EVALUATING TEMPORAL INTEGRATION OF EUROPEAN AIR TRANSPORT

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Keywords: *Passenger Travel Time, Flightpath 2050, Complex Temporal Network*

Abstract

Europe's recent strategic aviation research agenda, Flightpath 2050, asks for enabling four hour or less door-to-door travel time for 90% of all Intra-European travelers. To statistically deduce passenger air travel times, this paper presents a spatio-temporal graph search and passenger allocation algorithm that combines aggregated demand data and published flight schedules. The results indicate that 90% of all current Intra-European air travelers require four hour or less from origin airport to destination airport, rather than from door-to-door. Most passengers require 60-90 minutes to reach their final destination airports, but markets with a travel time between 90 and 210 minutes experienced greater growth rates. The share of journeys that take a long time to complete is highest for departures in the early morning or around noon. The vast majority of all Intra-European passengers travel direct and the directness of the overall system increased from 2002 to 2012, largely due to the emergence of low cost carriers. The results indicate that the demand structure of European air transport is such that there is only a very limited number of non-revolutionary measures that could make the Flightpath 2050 travel time goal achievable in the near future.

1 Introduction

Air transport is the only mode of transportation that hauls people and goods over long distances in a time efficient manner. From the perspective of lean management[1], an ideal air transport system would provide a direct flight every time a passenger wants to travel. However, due to economic and ecological constraints, airlines compete by offering a finite number of flights at a limited number of points in time. Temporal efficiency is a scarce resource in air transportation systems.

Europe's long term vision for aviation research, Flightpath 2050[2], asks for improving temporal performance for a growing number of journeys. By the year 2050, this call to action demands that 90% of all Intra- European travelers are able to complete their door-to-door journey within four hours. While achieving this goal will also require multi-modal and procedural improvements, the capabilities of air transport by itself should create a favorable operational environment that supports time-efficient travel. Identifying the key factors that eventually will help achieving this goal requires answering at least two questions.

1. What is an appropriate way to measure and model temporal integration in the European air transport system on a macroscopic level?

2. What is the current temporal integration performance of European Air Transport?

The goal of this paper is to contribute to answering these questions, foster research in suitable improvement strategies and support relevant decision makers by providing insight in current system peculiarities.

2 Literature Review

Most papers that study the architecture of air transportation networks focus on static aspects. Typical topics are spatial concentration and hub development[4, 5], centrality[6] and other non-temporal measures[7, 8].

Several previous works studied temporal aspects of air transport. Burghouwt and de Wit[9] use the concentration of flight arrival and departure times to cluster the network of European airlines. Paleari et al.[10] compared the connectivity of aviation networks in China, Europe and the US by calculating time-dependent optimal paths between each pair of airports. They found that the European network provided the most homogenous level of service to the passengers. Similarly, by calculating the shortest travel time path between the worlds largest airports, Redondi et al.[11] demonstrate the competition between airport hubs and the influence of geographic position on hub performance.

The study of temporal aspects has recently also drawn interest in complex network research[12]. For air transport studies, Pan and Saramäki[13] adapted a number of concepts from complex networks theory that are applicable for temporal networks.

These previous studies provided valuable insight into temporal aspects of air transportation. However, they either considered only the flight network (neglecting passenger demand), or they assumed demand between each airport node in the network and often calculated optimal paths between these nodes. However, passenger demand networks are typically not fully connected but show more subtle linking pattern[14]. Our previous research indicated that including considerations on the interdependence between supply and demand provides insight that can not be drawn from consideration of the flight network alone[14, 15, 16].

This paper describes the temporal integration of the European air transport system by adequately considering both, flight network and passenger origin-destination demand. Here, temporal integration refers to how the structure of scheduled air traffic affects the journey time for all traveling passengers.

3 Approach: Measuring Temporal Integration in European Air Transport

The Flightpath 2050 goals asks for a maximum door-to-door time of four hours for 90% of all Intra-European travelers. The definition of what comprises Europe in this case is not unique. Potential geographic definitions could range from excluding all nations that are not part of the European Union, up to including the entire geographic extent of Russia (default setting in the used commercial database). Here, we included all continental European nations plus the Azores and Canary islands. Since Flightpath 2050 stimulates a long term focus, we also included the country of Turkey as an emerging economic power that will likely play an important role in future air transportation. Fig. 1 shows the airports that make up the European air transport network in the definition of this paper.

