, relating the adjective *radical* to the perspective that is closest to the target customer (Equation 7). Our interest here is less related to flight frequency, and centres more closely on whether there is a convenient flight to the destinations or not.

$$RWOC_{i,t} = \sum_{d \in DC_{i,t}} \beta_{d,t} \cdot W_{d,t}$$

Equation 7.- Radical weighted onward connectivity

Where:

$RWOC_{i,t}$ is the Radical Weighted Onward Connectivity provided by Hub *i* at time *t*.

$DC_{i,t}$ is all possible destinations *d* from Hub *i*.

$\beta_{d,t}$ is the existence of a convenient connection. The value is 1 if there is at least one direct connection to the destination *d* taking off from the hub *i* between t+1 hours and t+3 hours when the route is continental and between t+1 hours and t+5 hours when the route is intercontinental. The value is 0 if there are no flights.

$W_{d,t}$ is a measure or indicator of potential passengers' interest in destination *d* at time *t*.

It is interesting to point out another interpretation of this measure. This interpretation depends on the weighting indicator used. If the number of customers interested in flying to each destination is used as weighting indicator, Equation 7 would provide the number of customers that have a convenient flight to their requested destination. If we use the percentage distribution of interest by destinations as the weighting indicator, Equation 7 would provide the total percentage of the interest that is satisfied through the hub in question. In other words, Equation

7 would provide the percentage of demand catered for by the hub. We can extend this analogy to the use of a proxy that estimates this indicator.

Applying this analogy to our case, we used the percentage of exports to each destination as the weighting indicator. By doing this, Equation 7 provides the percentage of the cluster demand that is catered for by a theoretical link to the hub. However, an additional adaptation must be introduced: since the export data refers to countries, rather than to the connection area of each airport, we adapted Equation 7 to this particular case, giving rise to Equation 8.

$$DC_{i,t} = \sum_{c \in C} \beta_{i,c,t} \cdot W_c$$

Equation 8.- Demand catered for

Where:

$DC_{i,t}$ is the percentage of demand connected by Hub *i* at time *t*.

C is all possible countries.

$\beta_{i,c,t}$ is the existence of a convenient connection. The value is 1 if there is at least one direct connection to a destination in country *c* taking off from the hub *i* between t+1 hours and t+3 hours when the country is in the same continent and between t+1 hours and t+5 hours when the country is in another continent. The value is 0 if there are no flights.

W_c is a measure or indicator of the interest in flying to country *c* (i.e. percentage of total exports to the country *c*).

2.4.- Data

In order to apply our onward connectivity measures to our case study, we used data from OAG, choosing a generic week, the week that started on Monday, 21 May 2017 and ended on Sunday, 27 May 2017. We analysed the three days of the week preferred by potential customers (Monday, Wednesday and Sunday), and compared the onward connectivity provided by three of the most popular European hubs: Paris Charles de Gaulle (*IATA: CDG*), Frankfurt am Main International (*IATA: FRA*) and London Heathrow (*IATA: LHR*). We measured connectivity from 8 am, because arriving at the hub before this time would mean taking off from Castellon before 6 am, which is not convenient for passengers. In addition, we measured connectivity in half-hour intervals.

We excluded all the flights to Spain in order to maintain coherence, and because they presumably are not convenient. They were rejected in almost all of the proposed measures because of their high detour factor or because export data were not applicable. Therefore, we homogenized their treatment and excluded them from the number of flights measure.

We used Google maps to measure distances between Castellon airport and the rest of airports, and the parameters provided by Allroggen et al. (2015) to estimate flight times based on distances.

2.5.- An exploratory survey

In order to obtain more accurate information about customer needs and wants, we conducted an exploratory survey with eight different-sized companies in the cluster (see Appendix for the survey script). The survey was run during the months of June and July 2017 via email and phone calls. We asked managers about the number of yearly trips made by sales staff and managers within their respective companies, as well as the quantity of incoming trips made by their customers. We also asked them about their favourite days of the week for travelling and the amount of time they needed at their destination. We added an additional question in February 2018, suggested by the direction of our research, asking them to what extent they preferred a wide range of destinations to travel to, instead of more frequent flights to a shorter list of destinations.

The eight companies are only a small fraction of the firms in Castellon's ceramic cluster, but they accounted for 37.37% of the cluster's total revenue. So, it can be understood as a significant survey at quantitative level for questions with few alternative options (e.g., weekday preferences), but not for questions with more options or with numerical answers (e.g., number of flights to different destinations).

