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The evolution of air transport networks and impacts on shortest travel times between NUTS-3 regions – a case study for intra-European trips originating in Germany

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Abstract

The European air transport market has evolved over the past decades at an amazing pace. Key developments include the rise of the low cost carriers (LCCs), originally at regional and military conversion airports and now also at the larger secondary airports and hubs, the withdrawal of network carriers from non-hub routes and a widely disappearance of classical regional air services with turboprops. We hypothesize that all these developments have had impacts on travel times between European regions.

In this paper, we present a methodology to analyse shortest car and air travel times including a combination of both modes for trips between European regions. We apply our model for travel from Germany to Europe on the level of NUTS-3 regions (districts and larger cities) in order to assess on which routes air transport provides a travel time benefit over individual motor car traffic. Moreover, we compare the development of travel times between 2000 and 2017 to show how the evolution of the air transport network has influenced shortest travel times. With the model, the authors address the following questions:

First, we assess for which region pairs and distances combinations of car and scheduled air transport offer travel time savings over trips by car only. Second, we evaluate how the evolution of the European air transport network has changed shortest travel times for trips from each German NUTS-3 region to Europe between 2000 and 2017.

Keywords: Air transport network; travel time savings; regional accessibility

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1. Introduction

In this paper, we develop a framework of comparison of shortest travel times of individual motor car traffic and scheduled air transport for Europe and apply the framework for intra-European travel originating in Germany. The aim of the analysis is two-fold:

First, we conduct a modal comparison, in order to find out from which average distance onwards combinations of car and scheduled air transport are faster than trips by car only. This topic has some political relevance as, from time to time political stakeholders demand a ban of short-haul flights (e.g. Berliner Zeitung, 2012). We hypothesize that apart from its function as feeder for long-haul flights, the use of air transport can result in travel time benefits for passengers even on relatively short distances.

Second, we aim at analyzing to what extent aviation growth and network changes have contributed to a reduction in shortest travel times for intra-European travel. Here, the hypothesis is that the growth of the low cost carrier network has contributed to a reduction in shortest travel times, particularly for travel originating in regions which formerly have had only a limited supply of flights. Hence, we analyze the outcome of airline and airport competition, as for instance widely discussed e.g. by Lieshout et al. (2016) and Redondi et al. (2013).

In the literature, we find a wide range of publications dealing with connectivity and the contribution of air transport to the accessibility of regions. Various papers deal with theoretical aspects, e.g. the development and/or comparison of different connectivity indicators, like the seminal paper of Burghouwt/Redondi (2013), in which a wide range of connectivity indicators are presented and their interrelations are analyzed. Concerning the application of connectivity models and indicators, numerous studies exist, which aim at the analysis of the connectivity of specific regions or airports. More recent studies have concentrated on the dynamic development of air transport in emerging economies, like Zhang et al. (2017). A very interesting approach is followed by Laurino et al. (2017) for Italian domestic transport. The authors have developed a generalized cost model for comparison of different transport modes. The approach is intended to find the most efficient mode when both time costs and fares for trips are considered in a multi-modal environment.

More recently, stakeholders in the aviation industry have realized that connectivity is a major argument to present benefits of aviation to the general public. Along this rationale, ACI Europe has repeatedly published its Airport Industry Connectivity Report (ACI Europe, 2017), showing connectivity indicators and their development on airport level.

2. Research Contribution

This paper tries to fill a gap, as the approach is to analyze accessibility in a very detailed geographical resolution and to compare the development of accessibility on region-to-region level over a comparably long time frame (2000 to 2017).

3. Methodology

Generally, it is the aim of our methodology to go beyond the level of airport-to-airport connectivity, which is used in other publications (e.g. ACI-Europe, 2017). We analyze connectivity on a small scale region-to-region level. The model includes realistic airport access times and searches for shortest region-to-region travel times for both car only and car/air combinations. For the car/air combinations, buffer times of 60 minutes for check-in/baggage drop/security and passport control/boarding before scheduled departure and 30 minutes after scheduled landing time for passport control, baggage claim and walking through the terminal to parking, rental car offices or the taxi rank are assumed (Figure 1).

