EUROCONTROL

EUROPEAN AVIATION IN 2040

CHALLENGES OF GROWTH

Annex 3
Mitigation Measures

SUMMARY

This annex is part of the fifth Challenges of Growth study, which aims to deliver the best-achievable information to support long-term planning decisions for aviation in Europe and tackles the following question:

What are the challenges of growth for commercial aviation in Europe between now and 2040?

Recent variability in traffic has re-emphasised the need to consider a range of possible futures, in order to manage risks. After a stakeholder review, we have defined four scenarios that are detailed in the European Aviation in 2040, Challenges of Growth report (ref. 1)

The most-likely scenario is Regulation and Growth. However, we see a number of long-term risks that would lead to higher growth, and thus we also give particular attention to Global Growth.

The forecast whose details are available in Annex 1 (ref. 2) was built with information about plans of airports to expand their capacity but these airport capacity expansion plans, even if they can be delivered, are not expected to be sufficient. By 2040, there will be 1.5M flights more in demand than can be accommodated, 8% of demand, in Regulation and Growth.

This report looks at closing this capacity gap. Taking a cue from how Industry has responded in the past, we modelled six different mitigations, apart from new runways, and we looked at two different combinations of these different mitigations. We assessed their effectiveness in terms of the percentage reduction in unaccommodated demand.

The impact of the following six mitigations was estimated:

- **SESAR:**
  Wave 1 of SESAR has a package of 10 improvements to increase airport capacity at peak times. The SESAR target gains are expected to stand around 7% in peak throughput at the major airports - if they can be fully delivered into operations. This gives around 1.5% increase in total capacity across all the considered airports but, since they are focused on peak hours, the effect in Regulation and Growth is to reduce the 1.5M flight capacity gap by 28% in 2040. They are much less effective in Global Growth, where the capacity challenge is much broader. Overall, this mitigation is more focused than in the Challenge of Growth study of 2013 and as a result gives a bigger reduction now.

- **Local Alternatives:**
  Major cities are typically not short of runways, but often they are not at the right airport and lack the right access and operation infrastructure, or they are not well-placed relative to residential areas. Where these obstacles can be circumvented, airlines may focus their growth away from the principal airport to avoid congestion, either under their own or as a government initiative. In this mitigation, we looked at some city-specific options for this, and found that some 16% of the capacity gap would be mitigated, if these options could be delivered. This is probably an upper bound, given the difficulties in implementing such changes. It is also lower than what was seen in the Challenge of Growth study of 2013.

- **Consensus Benchmark:**
  For smaller airports, capacity plans sometimes seem to be driven as much by current demand as by fundamental limits to local physical capacity. We took, as a what-if? the assumption that single-runway airports could, if necessary, reach the upper-quartile capacity of this whole group, 200,000 movements per year. This reduced the capacity gap by 13%, marginally better than in the Challenge of Growth study of 2013 (10%).

- **HST investment:**
  The forecast scenarios already capture known plans for improving high-speed train (HST) infrastructure, and our forecast includes a model of the local reductions in air passenger demand that will result. As a what-if? we looked at 43 other city pairs which have significant numbers of flights, and at distances where HST is often competitive. If these additional HST links were possible, it would move more passengers from air to rail, and reduce the capacity gap by 7%. The obstacles to making that possible are large, including funding and acceptance by residents along the route.

- **Larger aircraft:**
  Looking around Europe and current traffic, we can see wide variation in the size of aircraft used to serve city pairs that are otherwise similar in distance, in total passenger numbers and in having competition between airlines. As a what-if?, we modelled the effects if larger aircraft were more consistently used on such city pairs. This led to an 8% reduction in unaccommodated demand: more passengers able to fly, on fewer flights.

- **Schedule smoothing:**
  When airport slots at peak hours are unavailable, airlines add capacity at other hours. This can improve fleet utilisation, but has an impact on costs due to lower yields. In aggregated historical data, we can see the effect of this as the quieter hours at an airport fill up. Projecting the same forward, based on the current quiet-versus-busy-hour pattern at Heathrow, gives us the 'schedule smoothing' what-if? Here, the reduction in the capacity gap is 11%, considerably lower than in Challenges of Growth 2013 (20%).

For each mitigation method, there are limits due to business constraints such as yield and aircraft availability. There are benefits to passengers and shippers from the connectivity and quality of service that is improved. But there are also costs, from easily measurable ones such as the cost of building HST track, to the non-monetary costs such as the impact on neighbours from expanding quiet or dormant airports. As a result, none of these mitigations would be easy to achieve.

As each mitigation acts on capacity of airports in a different way, they can also be used in combination to complement their action. For the most-likely forecast scenario Regulation and Growth, the most effective combination analysed in this study has the potential to reduce unaccommodated demand by 45%. It is a combination of three methods: additional investment in high-speed train; assuming SESAR Wave 1 is fully available and implemented at the airports that are the most congested and the use of a consensus benchmark capacity for single runway airports whose capacity is under-estimated. However, this combination of three is not a proposal of a best option that should be implemented, but instead an indication of the scale to which unaccommodated demand can be reduced and how.

In reality not all of these gains will be achievable and the industry will have to use a little of each of the six methods, just as it has been in the past, in addition to building new infrastructure to solve the capacity issue.

INTRODUCTION

The Challenges of Growth studies aim to deliver the best-achievable information to support long-term planning for aviation in Europe. EUROCONTROL has completed four Challenges studies, in 2001 (CG01), 2004 (CG04), 2008 (CG08) and 2013 (CG13) (Ref. 3, 4, 5 and 6). This report is part of the fifth study, Challenges of Growth 2018 (CG18), which tackles the following question:

What are the challenges of growth for commercial aviation in Europe between now and 2040?

The main analysis of CG18 which looks at European aviation by 2040 (Ref. 1) is complemented by more detailed, technical annexes: Annex 1 details the forecast up to 2040 (Ref. 2), Annex 2 reports on environmental issues (Ref. 7) and Annex 4 reports on the impact of the lack of capacity in terms of congestion and delays (Ref. 8). This annex, which is Annex 3, looks at ways to mitigate the lack of capacity, starting with building more airport capacity, but also looking at how to use differently the capacity that is available.

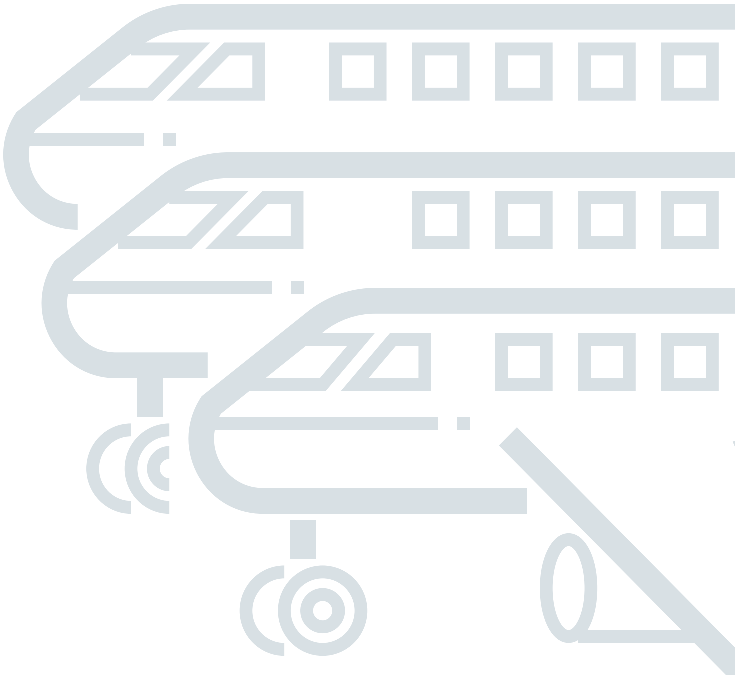
THE CAPACITY CHALLENGE

Recent variability in traffic has re-emphasised the need to consider a range of possible futures, in order to manage risks. After a stakeholder review, we have defined four scenarios, each describing a different future:

- **Global Growth:**
  Strong global growth with technology used to mitigate sustainability challenges;
- **Regulation and Growth, the most-likely:**
  moderate growth regulated to reconcile demand with environmental sustainability issues;
- **Happy Localism:**
  like Regulation and Growth, but with a fragile Europe increasingly, and contentedly, looking inwards for trade and travel.
- **Fragmenting World:**
  a World of increasing tensions and reduced globalisation;

The most-likely scenario is Regulation and Growth. However, we see a number of long-term risks that would lead to higher growth, and thus we also give particular attention to Global Growth.

The scenario results are discussed in the forecast report (Ref. 2) and in the summary report (Ref. 1). The results use information about plans of airports to expand their capacity but these airport capacity expansion plans, even if they can be delivered, are not sufficient. By 2040, there will be 1.5M flights more in demand than can be accommodated, 8% of demand in Regulation and Growth. That is 160 million passengers unable to fly. In Global Growth, the gap is 3.7M and 16% of demand. This report looks at closing this capacity gap.



NEW INFRASTRUCTURE TO MITIGATE THE CAPACITY GAP?

What do 1.5M flights represent in terms of operations? If these flights were operated on independent single runways as intensively as in Gatwick, 1.5M flights would represent about the operations of six such runways. If built as additional runways at existing airports, the gain in capacity would be less than this and the most-likely capacity gap would rather be covered by seven or eight busy runways.

More infrastructures would then be an efficient solution but, even if building these seven or eight runways could be achieved, these additional runways will not be a full solution to the capacity problem as the capacity gap is spread over 17 different States and 23 different cities. Furthermore, any change today in the existing infrastructure, like building a new runway or even a new airport, has become a true challenge. It involves many actors, including some whose interests go against the air-traffic business, and takes many years to be completed, when the project is not cancelled (e.g. Notre-Dame des Landes). Despite their ambitious capacity expansion plans, both Turkey and UK are forecast still to have additional capacity gaps.

Other options thus need to be implemented to complement the impact of new infrastructure and exploring such options to reduce unaccommodated traffic is the focus of the rest of this present report.

MITIGATION: EVERYONE CAN DO SOMETHING

In order to reduce the number of flights that cannot be accommodated, apart from new runways, we have analysed six different mitigation methods. Each method captures a different way in which the air transport industry and governments already respond when there is airport congestion. Each mitigation has its own limits that are discussed in the individual sections.

Their choice builds on the work done for Challenges of Growth 2013 (CG13) (Ref. 9). CG13 has further built on the work following CG08 (Ref. 10) that drew closely on the views of stakeholders, starting with a questionnaire and an interview process before choosing and designing the mitigation methods. CG18 repeats the task and further evaluates the impact of the same mitigations on the 2040 forecast available to date (Ref. 2).

This is not an exhaustive list of methods for increasing airport capacity. For example, we discuss neither aligning airport and flow management slots, nor adding rapid-exit taxiways. Our mitigation options are at a more strategic level, and the assumption is that a range of techniques would need to be applied to make the mitigation methods work, amongst which would be taxiway design etc.

The chosen methods are, in no particular order:

- **Larger aircraft:**
  accelerates the introduction of larger aircraft on congested airport pairs.
- **High-speed trains:**
  accelerates investments in the high-speed train network, beyond existing plans.
- **Alternative airports:**
  some excess traffic moves to secondary or regional airports from the main airports in Europe.
- **Consensus benchmark throughput applied to smaller airports:**
  compensates the fact that some smaller airports have a relatively short planning horizon and that their capacity may be greater in the future.

MEASURING WHAT-IF?

- **SESAR improvements:**
  assumes that, where appropriate, airports can invest to benefit from SESAR technologies and improve their capacities to deliver more flights.

- **Schedule smoothing:**
  moves flights to times of the day when more capacity is available.

Compared to CG13, we did not investigate the option of pooling the capacity of a city's airports into a city cluster as this option was seen as the least realistic of the what-ifs?.

We also analysed two combinations of complementary methods. We provide more detailed discussion of some parts of the what-if? methodology in the Annexes.

Each mitigation what-if? method is reported in the same way: as a percentage of the unaccommodated demand that can be accommodated if the mitigation is applied. This is the same format as in CG13.