3.- Results and discussion

An important suggestion made by interviewees was that three-leg flights have little appeal in a mature air transport market, when passengers have alternative two-leg flights to the same destination using other departing airports and hubs. This reinforces the suggestion made by the literature (see Section 2), implying that the bias introduced by ignoring two or more stopover routes is negligible (Allroggen, Wittman and Malina, 2015). Accordingly, we only considered two-leg flights in all the measures. In addition, they chose Mondays, Wednesday and Sundays as the best days of the week to travel on their business trips.

Finally, interviewees clearly prioritised flying to most of the destinations they exported to over greater flight frequencies to fewer destinations. We will come back to this in the Discussion section.

A summary of the main results is shown below. Differences between weekdays were not important, so only the results obtained for Monday are shown.

3.1.- Some issues on the application of connectivity measures to calculate onward connectivity

The application of the GCI algorithm to measure onward connectivity showed a relevant concern in that a great deal of the European routes that could be considered useful by customers were undervalued or directly rejected by the algorithm. Table 1 shows the onward connectivity provided by some flights involving a first flight arriving at Paris airport (CDG) at 8 am from Castellon. The value of several key parameters is given for each of those connecting flights, in particular the value of α_r.

These flights would be reasonably undervalued or rejected in a context in which they coexisted with a certain number of more convenient direct flights, but this is not our case. These flights were rejected because their detour factors are higher than the accepted maximum detour factor computed by Allroggen et al. (2015) in a context with alternative direct flights. When there are no alternative direct flights, rejecting these flights would mean discarding useful flights for several customers. We tried different strategies in order to solve this issue. We found the increase of the maximum detour factor to be the most suitable solution for this particular use of the algorithm. We also limited the waiting time at the hub. We specifically increased the maximum detour factor by adding 1 to the calculation proposed by Allroggen et al., and we limited the waiting time at the hub to 5 hours. The last two columns in Table 1 show the increased maximum for these cases as well as the new value for α_r. The dashed line in Figure 1 analogously shows the new maximum detour factor, as a function of the length of the hypothetical direct route. In this case (a flight arriving in CDG at 8 am from Castellon), the original algorithm takes into account 52 flights and the adjusted algorithm considers 125.

Final destination	Departing time from CDG	Maximum detour factor	Detour factor	α_r	Adjusted maximum detour factor	Adjusted α_r
Athens	9:40	2.347	2.66	0	3.347	0.291
Bucharest	9:55	2.302	2.62	0	3.302	0.297
Dublin	9:40	2.713	2.70	0.0049	3.713	0.372
Rome	9:15	3.211	3.34	0	4.211	0.272
Stockholm	9:45	2.200	2.15	0.0037	3.200	0.475

Table 1.- Some examples of flights undervalued or rejected by directly applying the GCI algorithm to measure onward connectivity

Figure 3 compares onward connectivity through the CDG hub using both measures (direct GCI application and adjusted GCI). Focusing on business travellers, we used the percentage of exports from the province of Castellon to the country of destination as the weighting indicator ($W_{r,t}$).

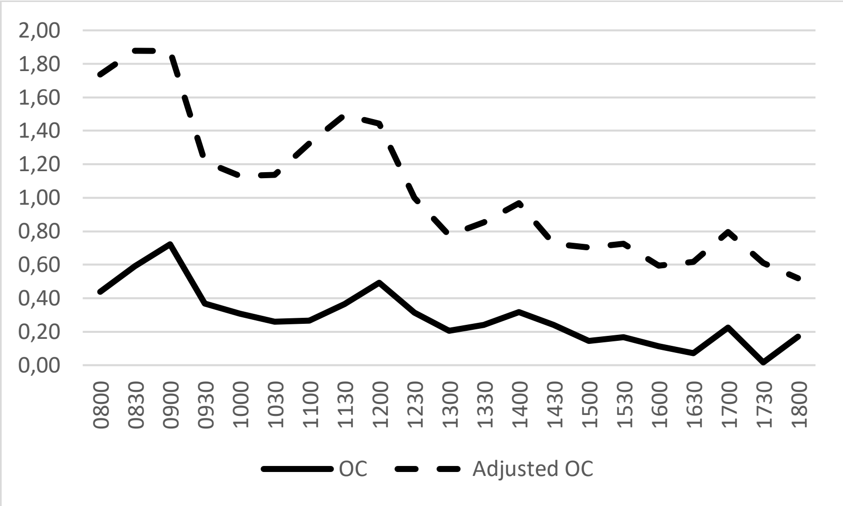

Figure 3.- Comparing onward connectivity based on the GCI algorithm and the adjusted GCI algorithm