The origins and destinations for each trip in our model are the geographical centers of each NUTS-3 region. NUTS (Nomenclature des unités territoriales statistiques) is a hierarchical system of regions defined by the European statistics authority EUROSTAT (EUROSTAT, 2017a). With the NUTS system, EUROSTAT subdivides European Union Member States and Candidate Countries into different geographical levels. NUTS-0 are the national states, NUTS-1 larger regions with typically about 3 million to 7 million inhabitants and NUTS-2 smaller regions with 800,000 to 3 million inhabitants. For our analysis, we have taken an even smaller geographical resolution, which is NUTS-3. NUTS-3 regions have on average between 150,000 and 800,000 inhabitants. In Germany, NUTS-3 regions consist of all 295 rural and 107 urban districts ("Landkreise" and "kreisfreie Städte"), i.e. a total of 402 zones, which are used in our analysis as trip origins. As trip destinations we define all NUTS-3 regions in Europe, which amount to 1,394 in total (including the NUTS-3 regions in Germany, so that domestic travel is included in the analysis). Hence, we analyze an origin-destination matrix of 402 x 1,393 = 559,986 combinations. We define the geographical center of each zone as trip origin and destination. EUROSTAT provides a database with the geographical coordinates of the center of each NUTS-3 region (EUROSTAT, 2017b). The central coordinates of each NUTS-3 region are calculated as centroids (geometric centers). Table 1 shows the countries considered in our analysis, the number of NUTS-3 regions in each country and the respective number of airports which had commercial traffic between 2000 and 2017.

The model has been designed using Microsoft's Access as database management system and Visual Basic for Applications (VBA) as programming language. It searches for the shortest travel times between NUTS-3 regions out of the travel options "car only" and the combination of car and scheduled air transport (Figure 1).

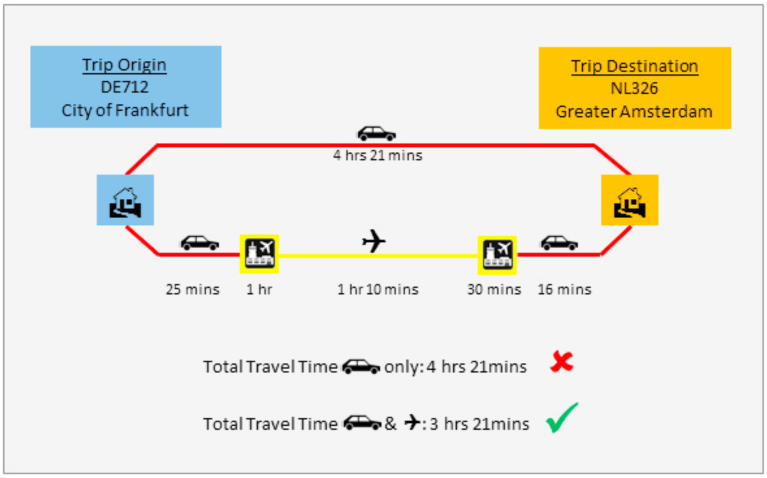

Fig. 1. Comparison of different trip modes "car only" vs. "car & air combined".

Driving times were queried using Google's Distance Matrix Application Programming Interface ("API", Google, 2017). With the Distance Matrix API, geographical coordinates can be sent to Google's web servers and driving times and distances are returned. For the calculation of driving times between NUTS-3 regions, the complete matrix of 559,986 combinations was queried. For the calculation of driving times between NUTS-3 regions and airports, we have selected for each NUTS-3 region only those airports located within a radius of less than 300 km. This results in a matrix of 35,719 combinations of NUTS-3 regions and airports.

The next step in our analysis is the modelling of the air transport network. Data source of the flight schedules used is Innovata, supplied via Sabre's AirVision Market Intelligence web portal. A matrix with shortest travel times with non-stop, 1-stop and 2-stop flights between all airports was created. The underlying conditions for the creation of a valid 1-stop or 2-stop connection are as follows:

- A valid connection is available at least once a week
- Minimum connection time is 45 minutes; maximum connection time is 4 hours. These values are uniformly applied for all airports/airlines;
- A valid connection must be online (same airline operating all flight segments) or codeshare (the same marketing airline code must be placed on all flight segments);
- No transfers between low cost carriers are allowed.

Based on this methodology, we admit that aspects of flight frequencies and capacities are not considered. Future enhancements could for instance weigh different connections according to their service quality characteristics with a quality of service index (QSI), considering travel time, number of transfers, weekly frequencies and seat capacities, as being done by Grosche/Klophaus (2018).