The results are based on the aggregate of the effect at individual airports. We have focused on the scenarios for which the capacity challenge is the greatest: Global Growth, Regulation and Growth and Happy Localism. The last scenario, Fragmenting World, has little capacity challenge that will be mitigated easily and has been taken out of the analysis. We will also focus on the places in ECAC where the capacity challenge is the greatest, i.e. in ESRA North-West, ESRA East and ESRA Mediterranean (see Figure 1).

STATFOR Traffic Regions

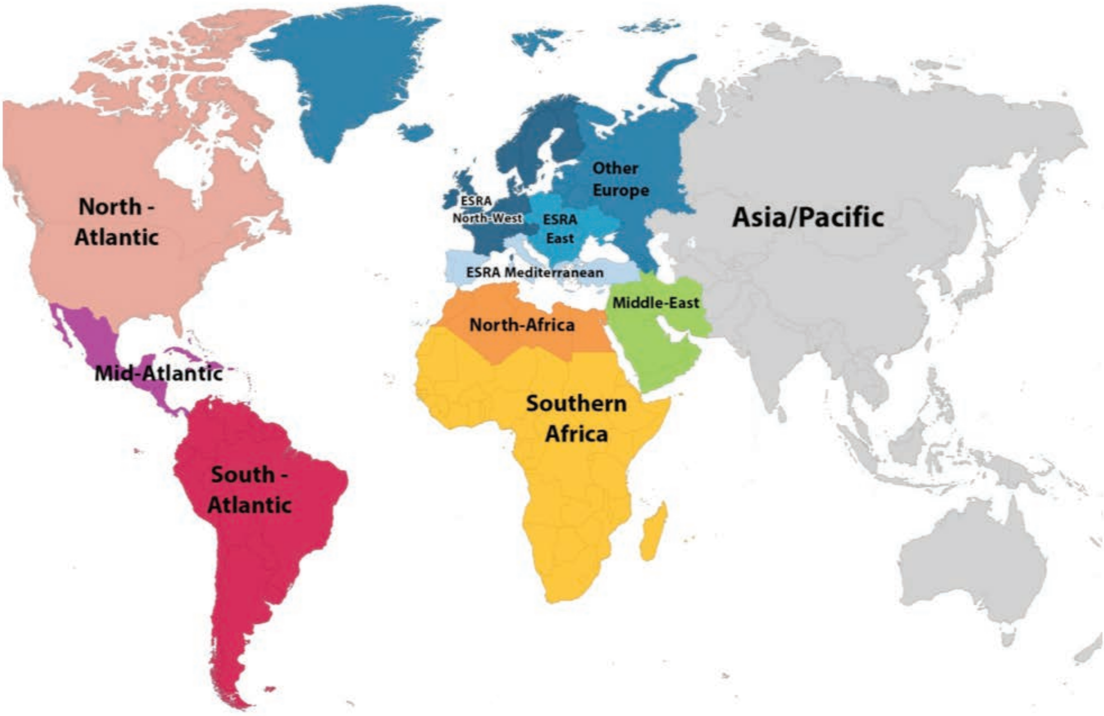


Figure 1 /
The analysis will focus on the three sub-regions: ESRA North-West, ESRA East and ESRA Mediterranean.

LARGER AIRCRAFT

Aircraft operators are limited in the short-and medium-term by their fleet decisions as to the size of aircraft they can use. Nevertheless the average size of aircraft has been increasing. We explore the effects of accelerating this increase on congested airport pairs, taking the size of aircraft operated by other airlines in similar circumstances as a benchmark. The potential gain is an 8% reduction in unaccommodated demand in 2040, with improvements spread across Europe and greater improvements in the North-West and Mediterranean since they will be more congested.

BUSINESS CONTEXT

The choices of airlines about the aircraft to use are constrained by long-term fleet decisions and the associated flight crew skills. Leases may add some flexibility, but changes to the plan still have a cost. Nevertheless, over periods of tens of years, the overall structure of the fleet can and does change substantially: think of the decline of the sub-50-seaters, the arrival of the regional jets, the up-gauging of low-cost carrier aircraft, reduction in seat pitch, exchange of business for economy seating, or the accelerated retirements that followed in the wake of higher fuel prices or noise stringencies. All of these have the potential to increase the number of passengers carried per flight ("up-gauging"), even without mentioning the continuing increase in load factors.

When an airport is congested in terms of flights, an airline may seek to increase passenger throughput by up-gauging. This is likely to be reinforced by the airport itself, perhaps through landing charges that favour larger aircraft, and will be further reinforced by any economies of scale of operating larger aircraft. Figure 2 shows up-gauging at London/Heathrow (EGLL, bottom left), from a minimum 190 to slightly above 210 seats per aircraft (estimated from average seats per aircraft type). On these data, however, it is not as constant a process as might be expected; there has been little net up-gauging at Heathrow between 2005 and 2011 and at Gatwick (EGKK). In the figure, up-gauging is also obvious at Stansted (EGSS); the shift to B737-800s by Ryanair will be a major contributor to this, but this was more driven by economics than congestion – so congestion is not the only cause of a change in aircraft size.

The 2040 forecast already builds in some assumptions about how aircraft sizes will develop (Ref. 2). The mitigation method described here therefore involves looking at enhanced scenarios for up-gauging.

Essentially, the mitigation assumes that, seeing a capacity challenge, airlines respond with faster or more extensive up-gauging on particular flows.

There are also regulatory approaches which would encourage up-gauging. At one extreme, this could be a cap on the number of times a particular airport-pair can be flown in a day. In the 2008 stakeholder consultation, no airlines were in favour of artificial capping of frequencies. Hub-and-spoke airlines saw scope for up-gauging, while low-cost in general did not. So here we aim to find a level of up-gauging which is consistent with what has been seen historically (as in Figure 2), and could be expected to be market-driven rather than enforced by caps on frequencies.

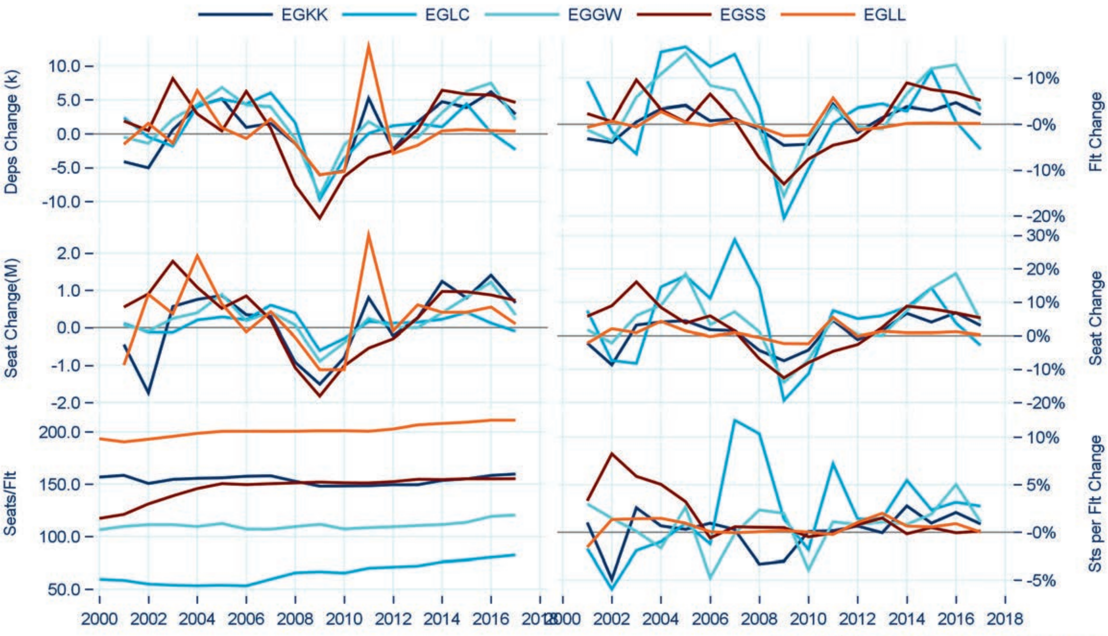


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Figure 2 /
Growth indicators at five London airports.

ANALYSIS METHOD

For the analysis we explore three factors that drive aircraft size: traffic density, distance and competition. Higher traffic density and longer distances between a given airport pair tend to mean larger aircraft operating on this route. This is more significant on airport pairs on which an airline has a monopoly whereas competition on this route can mean smaller aircraft , as airlines may compete to offer frequency of service.

To build the mitigation, we have looked at locally 'better' airport pairs that were operating larger aircraft on similar distances and for a similar number of passengers. More specifically, Airport pair AB is defined to be locally better (in the sense of operating larger aircraft in congested circumstances) than airport pair CD if all of the following are true:

- both AB and CD either have both a monopoly service, or both see competition;
- CD is further apart than AB in terms of great circle distance, the logic being that larger aircraft are normally more efficient at longer distances;
- CD involves more passengers than AB, since there is more opportunity to use larger aircraft on busier airport pairs;
- in spite of these three being true, CD uses smaller aircraft on average than AB.

We restrict the analysis to busy, short-haul airport pairs, defined here as separated by less than 1,500 km in terms of great-circle distance, and having more than 10 flights per day (total of both directions). We look only at intra-Europe flights.

Examining current data rather than forecast data, and with all of these criteria being true, Figure 3 illustrates the process. The figure shows that relatively larger aircraft are used on the route between Antalya and Istanbul/Sabiha, i.e the airport pair Antalya-Istanbul/Sabiha is 'better' than 1 other airport-pair (i.e. Madrid Barajas-Barcelona) in the manner just defined. If this size of aircraft were used on the Madrid Barajas-Barcelona route, then the number of flights could be reduced by just over 14,5 thousands.

Locally best airport pair		Number of other pairs it improves on	Total Flights Saved	Maximum Percentage Saving	Best Seats/ Flt
Adana Sakirpasa	Istanbul Gokcen	1	69	0.9%	321
Antalya	Istanbul Gokcen	1	14,491	53.4%	318
Athens	Chania Souda	2	1,766	20.3%	115
	Santorini	10	11,406	39.2%	113
Basel Mulhouse	Munich	1	239	5.7%	85
Several rows omitted for this example					
Frankfurt	Brussels	1	498	6.9%	138
Warsaw Okecie	Frankfurt	3	147	1.2%	148
Vienna	Brussels	4	898	5.5%	139
	Copenhagen	2	505	8.7%	152
	Hamburg	1	138	2.6%	155
Zurich	Barcelona	3	779	12.7%	188
	Brussels	1	1,712	24.6%	124
	Frankfurt	1	119	1.1%	135

Figure 3 /
Example for the larger aircraft mitigation (based on current data)

RESULTS

Figure 4 shows some characteristics of the airport pairs selected as benchmarks for the forecast (Regulation and Growth, airport pairs with competition, 2040). Each airport pair appears in the left-hand and in the right-hand diagram (at the same height). So the benchmark with the greatest number of seats, 204, is one which is around 450km and has 2.7 million seats flown per year (at 2040 load factors). This particular benchmark value is the only one having an impact on unaccommodated demand of more than 10,000 flights. Figure 4 illustrates that number of passengers (or at least the number of seats) drives aircraft size more clearly than distance, even though this is not as obvious as in CG13 (see Figure 5 in Ref. 6).

Overall, the effect of applying these benchmarks to other airports is to reduce unaccommodated demand by 8% in the most-likely scenario Regulation and Growth by 2040. Figure 5 illustrates this. The effect is very similar in percentage terms in both Global Growth and Happy Localism.

Figure 5 also illustrates that this approach is more effective in ESRA Mediterranean and ESRA North-West in Global Growth and in Regulation and Growth. The impact on ESRA Mediterranean is mainly associated to the benefits in the Istanbul airports that are expected to stand amongst the most congested by 2040 in all forecast scenarios. Even though some Turkish airport pairs appear in the locally-best-list in Figure 3, there are still enough other pairs that could benefit from larger aircraft to make a difference. In the most-likely Regulation and Growth scenario, all congested airports, whether in ESRA East, Mediterranean and North-West or other Europe, benefit from the approach: not necessarily by huge figures, but the unaccommodated demand is always reduced.