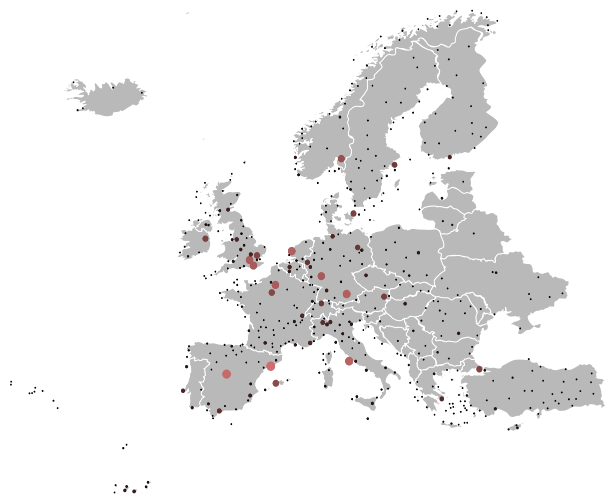

Fig. 1 Airports of the European Passenger Air Transport System. Node size indicates number of arriving passengers in April 2012.

Assessing the temporal integration of current European air travel requires statistics of total passenger air travel time, which we define as the elapsed time between the scheduled departure time of the first flight and the scheduled arrival time of the last flight of a given itinerary. An itinerary $I = (f_{AB}, f_{BC}, \ldots)$ (or temporal passenger path) is defined as a tuple of scheduled flights f describes the travel path.

A critical condition for evaluating temporal integration is data availability. To the best of our knowledge, there is no database, neither publicly nor commercially available, that contains all individual passenger paths including flight times. The database available for this study is based on computer reservation systems and other data sources. It contains information on both, airline flight schedules and monthly aggregated passenger path information. The latter consists of number of passengers per path, origin airport, destination airport, connecting airports and the airlines for all legs. This information is called the topological passenger path $P = (s_{AB}, s_{BC}, \ldots)$, where s are segments that provide information on connected airports but not the flight times. The number of passengers that took that path is $N(P)$ and The number of segments l is called path length.

To statistically deduce air travel times, an algorithm combines a spatio-temporal graph search with a capacity-based passenger allocation procedure. Fig. 2 illustrates the approach for a simplistic example.

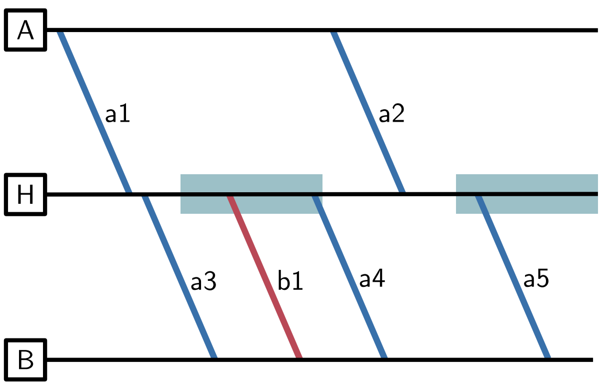

Fig. 2 Demonstration of the Temporal Path Assignment Algorithm using a Time-Space Map (time is progressing towards the right). Squares indicate airports, the colored lines are flights (color indicates airlines) and the green boxes denote valid connection time frames. For a given topological path from A to B via H with airline a, valid itineraries are (a_1, a_4) and (a_2, a_5)

Each topological passenger path can be realized by different itineraries (that contain the available flights). The first step is therefore to create a set of candidate itineraries for each topological passenger path based on the published flights schedules and topological passenger paths

$$f(P) = \mathbf{I} \tag{1}$$

These itineraries contain detailed flight information, including departure and arrival time of each leg, as well as the seat capacities of each flight. The itineraries are generated based on an assumed minimum and maximum connection time $30min \leq t_{connect} \leq 90min$. If no connection was found, the flight with the shortest connection time that is longer than 90 minutes was used. For each candidate itinerary, the total air travel time $T(I)$ is the sum of all flight and connection times. The results were relatively insensitive to varying the bounds on the connection time.