The air transport network considered for this study contains a total of 626 airports, with scheduled services between 2000 and 2017. The flight database contains flights on the level of flight numbers and departure / arrival times for the third week in June 2000, 2005, 2010, 2015 and 2017. In 2017, the database contains 136,330 operated non-stop flights and additional 149,823 non-operated codeshare flights. All these flights are taken into account when creating a shortest travel time matrix with non-, one- and two-stop flight connections. The following table shows the results of the airport-to-airport shortest travel time matrix for all years considered between 2000 and 2017.

Table 1. Results for the European airport-to-airport shortest travel time matrix.

Parameter	2000	2005	2010	2015	2017
Total number of airports served	546	527	516	502	496
Total number of operated flights	115,710	122,550	125,99	123,470	136,330
Total number of non-operated codeshare flights	51,411	76,016	98,754	128,365	149,823
Total airport pairs served	52,596	56,516	59,073	63,615	67,009
Non-stop airport pairs	6,583	7,955	10,301	11,184	12,796
One-stop airport pairs	29,575	29,449	29,159	31,609	33,552
Two-stop airport pairs	16,438	19,112	19,613	20,822	20,661

Interestingly, the number of airports served with scheduled passenger air transport has declined in Europe over the past two decades. This might be counterintuitive, as the low cost boom was largely based on underutilized regional and military conversion airports. Notable exits from scheduled passenger aviation include the airports of Altenburg, Bayreuth, Berlin-Tempelhof, Cochstedt, Hof, Kiel, Lübeck and Zweibrücken in Germany; Blackpool, Manston, Plymouth and Sheffield in the UK and Aosta, Bolzano and Crotone in Italy.

However, particularly the steep increase in airport pairs being served with non-stop flights (6,583 in 2000 to 12,796 in 2017) suggests at least some potential for a reduction in average shortest travel time between regions. When also transfer connections are included, the air transport network has become denser, with 52,596 airport pairs served in 2000 compared to 67,009 in 2017.

Figure 2 shows the final model setup. The model searches for the shortest travel time from trip origin to destination. First, the car travel time from origin to destination is queried from Google Distance Matrix API, in order to have a "base" travel time, against which the combined car-air travel is compared. Then, the model searches for all airports, which are located in a radius of 300 km around the trip origin and the trip destination. It then searches for all potential flight connections from the airport-to-airport shortest flight time matrix. In figure 2, potential flight connections are O_1 to D_2, O_2 to D_1 via B, O_2 to D_1 and O_2 to D_2. Airports A, B and C are not considered as origin / destination airports, as they are located outside the 300 km radius of each NUTS-3 region. Airport access and egress times are then added to the flight times O_1-D_2, O_2-D_1 and O_2-D_2 and a search for the shortest travel time is conducted.

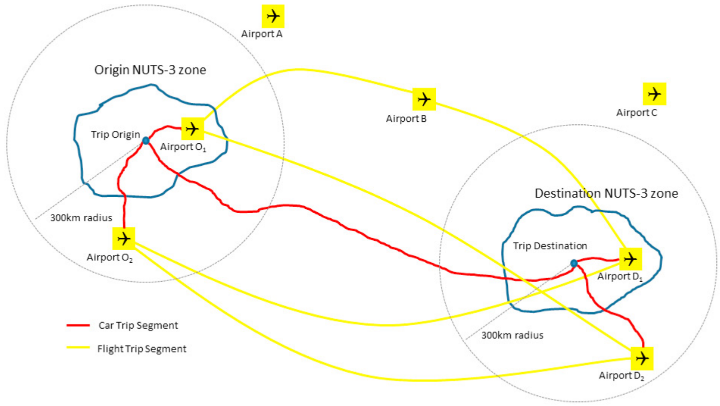

Fig. 2. Model setup, search for shortest connection.

4. Results and discussion

Figure 3 shows the travel time benefits of a combined trip by car and scheduled air transport in comparison to a trip by car only. Positive values on the y-axis depict a travel time benefit of the car/air combination and negative values a travel time benefit of car only. It can be shown that from an average great circle distance of 380 km onwards, air transport is faster than car as a single mode. However, the shortest region pair where air transport provides a travel time benefit is 193 km (Munich to Belluno, Italy), while the longest region pair where car only still provides a travel time benefit is 893 km (Ilm-Kreis, Thuringia to Białostocki, Poland). Out of the total 559,986 NUTS-3 region pairs, 137,643 (24.6%) are connected by car as fastest travel mode. 422,343 (75.4%) are served fastest with a combination of car and air transport.