An even more relevant issue appeared when we tried to apply the algorithm proposed by Redondi et al (2021) to measure onward connectivity. As the directness factor (DIR) was zero in all the routes (our case did not include direct flights), the utility of the route (V_i) always took a small negative value. On the other hand, the model uses its exponential value (e^{V_i}), which, in our case, always takes a value close to 1. In practice, the sum of this exponential value approaches the number of flights considered useful in our first onward connectivity indicator (the measure delivered by Equation 5, making α_r equal to 1 for all of the valid flights).

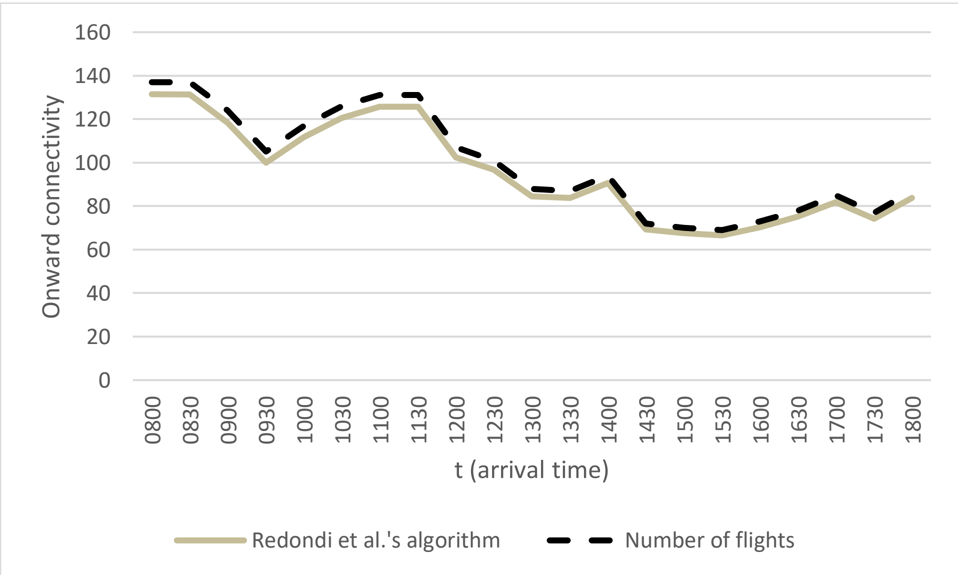

Figure 4.- Comparing onward connectivity measured by Redondi et al.'s algorithm and the number of flights

In order to show the variability of the different onward connectivity measures, we normalized all the results for Mondays at CDG (Figure 5) and FRA (Figure 6), converting the maximum of each measure to 1. We omitted the proposal based on Redondi et al. due to its similarity with the number of flights.

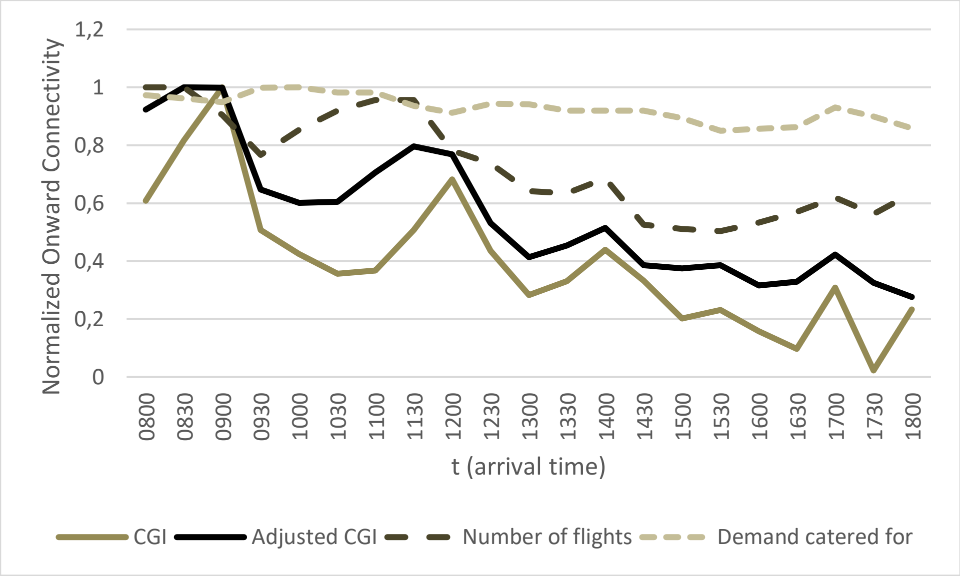

Figure 5.- Comparing normalized onward connectivity measures (at CDG on Mondays)