Each itinerary I has a flight with a minimum capacity $C^{min}(I)$. The vector $\mathbf{C}^{min}$ contains the minimum seat capacities of each itinerary in $\mathbf{I}$. The second step assigns a number of passengers to each itinerary based on the minimum capacity of an itinerary. It appears reasonable to assume that airlines ensured that for two itineraries that are otherwise identical (same connecting airports, same airline), the one that contains only large aircraft is used by more passengers than one that only contains small aircraft. Thus, the number of passenger $N(I)$ that took a given itinerary I is given by

$$N(I) = \frac{C^{min}(I)}{\mathbf{C}^{min}\mathbf{1}} N(P) \tag{2}$$

In summary, the algorithm assigns passengers to itineraries based on the share of the itinerary's minimal capacity flight per sum of minimal capacities of all itineraries for a given path. This procedure provides information on the number of passenger $N(I)$ that had an air travel time $T(I)$ for all valid itineraries.

A system property related to temporal integration is the directness of passenger travel paths. Directness here refers to how similar the structure of passenger demand is to the supply of offered airline flights. In a point-to-point network structure (the configuration with the highest directness), airlines offer a flight on each demand market and passengers do not have to connect. In contrast, a hub-and-spoke configuration reduces the number of connected airports but requires some passengers to connect. Thus, two aspects of directness are the number of flights and the connecting behavior of passengers. Following Ref. [14], two normalized directness measures are therefore of interest. The topological directness indicates the form similarity of the supply and the demand network

$$D_1 = \frac{Number\,of\,Direct\,Connections}{Number\,of\,Markets} \tag{3}$$

The second directness measure captures the passenger perspective and indicates the mean number of legs per passenger. Thus, the weighted directness measure is

$$D_2 = \frac{\sum N(P)l}{\sum N(P)} \tag{4}$$

Equation 4 simply relates the number of legs flown by passengers to the number of passengers. In a point-to-point network $D_1 = D_2 = 1$, and for more indirect systems $D_1 < 1$ and $D_2 > 1$.

4 Results: Temporal Integration of European Air Transport

The Flightpath 2050 goal targets a share of passengers that have a common upper bound travel time (90% share with t<240min). To gain insight into overall market mechansims, it appears desirable to not only consider the 90% passenger share, but to have an overview of upper bound travel times for all shares of passenger.

Figure 3 shows cumulative travel time distributions for the month of April in 2002, 2007 and 2012. The distribution reveals that in 2012, 10% of all passengers had a travel time of 60 minutes or less, 40% had an air travel time below 90 minutes and, most importantly, 90% of all Intra-European air travelers required less than four hours (240 minutes) from origin airport to destination airport. Note that the Flightpath 2050 goal asks for the same travel time for the same share of passengers, but for door-to-door travel (and not ramp-to-ramp). Transportation to and from the airports, airport processing (e.g. check-in, baggage handling, security) and gate waiting times can easily add another hour or more to passenger door-to-door travel time, making the Flightpath 2050 goal appear unrealistic to achieve in the near future.

Comparing the cumulative travel time distribution in 2002 and 2012 reveals a change in travel behavior. Below 150 minutes, the same share of passengers had lower upper bound travel times in 2002 compared to those in 2012. For example, in 2002, 50% of all passengers traveled less than or equal to 95 minutes, while in 2012, 50% of all passenger had a travel time below or equal to 110 minutes. For travel times greater than 150 minutes, the situation is the opposite and upper bound travel time became lower in 2012. As mentioned, 10% of all passenger traveled more than 240 minutes in 2012, while in 2002, 15% exceeded the four hour threshold.

To better understand the change in travel behavior, Fig. 4 displays passenger share per binned travel time. The results suggest that the largest share of passengers have a travel time between 60-90 minutes, followed by 90-120 minutes and 120-150 minutes. However, relative passenger share has significantly changed from 2002 to 2012. In particular, the share of passengers that had a travel time of 60-90 minutes decreased in favor of travel times between 90 and 180 minutes. Note that this decrease does not mean that the absolute number of passenger decreased, but rather that passenger growth in the 60-90 minutes portion (+0.4%) was lower compared to passenger growth in longer travel time intervals(+1.4% for 90-120 min and 120-150 min, +1.94% for 150-180 min). The share of passengers traveling more than 180 minutes was stagnating.

The passenger growth rate pattern helps explaining three manifestations of the cumulative travel time distribution in Fig. 3.

First, the share of passengers traveling more than 150 minutes remained constant (25%). This provides an explanation for the crossing of the 2002 and 2012 lines at 150 minutes in Fig. 3.