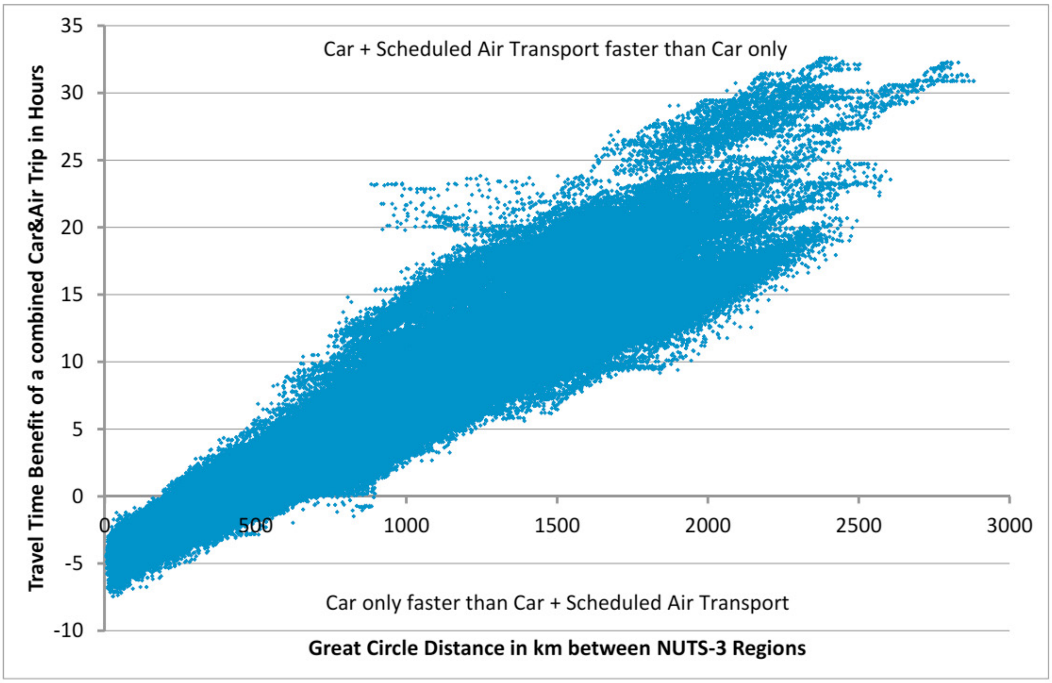

Fig. 3. Travel time benefits of combined car-air trips by distance from Germany to Europe, 2017.

As an indicator summarizing the connectivity of each region, we have selected the average shortest travel time from each originating NUTS-3 region in Germany. Hence, we summarize the shortest travel times to each destination NUTS-3 region and divide the result by the number of destination NUTS-3 regions. Figure 4 (a) summarizes the results in average shortest travel times 2017 for all German NUTS-3 regions, while Figure 4 (b) shows the travel time changes between 2000 and 2017.