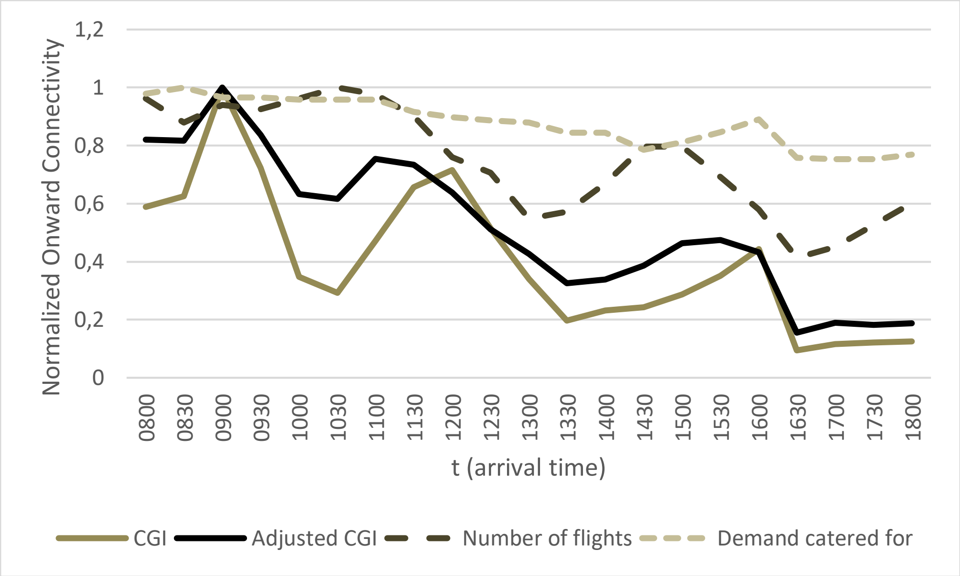

Figure 6.- Comparing normalized onward connectivity measures (at FRA on Mondays)

3.2.- Comparing hubs

Figure 7 and Figure 8 show Onward Connectivity (Number of flights) and Weighted Onward Connectivity (Adjusted GCI) on Mondays for each of the hubs and time window. As shown in Figure 7, CDG was the hub with the best OC during the early first part of the morning but was overtaken by FRA after 9:00 am. LHR was the hub with the best OC after 11:30 am. On the other hand, WOC showed LHR to be the leader throughout the day (Figure 8). The differences in OC were important during some parts of the day (particularly after midday). Differences were even more salient for WOC from 9:30 to 14:00, but CDG and FRA showed similar WOC.