Second, the growing share of passengers that travel 90 to 150 minutes led to an increase in upper bound journey times below 150 minutes. For

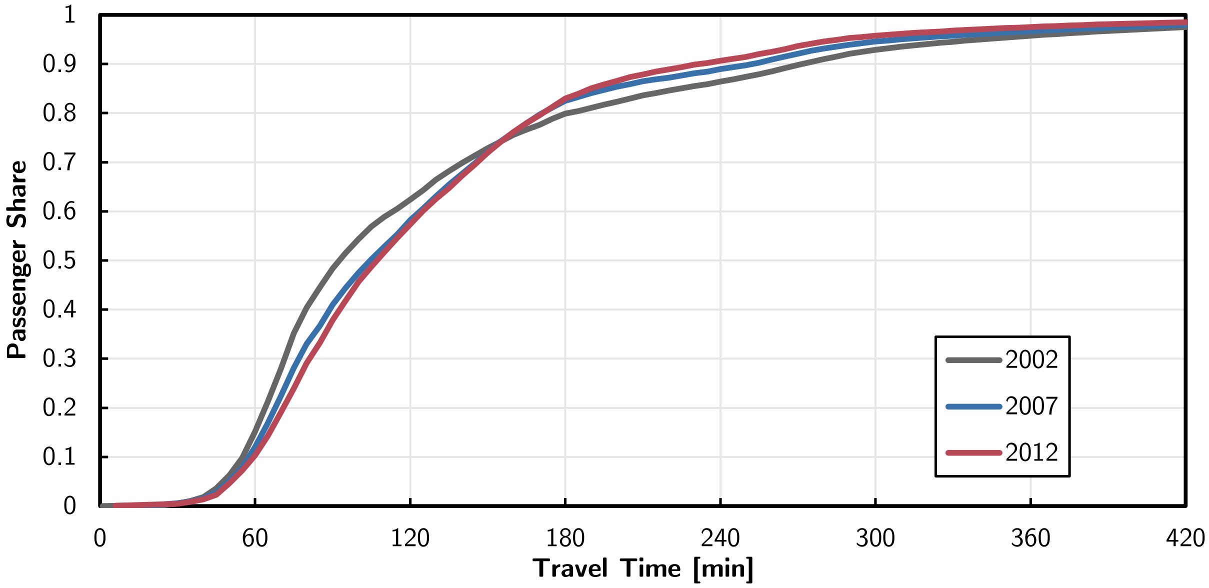

Fig. 3 Cumulative Travel Time Distributions for April 2002, 2007 and 2012.

these intervals a greater share of passengers traveled a longer time. As a consequence, there was a downward shift of the cumulative distribution curve for travel times less than 150 minutes.

Third, the intervals from 150 to 210 minutes experienced far greater growth rates than intervals with an even longer travel times, leading to an upward shift of the cumulative distribution (greater share of passengers had a lower travel time) for travels longer than 150 minutes. This development contributed to reducing the share of passengers that had travel times greater than 240 minutes.

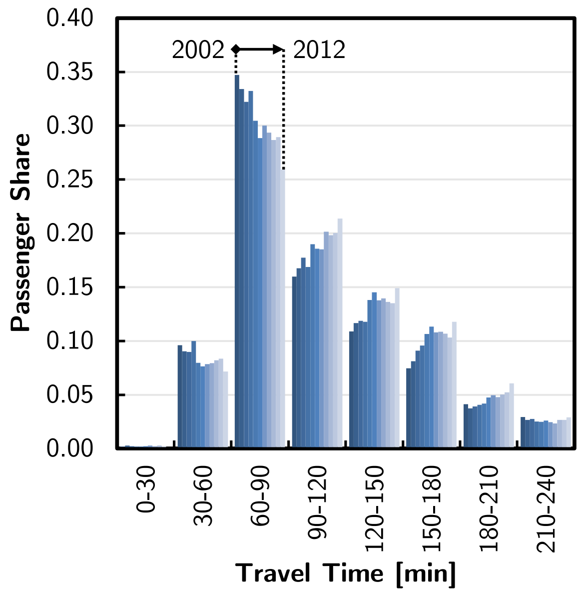

Fig. 4 Passenger share breakdown per travel time interval from 2002 until 2012.