These reductions in unaccommodated demand are being achieved while still reflecting the behaviours of existing aircraft operators. In particular it is noticeable in Figure 4 that a 200-seater threshold is being respected; crossing this threshold has cost and operational implications for an airline. In CG08, low-cost airlines observed that frequency capping could be detrimental to their business, since they operate single aircraft types. The evidence from Figure 4 is that the benefits of the mitigation of using larger aircraft is not pushing towards aircraft sizes significantly beyond those typically operated by low-cost carriers.

We have not analysed fuel and emissions for these results. This mitigation may require some investment by airframe and engine manufacturers to improve the efficiency of larger aircraft at shorter distances.

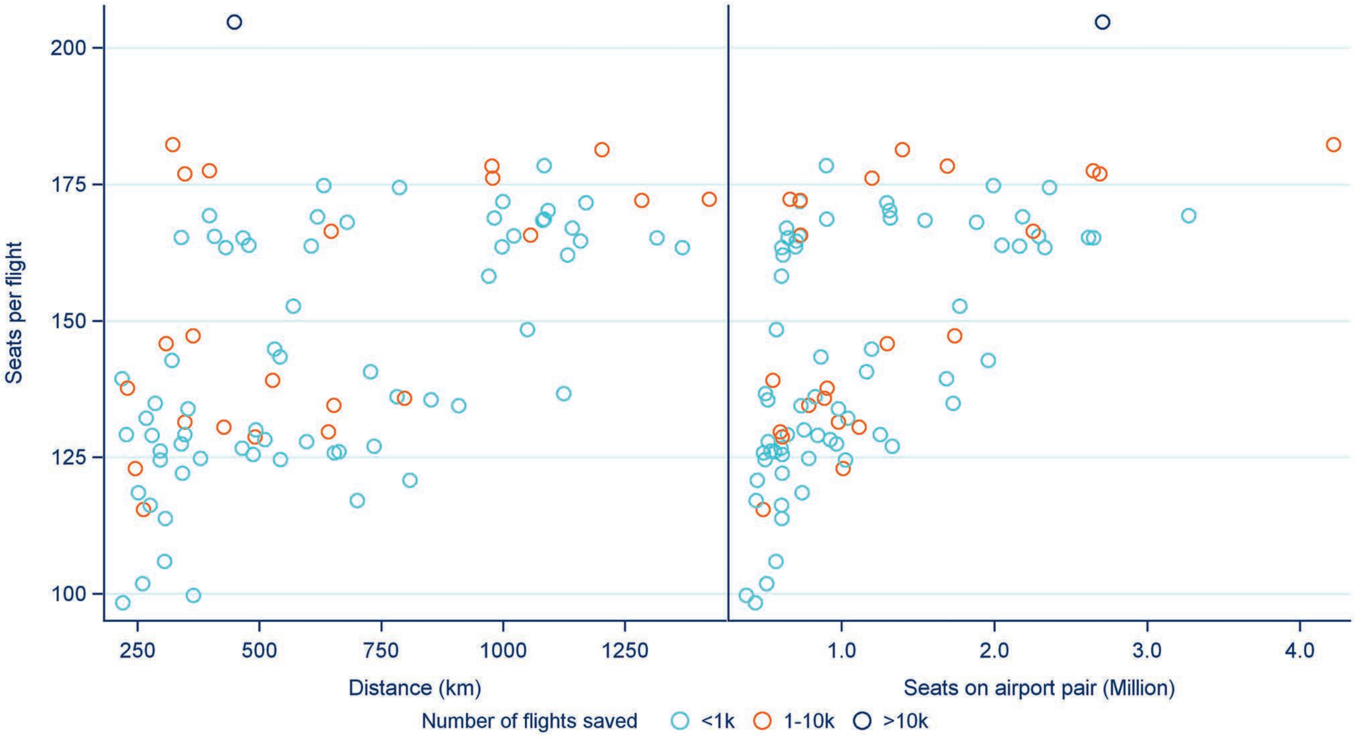

Figure 4 /
Airport-pairs with best seats/flight
(Regulation & Growth, airport-pairs with cometition,2040)

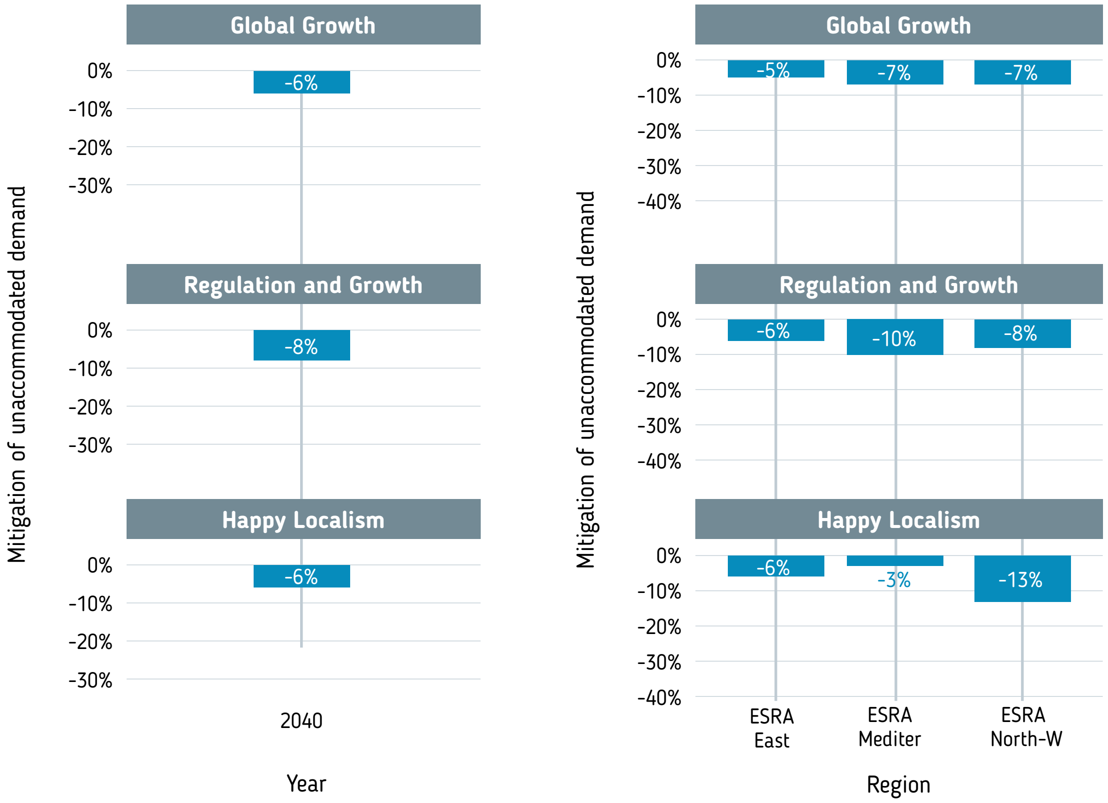

Figure 5 /
Mitigation gains for Accelerated shift to Larger Aircraft
(No analysis performed for 2035)

ADDITIONAL HST INVESTMENT

An HST network three times larger than the one that is actually planned would be expensive, but it would also contribute to a reduction of unaccommodated demand by 7%. The effect is particularly strong in the Mediterranean region, since it aligns with where capacity is lacking.

BUSINESS CONTEXT

Evidence from a wide range of studies world-wide shows that a reduction in rail travel time between two cities increases the share that rail has of the passenger market, compared to air. There are factors that limit the size of the effect – frequency of rail service, price, station location, flight frequency etc – but, with all these factors being equal, improvements to the speed of high-speed train (HST) reduce the number of flights.

The four scenarios used in the flight forecast to 2040 (Ref. 2) already include assumptions about how the HST network will develop, based on published plans. In the STATFOR forecast method, these network improvements affect demand according to a new time model that replaces the model developed by one the Co-operative Actions of R&D in EUROCONTROL (CARE) projects that was previously used as explained in Ref. 11. It is summarised in Figure 6.

One way to mitigate congestion at airports is to increase the attractiveness of alternatives by accelerating or increasing investment in HST. This is unlikely to be justifiable purely on aviation grounds, nevertheless there is political momentum behind the continued expansion of the HST network. The target from the EU Transport White Paper (Ref. 12) is for an HST network that is 3 times longer than the 2010 one by 2030 which was 6,380km (Ref. 13) and that can accommodate most of medium-distance passenger transport by 2050. We target a similar increase in scale for this mitigation, despite the scope of HST development has recently slowed down following various national budgetary cuts and local environmental debates on its benefits versus its impact.

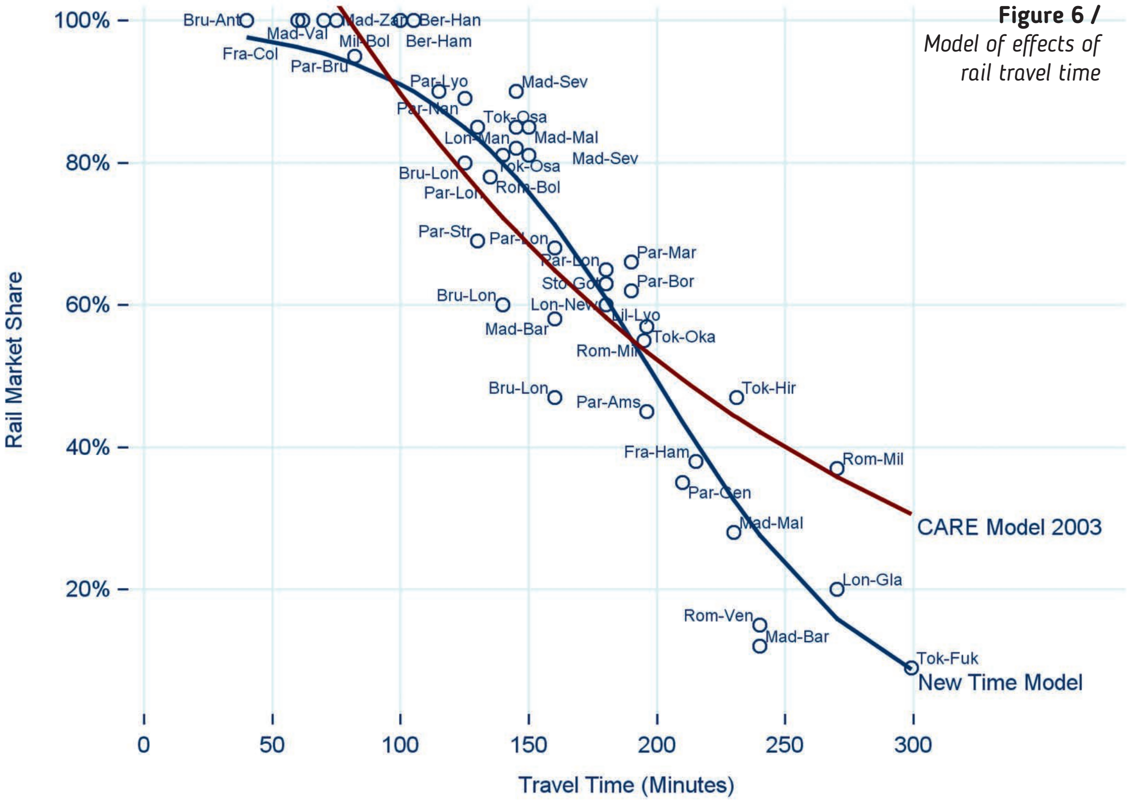

Figure 6 / *Model of effects of rail travel time*

ANALYSIS METHOD

Likely length of rail infrastructure is time-consuming to estimate, so for simplicity of analysis we have targeted at least an approximate tripling of the number of connections and cities connected to the network. This has the added advantage that it is also applicable outside the EU. As in 2013, we used the long-term forecast tool to model the impact of an extended HST network. To obtain the new connections shown in Figure 7, we applied the following steps:

- Identify those city pairs with more than 20 flights/day in 2040 (total in both directions) whose great circle distance between their airport of origin and their airport of destination is under 500km.
- Eliminate those which are island-based and appear infeasible as HST links. Crossing for the Bosphorus, Baltic at Copenhagen and Calais-Dover have been built or discussed, so can be allowed, but other sea crossings are eliminated.
- Set aside those city pairs with existing HST links, or planned links that are already built into the forecast, except if a significant improvement in the speed on the line could be expected as in the case of a partially-implemented high-speed railway. The remaining city pairs are the new pairs for this what-if?