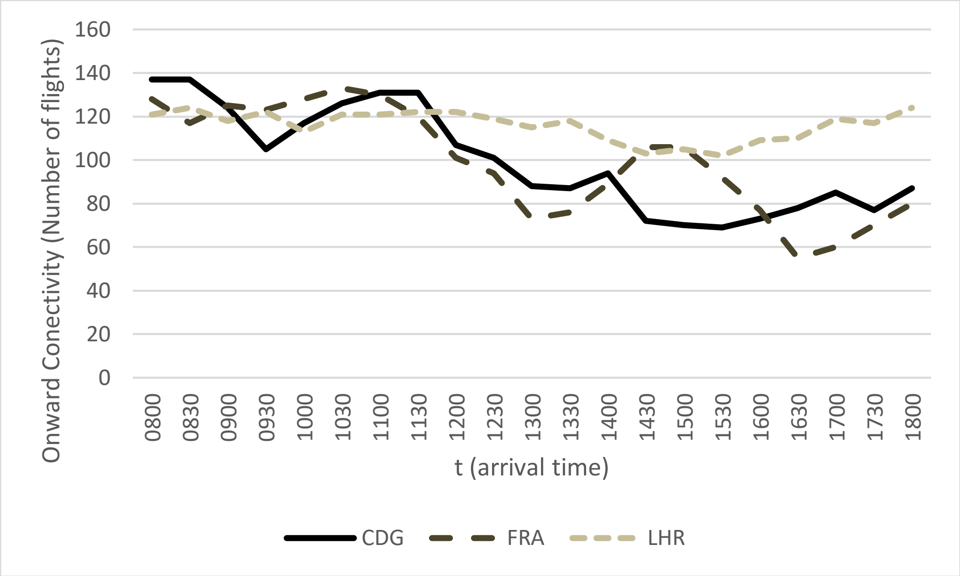

Figure 7.- Onward connectivity (Number of flights) on Mondays for the three hubs

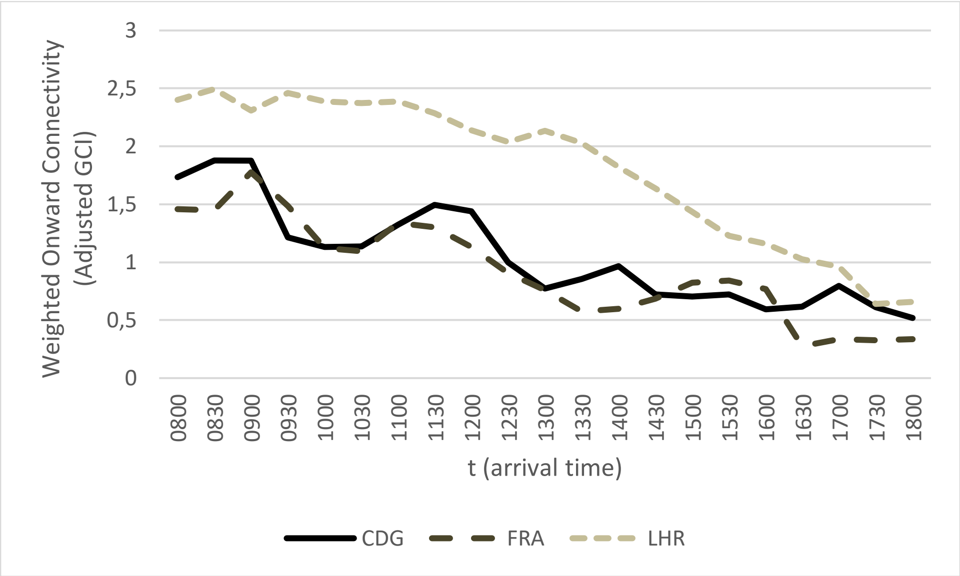

Figure 8.- Weighted onward connectivity (Adjusted GCI) on Mondays for the three hubs

Applying our third measure of onward connectivity, the results summarised in Figure 9 were obtained.

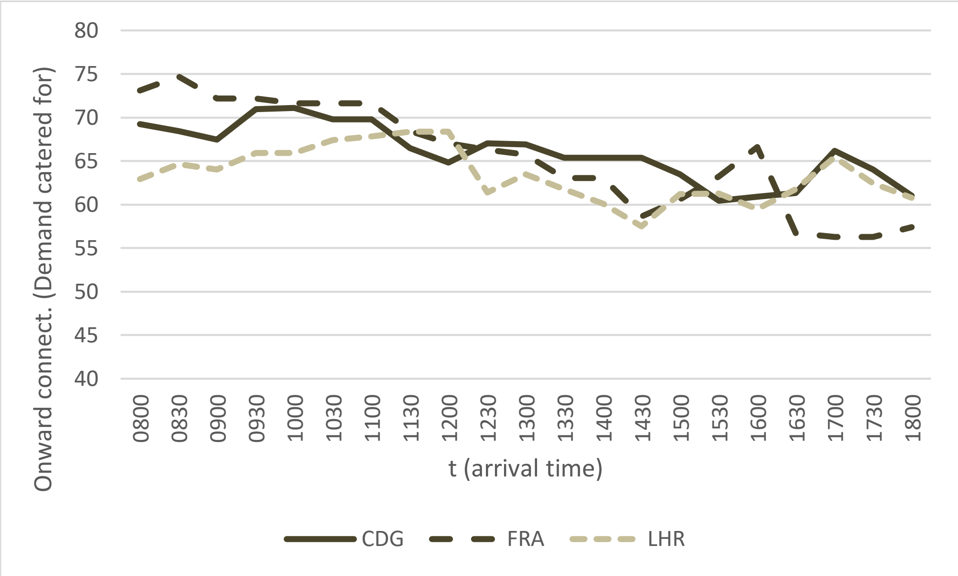

Figure 9.- Comparison of Demand catered for on Mondays for the three hubs

Compared to the weighted onward connectivity explored above, we can see how the results take an unexpected turn after applying our third measure. LHR, which was the hub with the greatest weighted onward connectivity, registered the minimum score out of the three hubs using the third measure, Demand catered for. On the other hand, FRA shows completely opposite behaviour, scoring the greatest demand catered for out of the three hubs, with significant differences.