Besides an aggregated view on travel time variation, another important aspect of temporal integration is its dependence on the journey starting time. Figure 5 plots the distribution and variation of travel times over hourly intervals of departure time, and the share of passengers that started the journey in these intervals for the month of April in 2002 and 2012. Thus, the results do not show a particular day during April 2002 or 2012, but rather an average over all days of the month.

The vast majority of passengers began their journey during typical airport business hours, i.e. between 6h and 22h of local departure time. Due to mitigating excessive noise for people living in the vicinity, many European airports have implemented a curfew hour scheme that prohibits, or imposes stringent limits, on departures and arrivals during night time. The few passengers that do start at night time do not significantly contribute to cumulative travel times. Since the share of these passengers is so low, it is not surprising that small variation led to big changes in the off-hours region of Fig. 5. The results of the passenger assignment algorithm suggests that in 2002, most passengers began their journey between 7-8

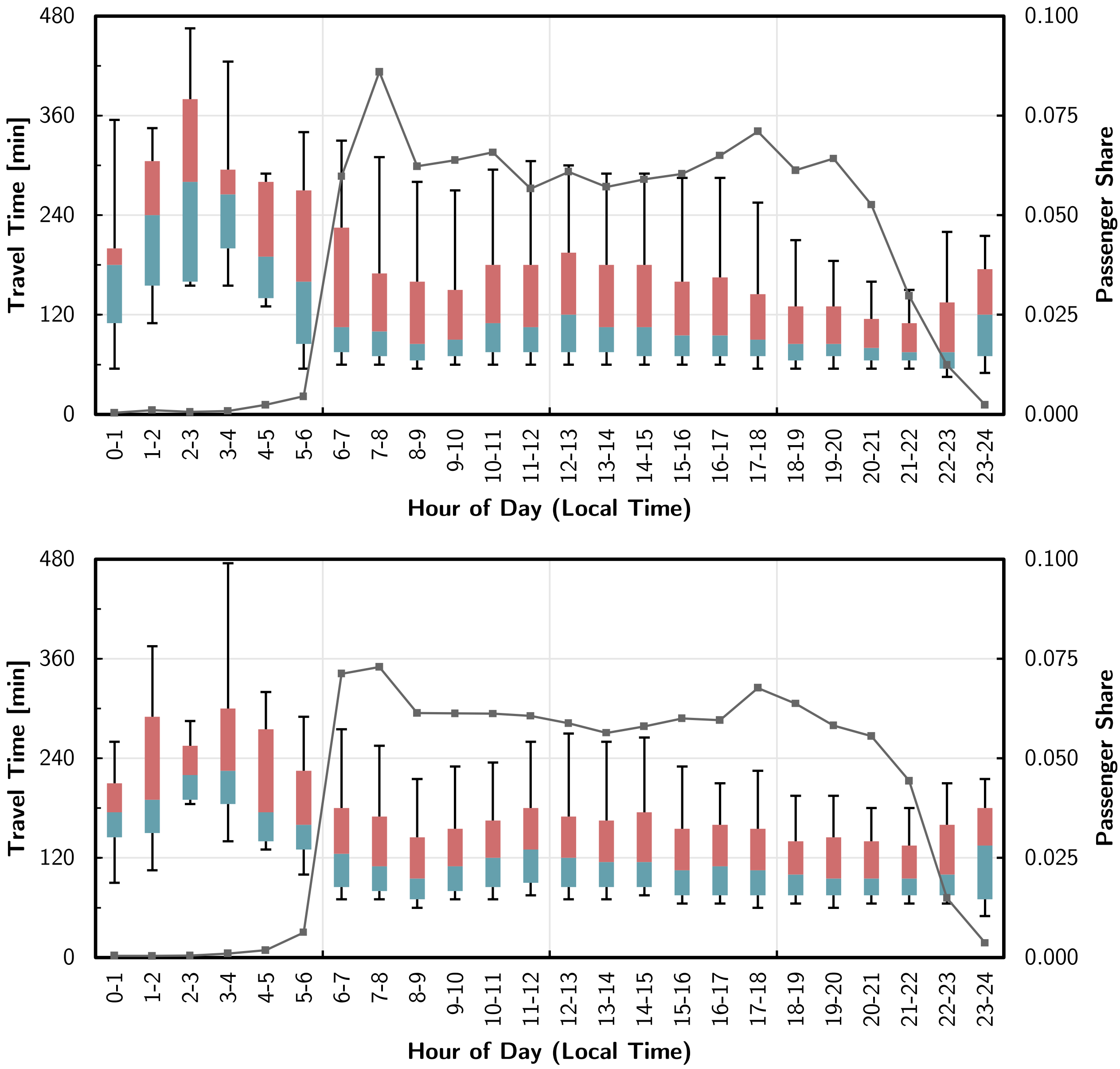

Fig. 5 Passenger travel times (boxes and left axis) and passenger share (grey line and right axis) per departure hour interval in 2002 (top) and 2012 (bottom). The lower whisker indicates 10% passenger share, the upper whisker denotes 90% passenger share. The box distinguishes first quartile, median and third quartile.

h and there is another peak in the 17-18h interval. In 2012, peaks exist in the same time intervals yet they are not as distinctive as 10 years before. Overall, passenger share became somewhat more evenly distributed during normal airport operating hours.

In virtually all on-hours departure time intervals, the travel time distribution is skewed to the right (or to the top, for this type of display), i.e. most travel times are small, but there exist a few exceptionally large ones. The box plot visually indicates that skewness was higher in 2002 than in 2012, with the median values more heavily shifted towards the 25% quartile box limit. This goes in line with a decrease in travel time spread. While the boxes (representing the middle 50% of all passenger) span 1.5 to 2 hours in 2002, the interquartile range reduced to one hour in 2012. Similarly, the spread of the 80% passenger share (difference between upper and lower whisker) showed a significant reduction. The reduction of skewness and spread suggests an increasing number of journey durations that are closer to the median travel time of a given departure interval.

Median travel times are largest around noon (12-13h in 2002, 11-12h in 2012) or in the early morning hours, but seldom exceeding 120 minutes. Minimum median travel times occur in the 8-9h interval and during the end of typical airport operating hours. Flights that start late can only reach short-distance targets before night time landing restrictions become effective at the destination airport. Additionally, curfew hours often prohibit passengers arriving late in the evening to connect to flights that leave the same day.