To estimate the new travel time with HST on those city pairs, we used the average achieved speed on known HST links: this is around 160km/hour for the links existing in September 2017 and around 190km/h for the lines that are expected to be available by 2040. For the purpose of this what-if?, a speed of 175km/h, in between the two aforementioned speeds, has been considered to estimate the what-if? future travel time. Although this is lower compared to 250-300km/hour cruising speeds, it allows for delays for intermediate stops, and the fact that the true distance travelled is longer than the great circle distance shown on the map and against which this speed is calculated[1] -it is the case for the links built over the ocean in Figure 7.

For the travel time before HST implementation, we chose to use the average of current travel times over a one week period.

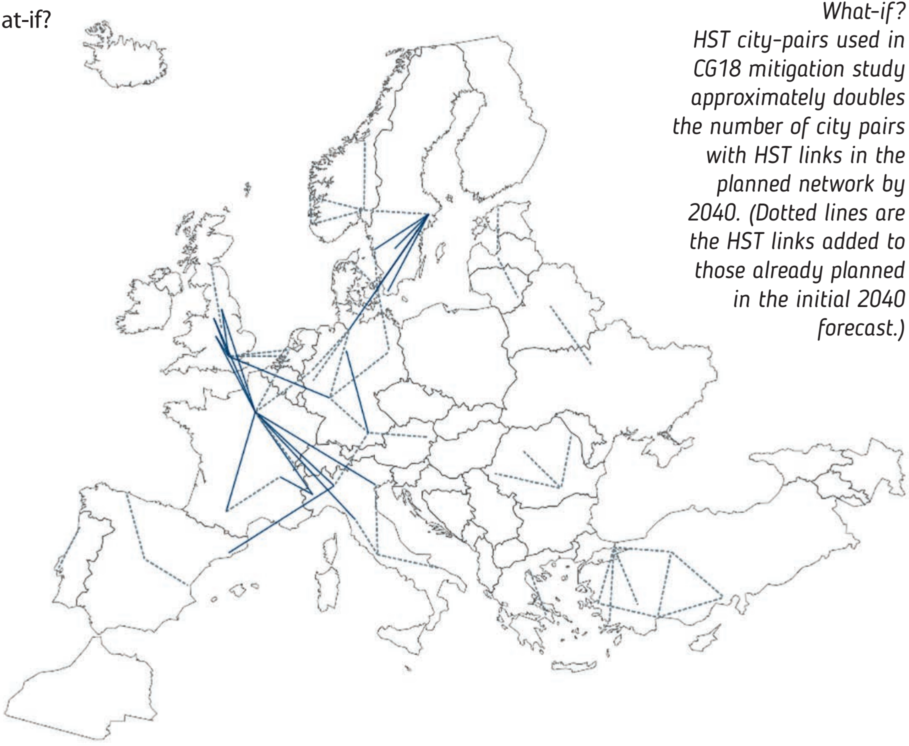

Figure 7 /
What-if? HST city-pairs used in CG18 mitigation study approximately doubles the number of city pairs with HST links in the planned network by 2040. (Dotted lines are the HST links added to those already planned in the initial 2040 forecast.)

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[1] *The average of 175km/hr just quoted is also based on great circle distance.*

RESULTS

The outcome of the conditions just described adds 43 city pair links by 2040, and connects 51 cities in total to the initial HST network anticipated in the 2040 forecast. In this initial forecast (Ref. 2), the HST network connects 23 cities with 27 links. So, we have approximately doubled the scope of (i.e. number of city links in) the network. In terms of great-circle distance, these additional HST lines would represent around 17 thousands additional kilometres of HST: on its own nearly a tripling of the length of the HST connections already existing in 2010, thus a rather optimistic development of the network in view of the objectives of the EU Transport White Paper (Ref.12). Compared to CG13, these 43 city-pair links are a lower number than the 75 links considered in CG13: this is associated to a more restrictive selection of the city pairs based on their distance (i.e. the 500km threshold), a restriction that is reasonable in view of the size of the HST network it still generates.

In the most-likely Regulation and Growth scenario, the reduction in unaccommodated demand is 7% by 2040. Figure 8 provides details of the results. In regional terms, the effect is mainly visible on ESRA Mediterranean as the additional HST lines in Turkey are sufficient to take over part of the passenger demand that exceeds the air transport capacity. However, the new HST lines are not effective at reducing congestion in ESRA East as there are not close to the congestion hotspots of the area that result mainly from the accumulation of traffic over many city pairs than on a few, specific routes where HST could have a significant impact. However, in each scenario and region, approximately half of constrained airports see some improvement of the situation as a result of this extended HST investment what-if?.

The effect of this mitigation action is lower than that reported in CG13 because of a lower number of additional links considered in CG18 than in CG13. However, a reduction in impact can be anticipated in view of the current slowing down of the development of HST because of its cost, which sometimes places HST no longer in the list of priority investments of European states (e.g. Portugal). Building railways takes time: infrastructure building is often delayed and the construction work affects directly a wider range of population, a population whose resistance has often delayed HST developments because of various reasons: noise impact, resistance to give land, etc.

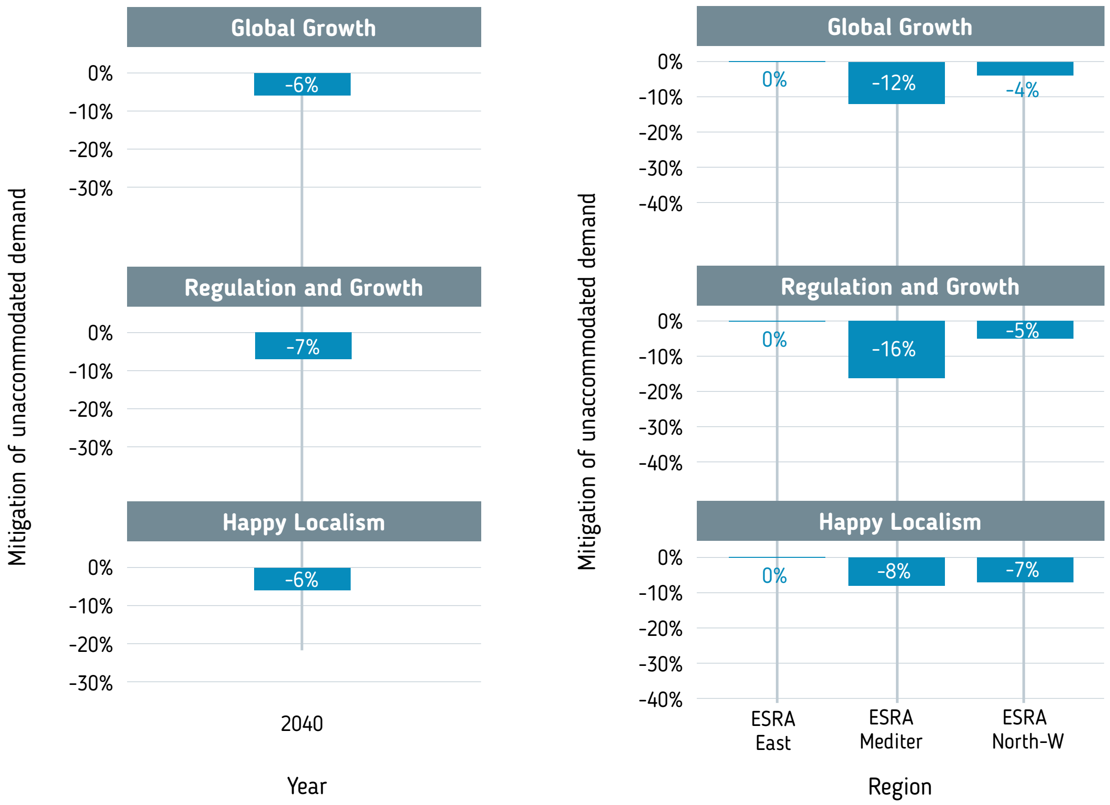

Figure 8 / *Mitigation gains from additional investment in HST*

LOCAL ALTERNATIVE AIRPORTS

Particularly in North-West Europe, there is a growing shortage of capacity around major cities. There are not necessarily the right runways in the right place at the right time. Nevertheless, faced with capacity constraints aircraft operators tend to grow their business where capacity is available, usually at neighbour airports. This mitigation explores the idea for a set of major airports in Europe.

For the most likely scenario, this option would reduce unaccommodated traffic by 16% and would be amongst the most promising what-if? options by 2040.

BUSINESS CONTEXT

In the 2008 study, we explored with stakeholders the business realities of the use of alternative airports. The mitigation report (page 34 in Ref. 10) discusses in detail the issues that stakeholders raised. From an airline perspective these issues are all linked to the pivotal question: would passengers be prepared to go to these alternative airports? There are additional questions linked to environmental or other capacity issues at the alternative airports or in their Terminal Manoeuvring Area (TMA). Some of the differences of opinion (summarised in Figure 9) include:

- Hub carriers stress the difficulty of operating split hubs;
- Business aviation operators note the importance of ground access times to final destination;
- Some low-cost carriers already exploit alternative airports, but noted the importance of ground access.

Cargo, it was assumed at the time, was more open to the use of alternative airports. However, all-cargo flights are a relatively small segment, around 4% of flights in Europe (Ref. 14), and they sometimes have access to belly or deck space capacity on other airlines (eg FedEx at LFPG), so their views are not likely to be entirely neutral in the matter of choosing alternative airports.

One undesirable consequence of using alternative airports is complexity in the air, especially in the TMA, as TMA capacity can already be the limiting factor for an airport. Spreading traffic around a number of close neighbours could exaggerate this, and could in practice limit the gains available from alternative airports.

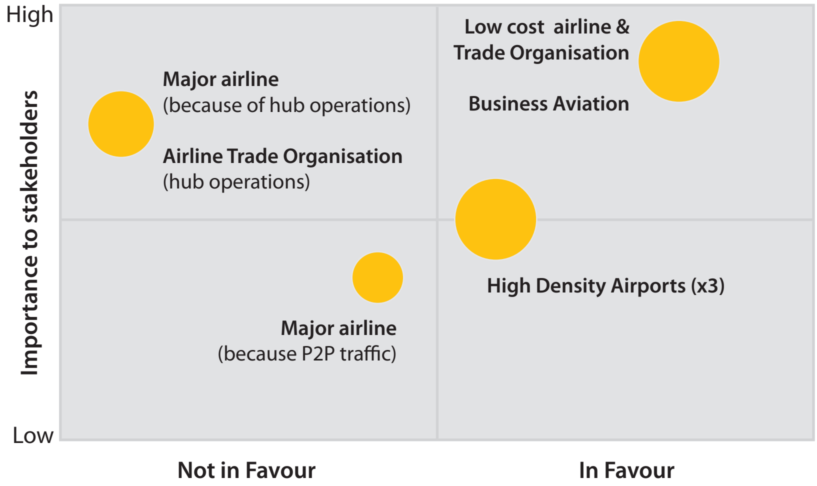

Figure 9 / *Summary of Stakeholder comments on alternative airports for 2008 study (Ref.10).*

The mitigation options for Challenges of Growth 2008 and 2013, were based on these results, and used alternative airports for some types of flight, subject to a distance threshold.

ANALYSIS METHOD

In this section, we have applied the same approach to the one used in CG13 where some specific traffic, either specific to the market segment or linked to the origin or destination of the traffic, has been transferred to other airports from the main congested hub. This modelling what-if? is intended to represent the choices of airlines in response to long-term congestion, as discussed.

With trends like these emerging on relatively short time scales, we might question how realistic it is to project current business models directly into 2040 when designing the considered transfers of traffic. For example:

- Transferring 'low-cost' short-haul traffic to other airports based on current traffic statistics is unlikely to be reliable. Short-haul traffic might be expected predominantly to follow a low-cost model by 2040, though the extent to which this is achievable for hub feeder services and (other) regional links is certainly open for debate. We might more neutrally identify a portion of short-haul traffic that might be expected to relocate.
- The idea that only local airports are suitable 'alternatives' may be too narrow; this certainly would exclude the Munich-Frankfurt pairing, let alone Paris-Amsterdam or London-Madrid that could be current strategic options at least when a transfer outside Europe comes next.