Table 2 shows the standard deviation of the onward connectivity measures for each hub and for all the data. GCI and Adjusted GCI are the measures with the highest deviation.

	Direct data				
	GCI	Adjusted GCI	Redondi et al., 2021	Number of flights	Demand catered for
CDG	0.170	0.430	22.674	23.880	3.291
FRA	0.145	0.637	23.939	24.939	6.154
LHR	0.237	0.631	6.405	6.956	3.093
TOTAL	**0.242**	**0.637**	**20.396**	**21.472**	**4.478**
	Normalized data				
	GCI	Adjusted GCI	Redondi et al., 2021	Number of flights	Demand catered for
CDG	0.235	0.229	0.172	0.174	0.046
FRA	0.244	0.247	0.188	0.188	0.082
LHR	0.278	0.253	0.054	0.056	0.045
TOTAL	**0.284**	**0.256**	**0.176**	**0.176**	**0.064**

Table 2.- Standard deviation for each onward connectivity measure and their normalized figures

3.3.- Discussion

Section 3.1 has introduced two considerations suggested by the adaptation of available connectivity measures to onward connectivity goals. The limitations in the GCI algorithm, when applied to onward connectivity goals, have been overcome through adjustments, resulting in an Adjusted GCI measure. On the other hand, the new connectivity measure proposed by Redondi et al. (2021), applied to onward connectivity goals, produces very similar results to the simple count of the number of flights. Consequently, we will focus this discussion on the results of three onward connectivity measures: (1) the Number of flights in a convenient time window, (2) the WOC obtained by the Adjusted GCI algorithm and (3) our new Demand catered for.

The nature of these three indicators is very different. The Number of flights just focuses on the number of convenient connections, without balancing these flights with any measure of their usefulness. The Demand catered for indicator centres solely on the work to be done by some specific customers, assessing the existence of flights, without any attention to their number (their frequency). Finally, the Adjusted GCI indicator mixed both drivers, considering all the available flights balanced by their convenience (using the parameter α_r) and by an indicator related to the interest of the customer (the parameter $W_{d,t}$, export figures in our case). From this point of view, Number of flights and Demand catered for have a first practical advantage: it is perfectly clear what they are describing. The meaning of Adjusted GCI is less clear, because it mixes different parameters in the same indicator.

The different nature of the indicators explains the different shapes of the curves in the figures shown in sections 3.1 and 3.2. For example, LHR shows clearly superior values for Adjusted GCI than the rest of the hubs throughout the day. This is not the case for the rest of the indicators. The explanation lies in the high percentage of flights departing from LHR to the USA, the second largest importer of ceramic products from Castellon (therefore, frequency and weight are high).

On the other hand, Demand catered for shows more stable results throughout the day than the rest of the indicators (see also standard deviation in Table 2). Number of flights and Adjusted GCI show more ups and downs, probably reflecting the wave-system structures in flight schedules, which are particularly present in hubs (Burghouwt and de Wit, 2005). This suggests an interesting synergistic use of the different onward connectivity measures, i.e. choosing the periods with better Demand catered for as a first approach, and then using Number of flights or Adjusted GCI for a more precise approach. For example, Demand catered for shows levels over 70% in FRA between 8 am and 11 am; Number of flights shows a local maximum at 10:30 and Adjusted GCI shows a local maximum at 9 am. It is important to state here that the theoretical best hub and time of arrival may not be viable, because we are talking about very congested hubs. Accordingly, alternative options need to be considered.

As we mentioned in Section 3, interviewees prioritised flying to most of the destinations they exported to over greater flight frequencies to fewer destinations, and this points to Demand catered for as the best indicator from a customer point of view. This was in fact the reason that prompted us to propose the measure. It is also true that the rest of the measures could be more useful when considering other reasons and customer segments.