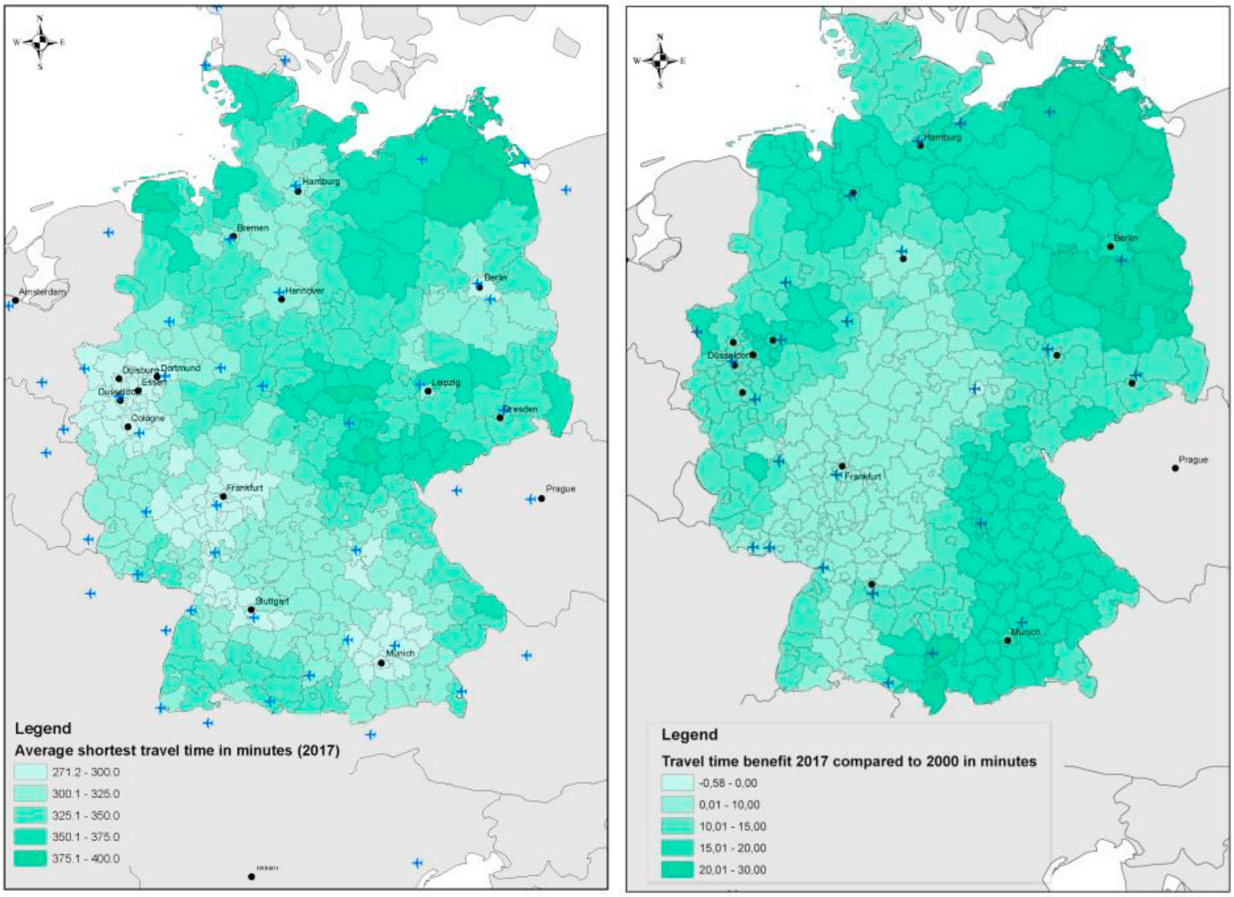

Fig. 4. (a) Average shortest travel times in 2017. (b) Changes in average shortest travel times 2000-2017

Table 2 shows the changes between 2000 and 2017 for each of the ten German NUTS-3 regions which have had the lowest and highest average travel times in 2017. One could argue that these regions are the best and worst connected regions in Germany. The best connected NUTS-3 regions have all in common that they are located in very close proximity to major airports like Frankfurt, Munich, Stuttgart, Düsseldorf and Cologne. On the opposite, regions with highest average shortest travel times are located at the periphery and/or with long travel times to major airports. The most interesting region in this regard are the NUTS-3 regions in Thuringia (e.g. DEG0I Saalfeld-Rudolstadt, DEG0A Kyffhäuserkreis or DEG0H Sonneberg), which are located close to the center of Germany, but are still among least well connected areas. When it comes to air transport connectivity, there is apparently a void in the middle – airports in the vicinity have no scheduled traffic (e.g. Magdeburg-Cochstedt or Altenburg-Nobitz), have insufficient levels of traffic to provide a good level of connectivity (e.g. Erfurt or Kassel) or are located at a distance of 150 km to more than 300 km (Leipzig, Dresden, Frankfurt, Hannover and Nuremburg). As these areas are only sparsely populated, public transport is also not a real time-efficient alternative for passengers travelling to or from the east-center region in Germany.

Table 2. Changes in average shortest travel time for best and worst connected NUTS-3 regions in Germany.