Responding to these concerns, in CG13 and CG18 we designed the mitigation for the busiest European airports so that air traffic might further develop when these airports become more congested. We list specific what-if? changes, for example supposing that cargo grows instead at an alternative airport, or that traffic to short-haul destinations (ie in the ESRA, or in the North-West, Mediterranean or Eastern parts of the ESRA[2]) is displaced to specific neighbouring airports. Figure 10 gives the details and Annex A shows maps of the cities discussed.

The chosen alternative airports are, of course, hypothetical, since this is a what-if?. Nevertheless, some controversy is to be expected by naming even hypothetical airports that might get extra traffic. Compared to CG13, some alternatives at London Stansted EGSS and London Gatwick EGKK are no longer considered as viable options as, with their given capacities, these airports are expected to have little room for additional operations by 2040. Similarly, LTFJ/Sabiha Gokcen as the alternative to Istanbul LTBA (Ataturk and new airport) was no longer considered. Other alternative airports might be considered in such cases but there was none we found sufficiently obvious to be added.

In most cases, only part of the traffic is transferred according to its market segment (e.g. All-Cargo) or its origin or destination (e.g. European traffic). Definitions of market segment can be found in Ref. 14.

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[2] *For a map of the ESRA region, see the FAQ page of www.eurocontrol.int/statfor.*

Figure 10 /
Hypothetical 'local alternatives'[3]

From	Type of traffic	to Regions	Amount	Observation
LFPG Paris	All-Cargo	All	50% LFOB/Beauvais	About 10% of total flights at LFPG; but given timing of cargo does it really save capacity?
	Scheduled/ Charter	ESRA/Other Europe	20% LFOB/Beauvais; 10% LFPT/Pontoise	
EDDF Frankfurt	All-Cargo	All	45% EDDK/Koln, 45% EDDP/Leipzig	Though only about 5% of total
	Business Aviation	All	90% EDFE/Egelsbach	
	Scheduled/ Charter	ESRA/Other Europe	10% EDFH/Hahn, 20% EDDB/Berlin	(Not so 'local')
EGLL London	Scheduled/ Charter	ESRA/Other Europe	15% EGMC/Southend 15% EGGW/Luton	Transfer to EGKK and EGSS considered in CG13 have been taken out of the list of possible options as they will have little space for extra operations from EGLL
EHAM Amsterdam	All-Cargo	All	80% EHRD/Rotterdam	EHAM is 5% All-Cargo (2% business)
	Scheduled/ Charter	ESRA/Other Europe	10% EHLE/Lelystad 20% EHEH/Eindhoven, 20% EHRD/Rotterdam	(EHEH and EHRD are rank 2 and 4 in NL)
LEBL Barcelona	Scheduled/ Charter	ESRA/Other Europe	15% LEGE/Girona 15% LERS/Reus	
EKCH Copenhagen	Scheduled/ Charter	ESRA/Other Europe	20% ESMS/Malmo	
	Business Aviation	All	90% EKRK/Roskilde	
LEMD Madrid	Scheduled/ Charter	ESRA/Other Europe	20% LEGT/Getafe	
LIMC Milan	Scheduled/ Charter	ESRA/Other Europe	20% LIML/Linate 15% LIME/Bergamo	
EDDM Munich	Scheduled/ Charter	ESRA/Other Europe	20% EDMA/Augsburg 20% EDJA/Memmingen	
ENGM Oslo	Scheduled/ Charter	ESRA/Other Europe	20% ESMS/Malmo	
LIRF Rome	Scheduled/ Charter	ESRA/Other Europe	20% LIRA/Ciampino	
LOWW Wien	Scheduled/ Charter	ESRA/Other Europe	20% LZIB/Bratislava	
LSZH Zurich	Scheduled/ Charter	ESRA/Other Europe	20% LFSB/Basel 15% LSZB/Bern	

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[3] *The 4-letter ICAO codes of airports can be found on ICAO Doc 7910*

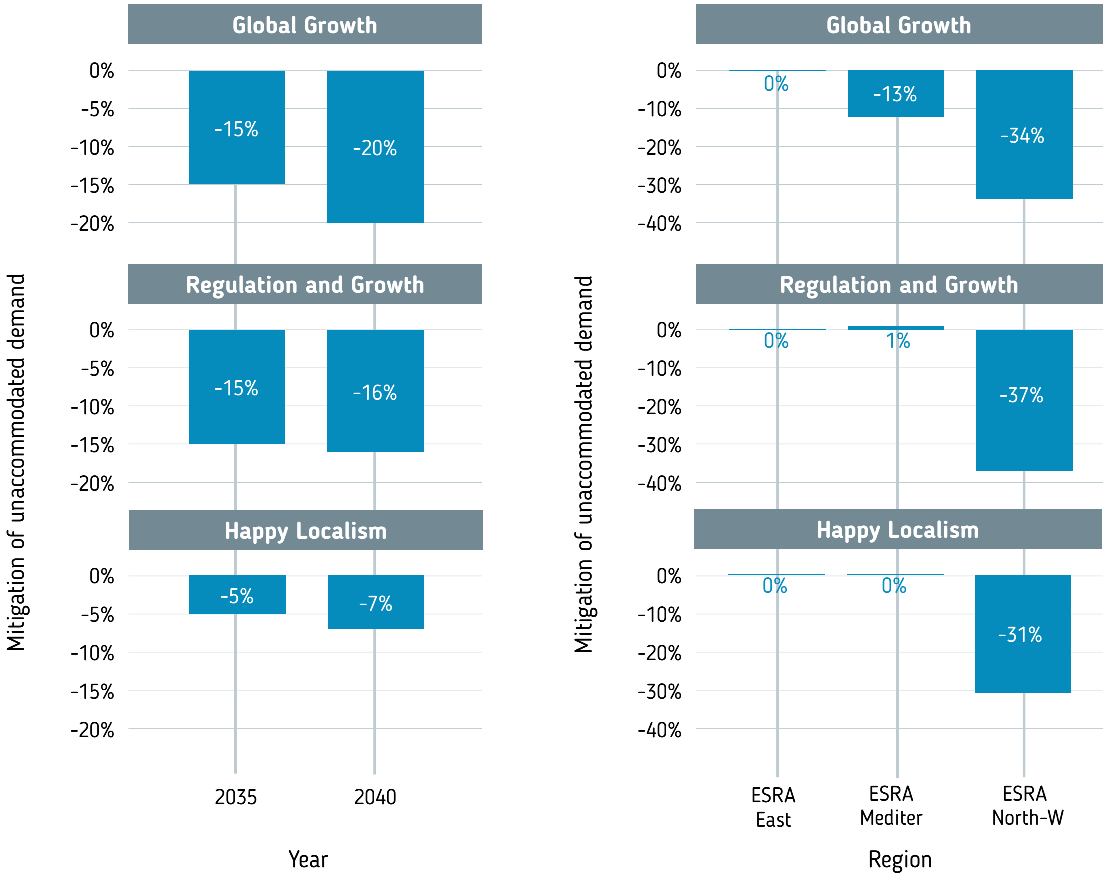
RESULTS

Note that this mitigation does not modify the existing capacity, but just proposes a different way to manage this capacity and share the demand across airports in the neighbourhood. The results are summarised in Figure 11 and reduce unaccommodated demand by 16% for Regulation and Growth, the most likely scenario, by 2040.

This mitigation only affects airports in the North-West and in the Mediterranean area so, there is no surprise in the fact that the benefits are only visible there. Impact in the Mediterranean area is only visible for *Global growth* that generates the stronger overall growth. The main congestion spot of the area is around Istanbul where no satisfactory local alternative could be found as all airports of the area are expected to operate close to their capacity without any additional traffic.

Note that this assessment is probably an upper bound, given the difficulties in implementing such changes in the management of airports with for example the implementation of the new departure and arrival procedures to deal with the additional traffic.

Figure 11 /
Mitigation gains of exploiting Local Alternative Airports



CONSENSUS BENCHMARK THROUGHPUT

Half of single-runway airports reported future airport capacities under 150,000 movements per year. These low values seem to be driven more by current traffic and demand than by fundamental limits to capacity.

As a mitigation what-if, we set the capacity of smaller airports to a minimum of 200,000. The effect of this mitigation is to reduce unaccommodated demand by 13% in 2040. This potential gain is not cost-free and may not always be possible when space around an airport is very limited such as on island airports, but this what-if? could at least be available without the building of a new runway at these airports.

BUSINESS CONTEXT

This 'benchmark throughput' mitigation task allows us to ask what capacities the single-runway airports might plan in the future if they were to be faced with a higher demand. The main results of CG18 use the capacity plans that airports have provided (Ref. 2). Few airports have provided information up to 2040, either for reasons of commercial confidentiality, but mainly, especially for smaller airports, because there might not be quantitative plans up to that horizon.

Figure 12 illustrates the issue that this mitigation is designed to solve by comparing current traffic (2017) and the reported future capacities for airports that currently operate with a single runway[4]. Their situation is compared in the figure to that of the Gatwick airport that is considered to be a reference airport to deliver the "maximum throughput that is achievable for single runway operations".

The figure shows that around half of reported future capacities are below 150,000, the majority clustered in the ellipse along a trend line suggesting an approximate link to current traffic. Some of these could be driven by local curfews, or geographical or physical constraints (e.g. islands airports), or an environmental cap on flight movements. But current demand is likely to influence capacity and future demand forecasts themselves start from current demand, and therefore will often be lower at airports which are currently accommodating lower levels of traffic: why would they invest in infrastructure, systems that are not expected to be necessary?

However, there is a difference between an airport saying:

- This is the capacity we plan on having, based on the volume of demand that we expect to see at the furthest horizon we have considered;
- And; we could provide more capacity than what we have declared if the traffic were to exceed the forecast in some future year beyond our current planning horizon

The objective of this mitigation is then to estimate the capacity that these small airports could accommodate if there would be a need to meet higher demand. Looking at the rest of airports in Figure 12 shows there is another group of airports whose future capacity is relatively independent of 2017 throughput and that lies within the area below the current Gatwick throughput and 100,000 annual movements. It clusters around 200,000 annual movements, the upper-quartile capacity of the whole group, which is not far from the Gatwick 'maximum' and a similar value to that obtained in CG13 after a similar analysis.

In reality, the maximum throughput will depend on the mix of traffic (eg the mix of aircraft in the heavy and medium wake turbulence categories), so the maximum achieved throughput at one airport is not necessarily achievable at other airports where that particular optimum mix of flights is not present, even if in theory they have equivalent infrastructure. However, a rounded capacity figure will be sufficient to estimate the benefits of such a capacity increase, if it were available.