Finally, although our survey was basically qualitative, we can see how a more representative survey could be used to estimate demand, using our onward connectivity measures and, in particular, Demand catered for. With a good estimation of the annual trips planned by the cluster, Demand catered for delivers the percentage of flights that could be catered for by a linking flight from Castellon to a specific hub at a specific time.

In our case, we estimated a total of 5,768 annual trips, based on the answers to our survey. When this figure was averaged out to the entire cluster, based on company revenues, it generated an estimated 15,434 annual trips for the cluster as a whole. Interviewees refused to respond about the destinations of these trips, for confidentiality reasons. Additionally, the numbers shown in Figure 9 have a direct correlation to the passengers catered for. For example, a flight from Castellon arriving in Frankfurt at 8:30 am would provide a convenient connection to relevant destination countries for 74.71% of the cluster's demand. Applying the estimate described in the previous section, we can infer that this flight would provide convenient connections for 11,530 annual trips, meaning 221 weekly trips, or what is almost enough passengers to fill an A320 or B737, typically used for short and medium range flights by both low-cost and network airlines. Although this would be complemented by the demand from other sectors and from VFR and leisure passengers, it would probably be difficult to convince any airline to run this flight. It would also be difficult to get a slot at that time in FRA.

4.- Conclusions

There is a broad stream of research on the field of connectivity, but onward connectivity has received less attention. We have suggested some ways to measure onward connectivity, adapting available literature on connectivity and proposing new options. We have focused on weighted connectivity, which adds an indicator related to destination appeal to the connectivity calculation. Literature has proposed generic economic (i.e. GDP) and demographic (i.e. population) variables as useful indicators, but our research puts forward a more specific variable.

In this study, we have focused on a specific and relevant demand segment, the ceramic cluster in Castellon, proposing a more customer-oriented measure of onward connectivity. This measure is based on potential business passengers' needs and wants. These needs and wants were identified through a survey aimed at companies that accounted for more than 37% of the segment's revenue. This survey suggested that customers are more interested in multiplying the number of destinations than in increasing the frequency of flights to some of these destinations. Consequently, we have proposed an onward connectivity measure that directly relates to the demand catered for by onward connections.

We also compared this measure with others based on an adaptation of the literature, using the case study of Castellon airport and its potential connection to three of the most important hubs in Europe. We found significant differences between the results offered by the different measures. The three hubs ranked differently according to the measure of onward connectivity used.

Our research could be expanded by studying onward connectivity in two or more hubs. On the other hand, our work constitutes a first approach to a finer grained analysis of demand, using a point of view based on demand *microsegmentation*. Our research also offers a tool that could be useful in different research goals, or to analyse already studied subjects through a different perspective. The analysis of thin routes is an example. The factors that ensure the breakeven point have not been properly studied. This analysis could be key to studying this subject in a context of growing competition between airlines and airports.

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Appendix: Survey script

Presentation: Good morning/afternoon. We are doing a research study among ceramic tile companies about air travel. Your answers to the following questions would be very helpful. Your responses will be treated anonymously. Thanks for your collaboration.

(Contact details)

Q1. Please tell us how many people in your organization travel by plane at least once a year.

Q2. What destinations do they travel to? (Please list them on the table)

Destination	Number of people	Frequency	Preferred week days	Stopover airport	Airline	Business volume in the destination (%)	Main goal
Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9

Q3. How many people travel to these destinations? (please add this figure to the table)

Q4. How often do they travel to these destinations (trips per month, year)?

Q5. Which days of the week do they usually travel?

Q6. Which route (stopover airports) do they use?

Q7. Which airlines do they fly with?

Q8. What volume of business does your company have in these destinations?

Q9. What is the main reason for travelling to these destinations (visiting customers, visiting distributors, fairs, etc.)?

Q10. How many days do these trips usually last (on average)?

Q11. Do these trips include visits to more than one country? How many (on average)?

Q12. Do customers, distributors, etc. usually come to visit you at your facilities? How many (yearly)?

Q13. From which countries? (please add these to the table)

Q14. How many people travel from these countries?

Q15. How often do they come to visit you (yearly)?

Countries	**Number of people**	**Number of visits**
Q13	**Q14**	**Q15**

Q16. Which new countries do you plan to expand your commercial exports to in the future?

Q17 (additional question). If you had a choice, to what extent would you prefer a wide range of destinations to travel to, instead of more frequent flights to a shorter list of destinations?

(Day and time)