In 2002, more than 10% passengers had a travel time greater than 240 minutes – given the journey started before 18h. Thus, the 4 hour/90% threshold was not achieved for the most part of the day. Only evening and night time intervals showed a significant decrease in travel time for 90% of departing passengers.

In agreement with the cumulative distribution in Fig. 3, the travel time for 90% passengers was below or equal to 4 hours for most departure time intervals in 2012. The share of journeys that take a long time to complete is highest in the early morning (5-8 h) or around noon (11h-15h). While the first interval corresponds to a peak in the overall passenger share, the latter is a time of low-to-medium passenger traffic. The other time intervals during normal operating hours have an upper bound travel time for 90% of the passengers that is below 4 hours. Thus, while the 'four hour rule' is violated in the morning high-traffic interval (7-8h), 90% of the passengers that depart during the evening peak hour from 17-18h have travel times of less than 220 minutes.

So far, the analysis discussed the details of the air travel time development in Intra-European travel. To provide insight into one of the main drivers of this development, it is necessary to study how flight connecting behavior changed. Equations 3 and 4 introduced different measure for directness in air transportation. Fig. 6 plots topological versus weighted directness for the Top 20 European airlines in terms of origin- destination passengers as well as the entire market. Fig. 6 suggests that there is a dependence of topological and weighted directness in this market.

In April 2002, the average number of segments per passenger itinerary was 1.1, with flights only on 23.9% of all routes between airports that are part of a common demand market. The largest airlines all operated relatively indirect networks. Air France (0.15/1.05), Lufthansa (0.13/1.18) and SAS (0.09/1.2) were the three airlines that transported the largest number of Intra-European travelers. Market share of carriers with a higher directness was low, with Ryanair and easyJet ranked 7th and 8th in terms of demand passengers.

According to Fig. 6, there were direct flights on 25.7% of all markets and the average number of hops per passenger reduced to 1.04 in 2012. The largest Intra-European airlines, Ryanair and easyJet, were point-to-point operatores. Taken together, these two airlines had more than six times the number of passengers as the third largest airline, Lufthansa. The latter operates a typical hub-and-spoke system, where 7% of markets have a direct connection and an average leg-per-itinerary coefficient of 1.16. While this number is higher than those of the point-to-point carriers, it still shows an increase in directness compared to the 2002 value.