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[4] *The values and year are hidden to discourage airport identification. Gatwick is excluded for the same reason.*

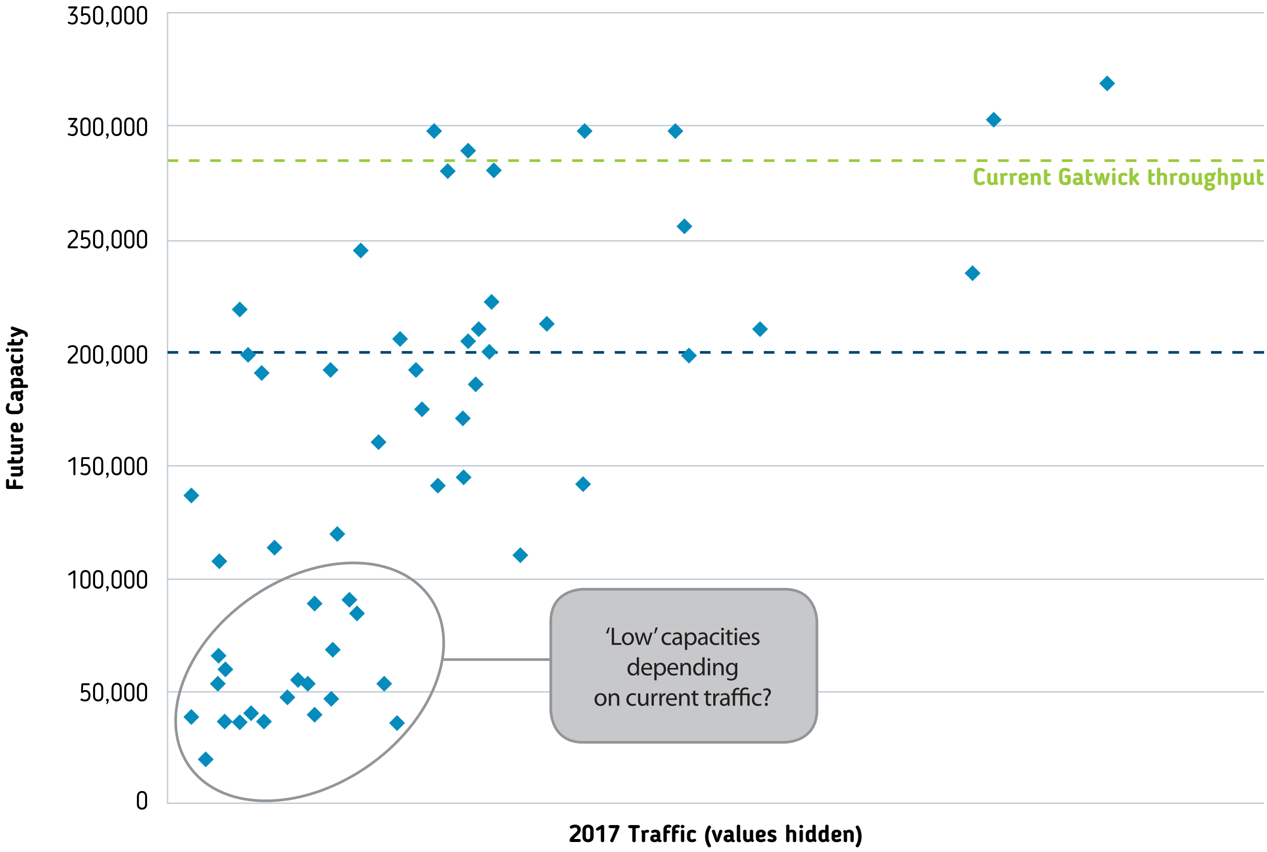


Figure 12 /
Reported future capacity at single-runway airports

ANALYSIS METHOD

This 'benchmark throughput' mitigation estimates the capacities that the smaller single-runway airports might plan in the future if they were to be faced with a higher demand and derives from these new capacity figures which reduction in unaccommodated flights could be achieved.

To estimate this impact, we have replaced the capacities of airports below the blue dash line, the benchmark throughput of 200,000 annual flights, in Figure 12 by an estimated 200,000 flights per year, i.e. the single runway capacity that we consider to be realistically achievable (see previous section) if there were a need to accommodate a higher demand.

RESULTS

Overall, the process increases total capacity available at the 111 airports by 8.1% in 2040, but the impact of such an impressive measure strongly depends of the future demand at the impacted airports. In the most likely scenario Regulation and Growth, it reduces unaccommodated demand by 13% in 2040, an impact mostly in Eastern Europe where small single-runway airports are predominantly located.

The reduction of unaccommodated demand hardly impacts ESRA North-West and ESRA Mediterranean that is affected by 72.6% of this unaccommodated demand but where capacity shortage is mainly in major airports that cannot be considered by this what-if?. This mitigation is thus not a enough to solve the capacity issue in Europe.

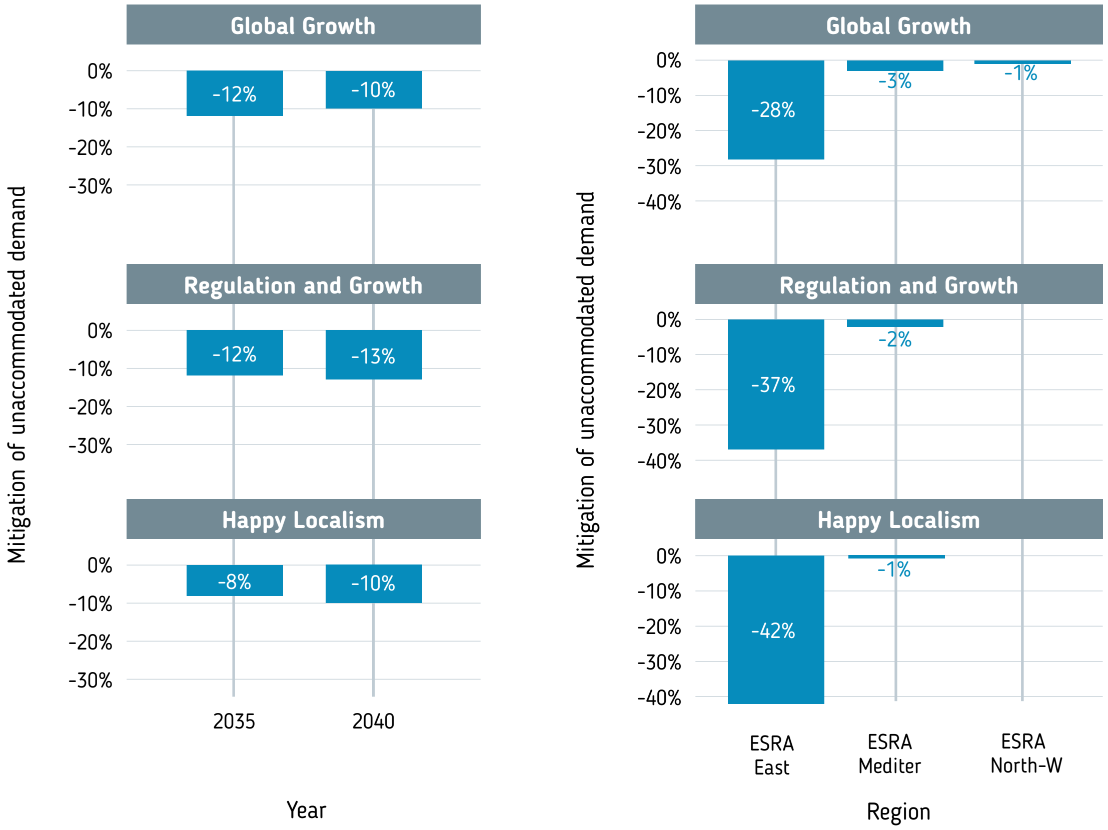


Figure 13 /
Mitigation gains for Schedule Smoothing.

SESAR IMPROVEMENTS

Over all airports, SESAR Improvements perform a global capacity increase by 1.6% in 2040 and, for the most likely Regulation and Growth scenario, this capacity increase led to a reduction of unaccommodated flights by 28% by 2040. These benefits are also relatively well spread across Europe and the mitigation is the what-if? option that brings the greatest reduction of unaccommodated demand over the mitigations that were tested.

BUSINESS CONTEXT

The Single European Sky ATM Research (SESAR) project was launched in 2004 as the technological pillar of the Single European Sky (SES). Its role is to define, develop and deploy what is needed to increase ATM performance and build Europe's intelligent air transport system. The first wave of SESAR 2020 industrial research projects (SESAR Wave 1) has got underway, addressing many areas critical for the modernisation of European air traffic management (ATM). Contracts have already been signed for 20 projects that are included in what is called the first wave of SESAR 2020 industrial research and large-scale validation activities. These projects will run until the end of 2019 and will aim to deliver new or improved technological and operations solutions to increase the performance of airports, air navigation service provision and the overall European ATM network.

In both CG08 and CG13 mitigation studies, SESAR improvements were one of the most promising options to reduce unaccommodated flights. This mitigation brings up to date such an impact.

Amongst the 111 airports reporting future capacities in CG18, it is probable that some have not taken into account these potential benefits. This mitigation is designed to evaluate the potential gain in capacity planning if SESAR benefits had been fully planned and reported by airports.

This time, the analysis has been performed in a different way from CG08 and CG13 using no detailed impact assessment on hourly capacity but rather starting from the SESAR Wave 1 performance asessment in terms of airport capacity: "The SESAR2020 Validation Targets for Airport Capacity is set to 7% increase in peak hour throughput" (Ref. 15).

More specifically, the expected impact is a function of the size of the airport, with bigger airports in terms of throughput more likely to be the ones to benefit the most from SESAR implementation within the SESAR2020 deployment timeframe as provided in Figure 14 and figure 15 below.

SUB-OPERATING ENVIRONMENT	Very Large Airport	Large Airport	Medium Airport	Small Airport	Other
AIRPORT CAPACITY IMPROVEMENT	7.00%	7.00%	6.92%	0.00%	0.00%

Figure 14 /
Validation Target Breakdown per Sub-Operating Environment for Airport Capacity Improvements

OEs	SUB OPERATING ENVIRONMENTS	DEFINITION
Airport	Very Large Airport	Airports with more than 250k movements per year
	Large Airport	Airports with more or equal than 150k and less or equal than 250k movements per year
	Medium Airport	Airports with more or equal than 40k and less than 150k movements per year
	Small Airport	Airports with more or equal than 15k and less than 40k movements per year
	Other	Airports with less than 15k movements per year

Figure 15 /
Sub Operation Environments Definition

ANALYSIS METHOD

To mirror the performance assessment on SESAR Wave 1, the benefits of Figure 14 have been added to the capacity of the most constrained European airports and not at the ones that will provide a capacity well above their demand.
The analysis steps are therefore:

- Identify from the 2040 forecast all airports which by 2040 will have a demand over 95% of their capacity (i.e. use the unconstrained forecast);
- Based on the expected capacity improvements of SESAR full implementation (Figure 14), derive the expected capacity at these airports, using their annual throughput in 2017 to identify their size category: the associated capacity benefits are added on top of the declared annual capacity;
- Calculate with the new capacities the updated forecast that would be delivered;
- Assess the reduction in unaccommodated traffic compared to the initial 2040 forecast.

RESULTS

From the analysis, 27 airports whose capacity could be increased by SESAR improvements were identified. Over all airports, it represents a global capacity increase by 1.6% in 2040 and, for the most likely scenario Regulation and Growth, this capacity increase led to a reduction of unaccommodated flights by 28% by 2040. This is more than what was identified in CG13 but, in line with SESAR's own analysis, the approach was different and targeted primarily the most congested airports identified in the forecast for 2040, thus reducing congestion at airports where the need is expected to be the greatest. As a consequence, the benefits are more significant than in CG13 and are also relatively well spread across Europe. The results are, however, much less effective in Global Growth, where the capacity challenge is much broader as the greater growth of traffic in this scenario means more unaccommodated flights.

Compared to CG13, the benefits for SESAR impact are also more significant for the Mediterranean area. The unaccommodated demand in the area by 2040 can mainly be found at Turkish airports where, on the contrary to CG13, SESAR could be taken into account, which explains the greater impact compared to CG13.

Benefits in 2035 seem greater than for 2040: this is linked to the fact that, despite the increase in capacity by SESAR, the difference in available capacity between 2035 and 2040 remains limited as few airports have planned their capacity after 2035. Capacities remain thus similar in both years whereas traffic is expected to continue its growth and numbers of unaccommodated traffic by 2040 will then proportionally become greater than in 2035, whether SESAR is applied or not.

The impact of SESAR considered in this section account for only part of the solutions included in the project (i.e. SESAR Wave 1): greater benefits could thus be expected with an implementation of more SESAR solutions. However, considering the fact that each solution takes time to be fully put into operations at all airports, or even implemented at all at some airports because of its costs, there is also a risk that the benefits are lower than indicated in this assessment.