NUTS-3-Region Name	NUTS-3-Region-Code	2000	2005	2010	2015	2017	Absolute change in minutes 2000 - 2017
Frankfurt am Main	DE712	271	271	271	271	270	-1
Duisburg	DEA12	286	280	275	273	273	-13
Freising	DE21B	290	282	280	278	273	-17
Esslingen	DE113	284	276	278	277	274	-10
Leverkusen	DEA24	288	279	276	275	274	-14
Düsseldorf	DEA11	287	281	277	274	274	-13
Offenbach	DE713	275	275	275	275	274	-1
Oberhausen	DEA17	288	282	277	274	275	-13
Mülheim a.d. Ruhr	DEA16	288	282	277	274	275	-13
Köln	DEA23	289	277	276	276	275	-14
Görlitz	DED2D	382	375	367	370	367	-15
Stendal	DEE0D	387	376	373	372	368	-19
Sonneberg	DEG0H	381	376	378	378	369	-12
Flensburg	DEF01	382	377	376	374	370	-12
Kyffhäuserkreis	DEG0A	384	376	378	377	377	-7
Vorpommern-Greifswald	DE80N	408	397	386	383	378	-30
Aurich	DE947	396	388	381	382	380	-16
Mecklenburg. Seenplatte	DE80J	403	393	385	382	380	-23
Saalfeld-Rudolstadt	DEG0I	393	385	388	388	381	-12
Vorpommern-Rügen	DE80L	417	402	390	391	389	-28

The data underlying figure 4 (b) shows that regions in the state of Mecklenburg-Vorpommern have gained highest travel time reductions, due to several new routes at the airports of Rostock and Heringsdorf. These results show that initially, when only very few flights are added to a regional airport, the achieved travel time savings can be quite high. However, the law of diminishing returns sets in and each additional route/destination contributes to a smaller degree to travel time savings. Other regions which have gained connectivity are the areas in the vicinity of the airports of Berlin, Bremen, Nuremburg and Memmingen, due to the low cost carrier boom at these airports. To a lesser extent, this also applies to the area of Cologne and Dortmund. NUTS-3 regions in southern Bavaria have gained through the establishment of Lufthansa's hub in Munich, albeit this improvement is smaller than for the regions near booming low cost airports. On the opposite, the data shows that regions with already very good connections in the year 2000 did not benefit from air transport network changes to a great extent. Particularly the regions around Frankfurt airport already had in 2000 very good connections and this did not change significantly until 2017, showing the long-term stability of the hub-and-spoke network of Lufthansa and Star Alliance in Frankfurt. It also indicates that mainly due to long-term capacity constraints and the non-existence of new low cost connections in Frankfurt to destinations not served by existing network airlines until early 2017, no travel time savings could be realized.

5. Conclusions

The analysis has shown that - on average and based on the data set for travel from Germany to Europe in June 2017 – combinations of scheduled air transport and car as airport access/egress mode offer travel time savings for trips on distances longer than 380 km. However, the variation is relatively high, as we find region pairs of only 193 km, where air transport offers travel time benefits and region pairs of 893 km, where the car alone is still faster than a combination of air transport and car.

Concerning the changes in average shortest travel times in the period from 2000 to 2017, we have identified regions that benefitted most from the growth of the air transport network. Particularly NUTS-3 regions in the state of Mecklenburg-Vorpommern, as well as around the booming low cost airports of Berlin, Bremen, Memmingen and Nuremburg have benefitted. Travel time savings in these regions are on average between 30 and 50 minutes per region pair. However, we have also discovered that the regions with best connections in the year 2000 have only insignificantly improved until 2017.

The data generated with the model also show the relative importance of car travel, both as a means of direct connection between two NUTS regions, but also as a means of time efficient airport access and egress mode. Further research should evaluate the time efficiency of high speed trains in comparison to car/air travel. This is a particularly interesting aspect from perspective of political economy, given the high investments into high speed trains in Germany on the one hand, but also the importance of the automotive industry for the Germany economy. Further applications for the model developed here could include the analysis of radical new concepts, like autonomous air taxis, which could connect any European airport with any other airport as on-demand non-stop services. The travel time savings of such business models can be considered as substantial. The model could also be used to evaluate the contribution of regional airports to connectivity of regions. Particularly due to the European Commission's decision to limit operating aid for regional airports (European Commission, 2014), regional airports with less than 3 million passengers per year might be forced out of the scheduled passenger business, if they cannot cover their operating costs after 2024. The model is well suited to conduct a "with-or-without" analysis focused on the network effects of regional airports. Moreover, the model can also be applied for analyses showing the advantages of using different modes over different distances and identify weakly connected links within Europe, where travel times are comparably high. The addition of a generalized cost model, as shown by Laurino et al. (2017), could further identify optimal modes for trips between different regions and by different passenger groups. This would also include the addition of public transport, which can be queried easily with Google's Distance Matrix API in the same way as car travel was queried for this paper.

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