A general observation here is an increase in system directness over the ten year period of consideration. The share of passengers that traveled more than one leg during their Intra-European journey reduced from 15% in 2002 to only 8% in 2012. A major contribution to this evolution was the emergence of Low-cost-carriers in the Intra-European market and the market-leading position they posses today. Additionally, even more traditional hub-and-spoke carriers showed an increase in the passenger-related directness metric.

The increased system directness has profound implications for potential measures to reduce Intra-European travel time. Since the flight network closely matches the demand network, the typical travel times are, in most cases, equal to the duration of a single flight. In other words, there is a significant share of passengers on mar-

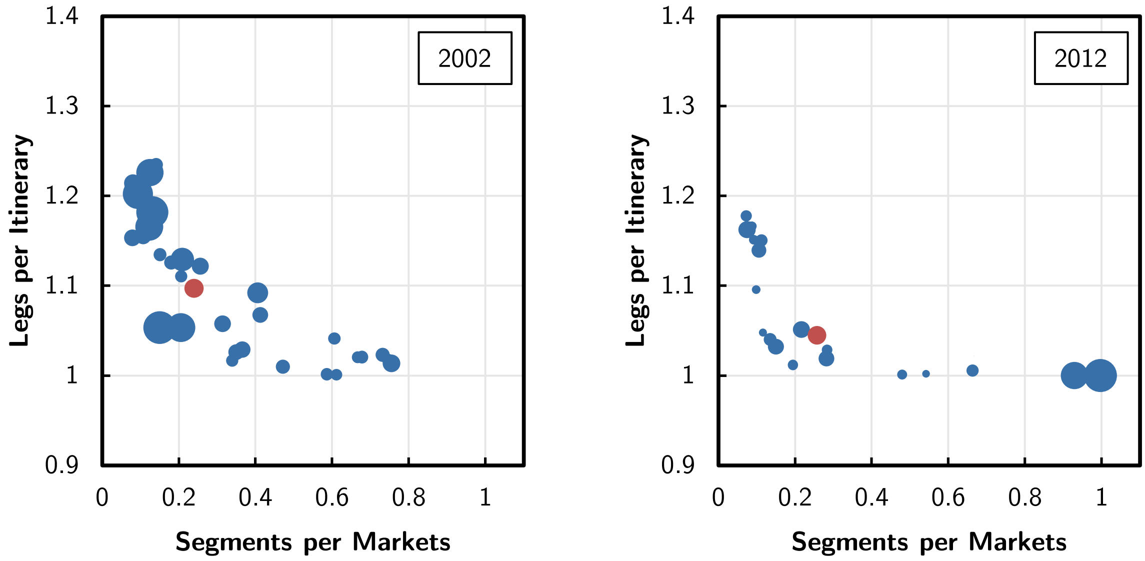

Fig. 6 Directness of the Intra-European Passenger Transport Segment of European Airlines. The blue bubbles indicate airlines, the red bubble denotes overall market directness. The bubble size illustrates an airline's share on the total number of demand passengers.

kets with a direct airport-to-airport flight time that makes four hour travel prohibitive.

5 Discussion and Conclusions

This paper proposed an integrated algorithm for deducing passenger travel time from aggregated demand data and published flight plans. The algorithm evaluated the temporal integration of Intra-Euorpan passenger air travel between 2002 and 2012.

The findings should be seen in the light of the recent European high level strategic research agenda (Flightpath 2050) that asks for 90% of all Intra-European travelers reaching their final destination within four hours. This paper demonstrated that, if only passengers traveling by airplane are considered, 90% of all passengers have an airport-to-airport travel time of less four hours in 2012. There would be no extra time left for airport processing and transportation from and to the airport. The travel time distribution has developed in such a way that a growing share of passenger itineraries were completed in less than four hours, i.e. in favor of the Flightpath 2050 goal.

In the current system, many passengers travel direct. Since less than 10% of all passengers connect, measures to improve connection performance for Intra-European travels will have only a marginal impact on overall system performance. Rather, there are a significant number of demand markets that would require more than four hours to complete even if a direct flight would be offered.

One obvious option for reducing flight time is increasing flight speed. However, current aircraft flight velocities are already close to Mach 1, providing only a very narrow region for improvement. From the current perspective, any supersonic Intra-European travel can safely be ruled out due to supersonic travel being prohibited over land virtually in the entire world and the absence of plans for supersonic aircraft concepts that target short ranges.