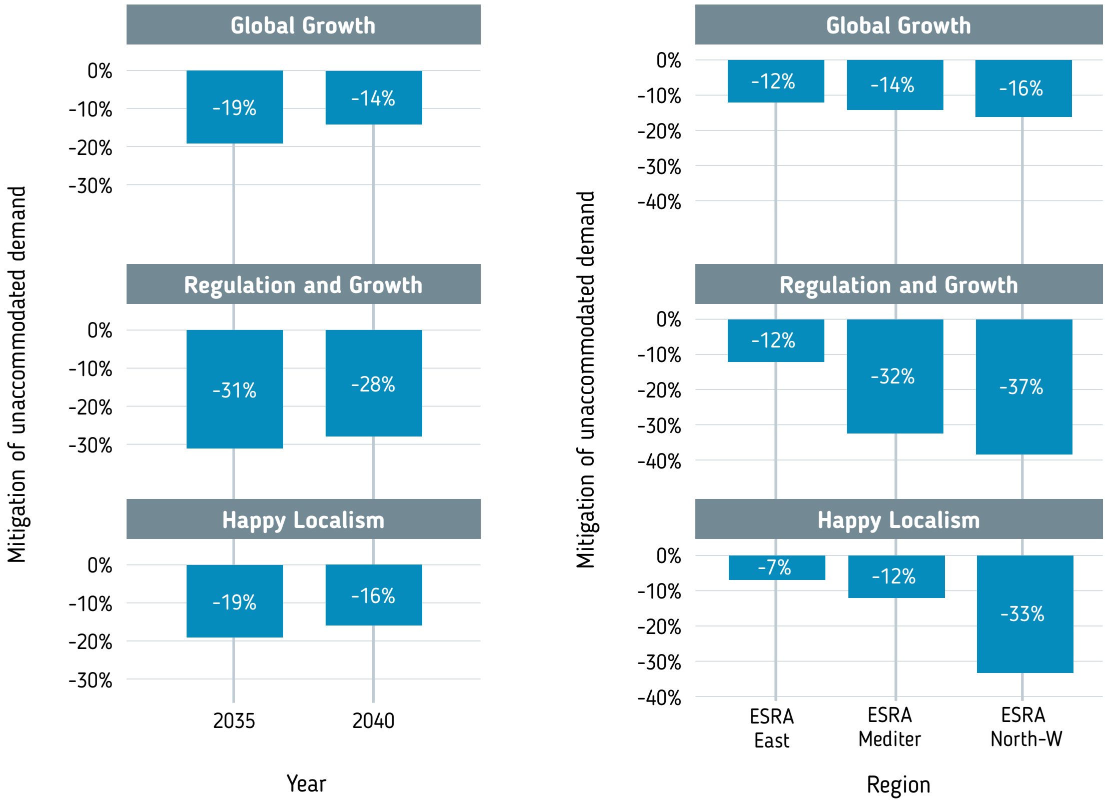


Figure 16/
Mitigation gains from SESAR deployment

SCHEDULE SMOOTHING

At congested airports, the quieter hours of the day gradually fill up even if airlines find that yields are worse during these off-peak hours (off-peak in the day, week or year) than during peak-hours. At busy airports, traffic demand thus becomes smoother and tends towards the annual profile of an airport such as Heathrow where the hourly throughput at day time approaches the maximum capacity available. We estimate the additional capacity that this would bring if such an evolution were applied at more busy airports.

Although this is applicable only to a limited set of airports, the effect is to reduce unaccommodated demand by 11% in Regulation and Growth by 2040.

BUSINESS CONTEXT

'Schedule smoothing' is an abbreviation for a wide range of decisions made by airlines to adapt the timing of their offer, or to change their schedules in a way that suits the hourly capacity at airports. Normally this refers to daily timing, but it could also refer to day of the week, or week of the year. 'Schedule smoothing' is not just about hourly airport capacity, but also about the need to maximise aircraft utilisation, and the airline's ability to manage the delicate trade-off between demand, ticket price, timing of the flights on offer, and competition.

In this section, we use 'schedule smoothing' as a solution to add more traffic at an airport (and thus increase its yearly capacity) by increasing traffic during the less busy hours of the day without changing its maximum hourly capacity.

In the 2008 consultation with stakeholders, the consensus of airlines was clearly against our concept of schedule smoothing. Individual airlines see the idea of moving existing flights away from peak times as being not what their customers want. Many passengers indeed have strongly preferred times to fly, and off-peak yields as a result are lower. So the arguments in individual cases of flights are against smoothing. However, in aggregate over all flights and carriers at an airport, the evidence is that demand profiles at congested airports do become smoother as traffic increases. Figure 17 shows two examples in which the middle-of-the-day hours gradually filled in at two relatively-congested airports, London Gatwick and Munich airport over a 4-year period of growth.

Figure 18 shows a different view of the hourly traffic at the same two airports as in Figure 17: this time all the hours are ordered from the busiest to the least busy and, to reduce the volume of data, these hours have been grouped into 100 'percentile' groups with the mean value plotted for each group. Schedule smoothing can be seen in the more rapid growth from year to year around the 40th and 60th percentiles than at busier hours in the year, simply because it is difficult to add much traffic at an hour that is operated close to the maximum hourly capacity. This type of plot does not indicate whether those hours in the 40th to 60th groups are a particular time of day, a particular day of the week, or period of the year. In practice they are likely to be a mix of all three.

The plot also shows that growth did not come in the quietest hours (80th -90th percentiles). They are quiet for a reason: either operating restrictions, or lack of demand (eg the night hours for passenger flights). The plot simply shows that traffic growth was stronger at busy, but not at congested times.

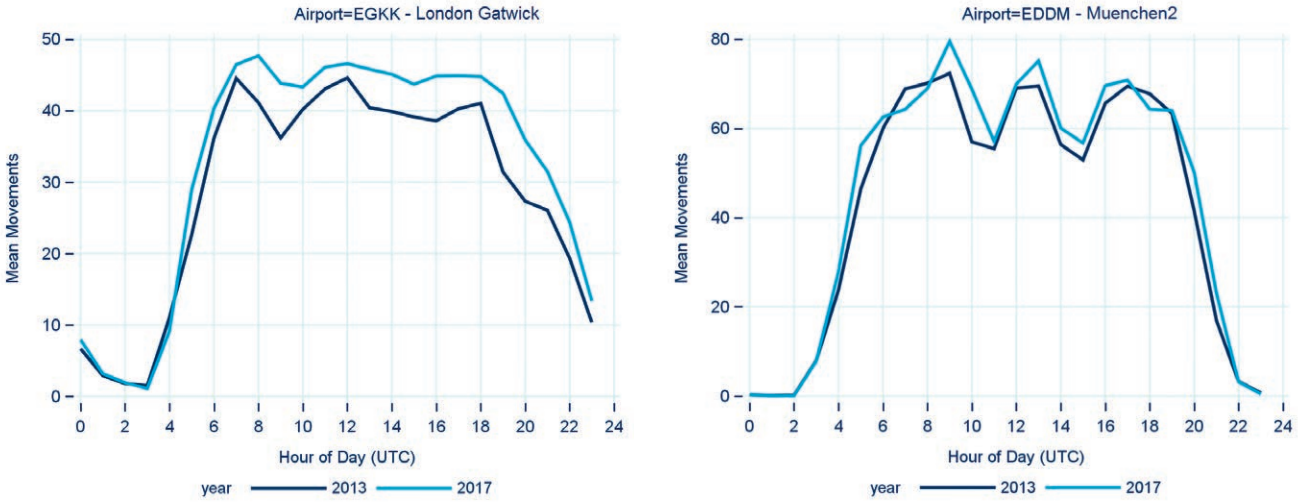


Figure 17 / *Traffic changes which can be interpreted as 'schedule smoothing'.*

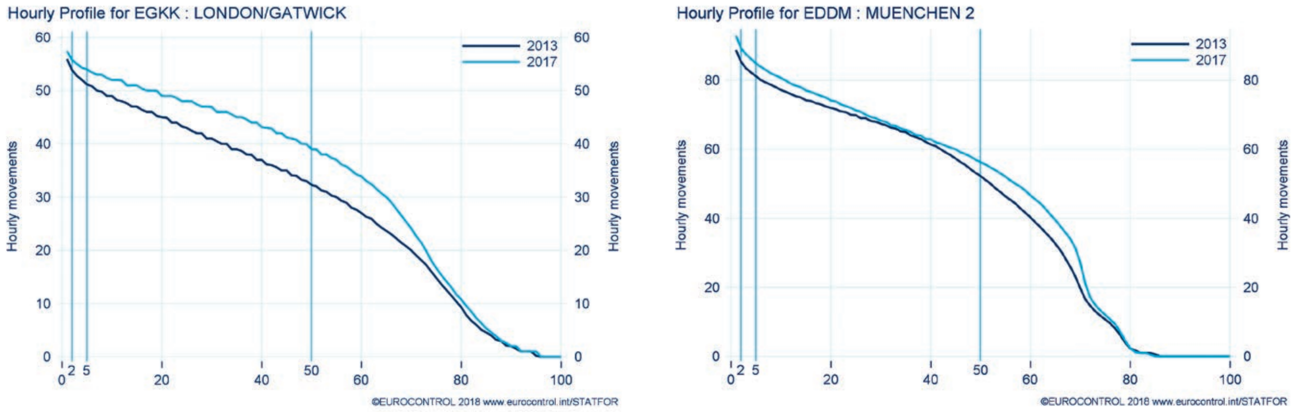


Figure 18 / *An Annual view of 'schedule smoothing'.*

ANALYSIS METHOD

Firstly, we have ruled out a method that involves building a realistic sequence of flights into a schedule. This would be possible in theory. However, the process involves 'cloning' existing flights to build up to the forecast amount of traffic. The approach creates an apparently precise set of data (aircraft operators, aircraft types, times of day, etc.) which in practice is full of assumptions and at the horizon of 2040 is likely to be unrealistic.

Our method instead adapts the annual traffic profile. We saw that the annual traffic profile in Figure 18 focuses on traffic during the year compared to hourly capacity and does not focus on particular times of day or days of the week. So by working directly on the annual profile of a given airport, we can simulate what could happen for a given year if this profile were to change. This then works for airports which have strongly-peaked summer days, or night curfews, or busy weekdays, etc.

For the exercise, we used the annual demand profile of Heathrow - EGLL (Figure 19) as a benchmark, and assumed the profile of other airports would come to copy this one to match the increase in demand. We excluded from the calculations the tail of the demand, i.e. the least busy, 35% of hours, since these seem to be driven more by local operating constraints, such as opening hours.

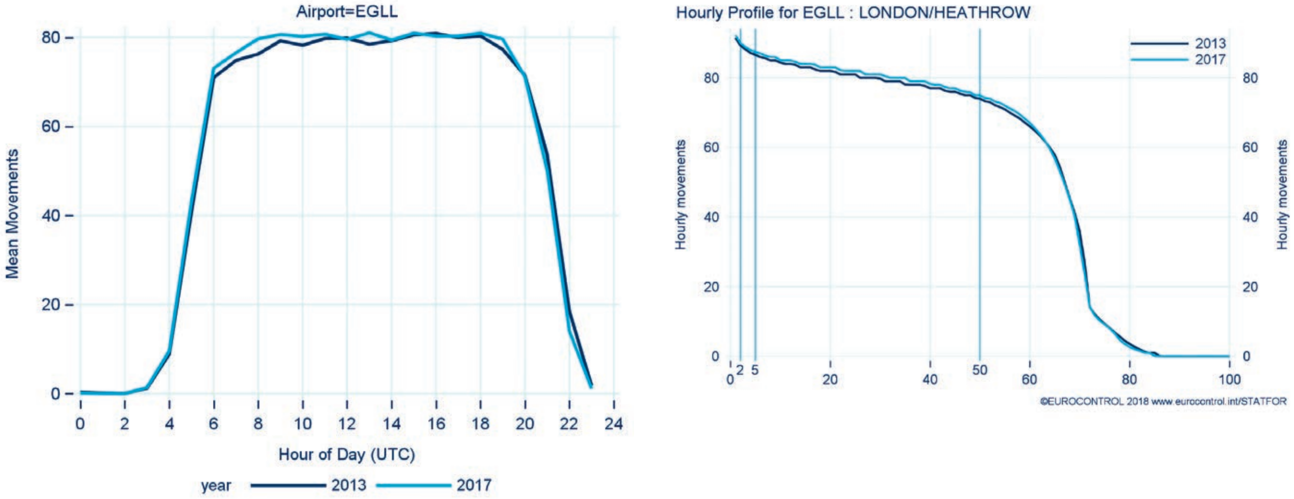


Figure 19 / *'Schedule smoothing' at Heathrow and its annual view.*

The approach is more appropriate for a hub airport than for a seasonal holiday destination; in the sense that it seems unreasonable to assume that an airport which is very busy on two days each week during the summer season and has very little of a home market would ever fill all of the quiet hours and days to the same extent as a large hub airport can. So the method should be applied to specific airports rather than blindly to all airports.