Since scheduled flight times often include ample time for ground and terminal operations (like taxiing and navigation near the airports), there is some improvement potential for these parts of the flight mission. Since these improvement are in the order of minutes, the impact of overall system performance is still limited.

Even if airport passenger processing time would be cut dramatically (Flightpath 2050 asks for a seamless air travel experience), there is still the need for a radical cut in transportation time to get to and from airports. Thus, what is need is a better integration of airports into other modes of transportation. Alternatively, opening more regionally distributed airports could reduce transportation time. A more revolutionary approach would be to investigate more-personalized air transportation concepts that pick up passengers from closer to origin and bring them closer to their final destination than the current system.

This paper focused on scheduled air traffic. The impact of disruptions on real world flight operations (e.g. influence of weather) could highlight additional aspects of temporal integration.

Ref. [3] asks for customer-oriented metrics to monitor Europe's mobility system performance. The four hour goal sets such an overall performance target, but it is biased if an increasing number of passengers travel between more distant airports. Thus, this goal might not do justice to mirror the concerns of passengers in the most illuminating way. We would like to foster future research on travel time measures that support stakeholders in improving Europe's air transport network and better suit passenger needs. The results presented here provide a performance baseline for temporal integration of current European air transport.

References

[1] Womack J P and Jones D T. *Lean Thinking: Banish Waste And Create Wealth In Your Corporation*. New edition, Simon & Schuster, 2003.

[2] High Level Group on Aviation Research. *Flightpath 2050: Eurpope's Vision for Aviation*. European Union, 2011.

[3] ACARE. *Strategic Research & Innovation Agenda*. 2012.

[4] Reynolds-Feighan A. Traffic distribution in low-cost and full-service carrier networks in the US air transportation market. *Journal of Air Transport Management*. Vol. 7, No. 5, pp 265-275, 2001.

[5] Burghouwt G, Hakfoort J, Ritsema van Eck J. The spatial configuration of airline networks in Europe. *Journal of Air Transport Management*. Vol. 9, No. 5, pp 309-323, 2003.

[6] Guimera R, Mossa S, Turtschi A and Amaral L A N. The worldwide air transportation network: Anomalous centrality, community structure, and cities' global roles. *Proceedings of the National Academy of Sciences of the United States of America*. Vol. 102, No. 22, pp 7794-7799, 2005.

[7] DeLaurentis D, Han E and Kotegawa T. Network-Theoretic Approach for Analyzing Connectivity in Air Transportation Networks. *Journal of Aircraft*. Vol. 45, No. 5, pp 1669-1679, 2008.

[8] Wuellner D, Roy S and D'Souza R M. Resilience and rewiring of the passenger airline networks in the United States. *Physical Review E*. Vol. 82, No. 5, 056101, 2010.

[9] Burghouwt G and de Witt J. Temporal configurations of European airline networks. *Journal of Air Transport Management*. Vol. 11, No. 3, pp 185-198, 2005.

[10] Paleari S, Redondi R and Malighetti P. A comparative study of airport connectivity in China, Europe and US:Which network provides the best service to passengers?. *Transportation Research Part E*. Vol. 46, No. 2, pp 198-210, 2010.

[11] Redondi R, Malighetti P and Paleari S. Hub competition and travel times in the world-wide airport network. *Journal of Transport Geography*. Vol. 19, No. 6, pp 1260-1271, 2011.

[12] Holme P and Saramäki J. Temporal Networks. *Physics Reports*. Vol. 513, No. 3, pp 97-125, 2012.

[13] Pan R K and Saramäki J. Path lengths, correlations, and centrality in temporal networks. *Physical Review E*. Vol. 84, No. 1, 016105, 2011.

[14] Lehner S. Separate Yet Interdependent Networks: The Structure and Function of European Air Transport. *Complex Networks IV*. Springer-Verlag, 2013.

[15] Lehner S, Nishant S and Gollnick V. Analyzing collaboration in self-organizing complex systems of flow. *IEEE Systems Conference*. Ottawa, ON, Canada, pp 417-424, 2014.

[16] Lehner S and Gollnick V. Function-Structure Interdependence of Passenger Air Transportation: Application of a Systemic Approach. *AIAA Aviation 2014 and 14th AIAA Aviation Technology, Integration, and Operations Conference*. Atlanta, GA, USA, 2014.

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