This method does not impact the hourly capacity of airports. Instead we are saying that, given a smoother mix of traffic, congested airports can approach an annual throughput profile similar to that of Heathrow, and thus operate for longer periods of time in the day close to their own maximum hourly capacity.

The effect of applying a Heathrow-like annual profile at other airports can be converted into yearly capacity increases which can then be modelled directly in the long-term forecast tool. This increased capacity can then be transferred back into a new hourly rate, i.e. implied hourly capacity, by assuming 24/7 operations: this implied capacity shall never exceed the airport own declared maximum hourly capacity. Annex B gives details.

Figure 20 illustrates the likely smoothing effect at the busiest 25 airports in 2040 in all the four scenarios: this provided a final list of 30 airports. The graphs here have been normalised to all be displayed on the same scale between 0 and 1 and thus get rid of the difference in hourly capacity between the concerned airport and Heathrow.

We have capped the overall gain associated to this method to 25%, on the assumption that airports gaining more than this would be subject to significant seasonal variations that would restrict their ability to smooth demand for the whole year. We then excluded a number of airports from these 30:

- if an airport reported an external constraint such as an environmental cap;
- if an airport had already based its capacity estimate on 24/7 operation, so the 2017 profile was not a good starting point for modelling;
- where the result was an implied hourly capacity that was greater than the maximum hourly capacity declared by the airport;

The result was that smoothing gains were applied to 6 out of the 30 airports: EBBR – Brussels National, ENGM – Oslo Gardermoen, ESSA – Stockholm Arlanda, LFPG – Paris Charles de Gaulle, LKPR – Praha Ruzyne, and LTFJ – Istanbul Sabiha Gökçen.

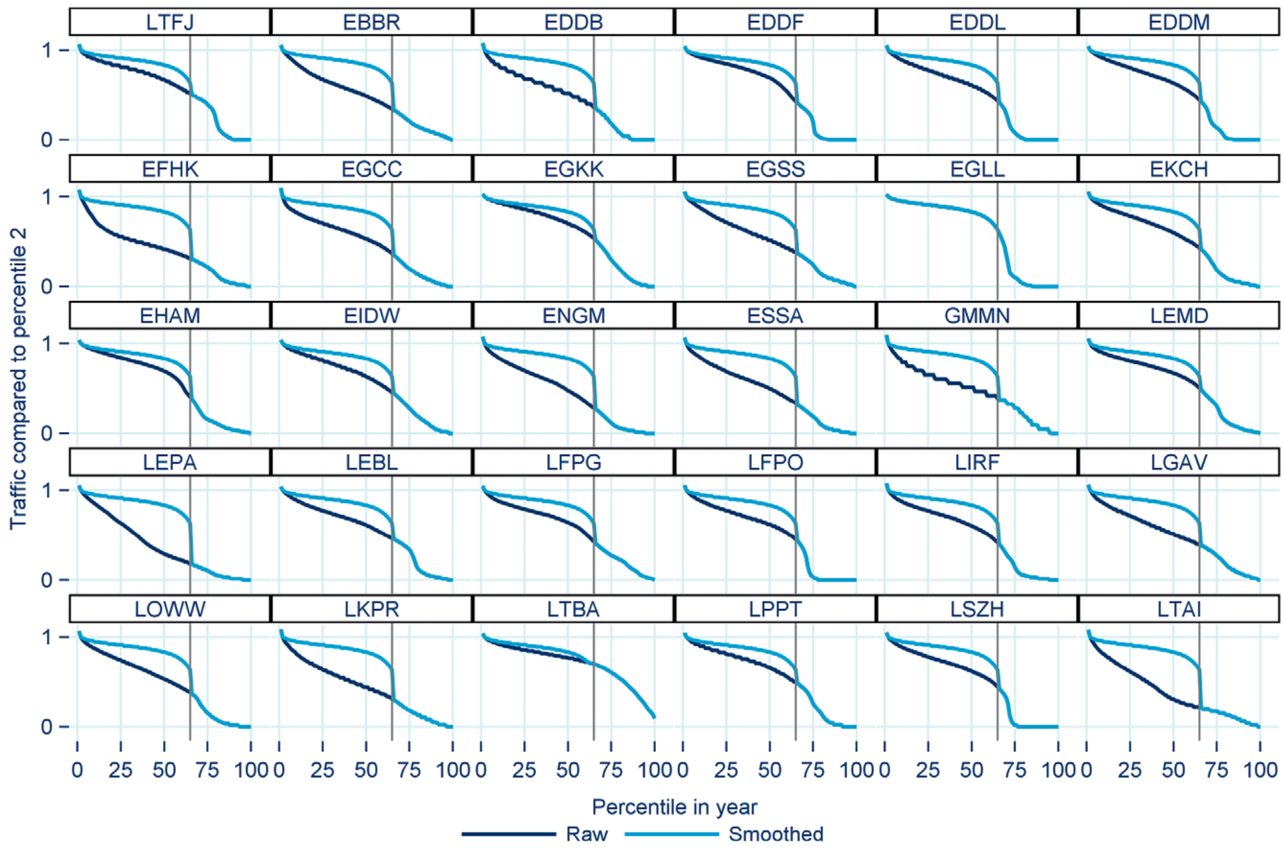


Figure 20 /
Smoothing effect in 2017 for 30 airports in the top 25 in 2040 in at least one scenario.

RESULTS

The outcome of this method was that smoothing gains were applied to 6 out of the 30 airports, increasing total capacity in 2040 for the 110 airports (i.e. EGLL is not included) by 1.7%. In the most likely scenario Regulation and Growth, this reduced the unaccommodated demand by 11%, indicating that the additional capacity is often just where it is needed. However the impact remains lower than that of SESAR improvements for similar capacity gains. It can be explained by the fact that SESAR improvements were in priority applied to the most congested airports, whereas the schedule smoothing could only be applied to a few of these congested airports, even if in many cases 'schedule smoothing' reduced unaccommodated flights in a greater proportion than SESAR improvements at the same airports.

The pattern of improvement is quite similar in Global Growth and Happy Localism. The area where the impact on unaccommodated traffic is the greatest is in ESRA Mediterranean and ESRA North-West that are the most congested in 2040.

The detailed results are provided in Figure 21.

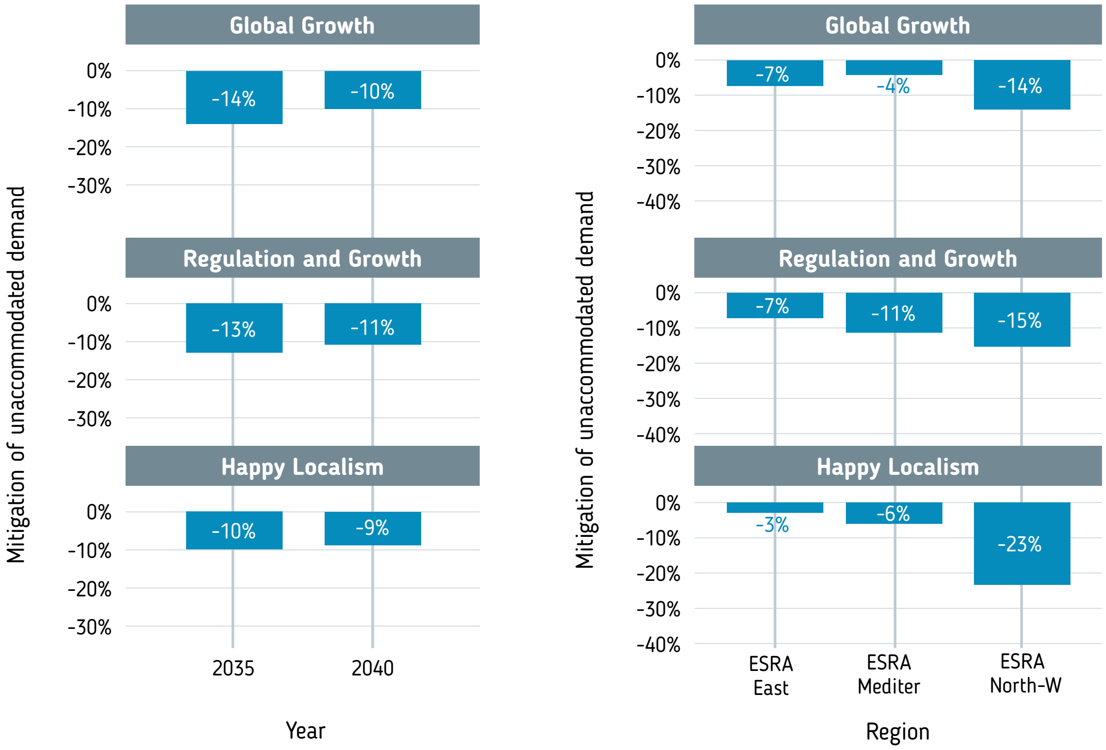


Figure 21 /
Mitigation gains for Schedule Smoothing

COMBINED MITIGATION

We have combined complementary mitigations that represent opportunities for different stakeholders to invest to reduce unaccommodated demand. Two combinations of mitigations have been evaluated: capacity benchmark for small airports with additional HST investment combined either with Local Alternatives or SESAR Improvements.

Gains from different mitigations cannot simply be added and for the combination with the greatest impact, in the most-likely scenario, a reduction of 45% of unaccommodated demand could be measured, 7 percentage points less than the gross sum of their individual effects.

BUSINESS CONTEXT

Through developing the mitigation options, we have deliberately looked from a number of different perspectives to solve the capacity problem at an airport: improving the operations at the airport itself (i.e. SESAR, schedule smoothing, consensus benchmark throughput at small airports), enhanced exploitation of neighbouring airports (i.e. Local alternatives), and enhanced alternative transportation means to meet the demand (i.e. High Speed Train).

Each solution is in the hands of different stakeholders in the air transport industry:

- **Airport operating companies** when it is up to airport operations and implementing new tools and procedures at the local level (e.g. SESAR improvements, schedule smoothing). Airport operating companies have also a role when building new infrastructures at a given airport: new taxiways, new runways, and when building a new airport. They operate in close cooperation with the local Air Traffic Control authorities.
- **Local Air Traffic Control authorities** when it is up to deliver safely a smooth flow of traffic as planned. They operate most of the tools and procedures and are also involved in their development and implementation.
- **Aircraft operators**, when it is up to choose the airport destination (e.g. for the use of local alternatives), the aircraft size, and the time of operations (e.g. Schedule smoothing)
- **National government authorities**, when it is up to invest in new infrastructures: not only at airport level or when it is up to build new airports, but also when it is up to build and invest in other means of transportation to facilitate intermodal connections (e.g HST) and ease access to airports from the cities, or access between airports

All these stakeholders cannot operate without cooperation with each other and the national government authorities are also often constrained by the European and international authorities and regulations.

Each solution has also a different scope of impact:

- SESAR focuses on the **most constrained airports**;
- Schedule smoothing and Local alternatives focus on the **biggest hubs of air-transport**, i.e. at the biggest airports that are often also amongst the most-constrained airports;
- HST additional investments, in the way they were built focus on the **busiest routes in terms of air traffic**;
- Consensus benchmark throughput will apply to **single runway airports** and be efficient to solve congestion when some exists at smaller airports.

To maximise their complementarity, we combined three mitigation methods amongst the six that have been tested. Two different combinations have been explored, although others could be possible:

- **Local alternatives – Benchmark – HST**: operating local alternatives airports along with benchmark capacity for single runway airports and additional investments in HST.

- **SESAR – Benchmark – HST**:
  SESAR improvements along with benchmark capacity for single runway airports and additional investments in HST.

ANALYSIS METHOD

For these combinations, we have re-run the forecast including the new inputs:

- Additional HST railways with their potential travel times of operation that might concurrence air-transport;
- New airport capacities corresponding to the benchmark capacity for the small single runway airports
- EITHER new airport capacities corresponding to SESAR implementation at the most congested airports, OR a traffic switch for the Local alternatives at the major hubs in Europe

RESULTS

The results focus on 2040 where the HST development plans, either real or additional, as built in the section about HST, are fully implemented and their impact measurable. They can be found in Figure 22 and Figure 23.

The first combination, **Local alternatives – Benchmark – HST**, provides an impact on capacity that is relatively equivalent for all the growth scenarios of the forecast by 2040: from a reduction of 23% of unaccommodated traffic in Happy Localism to a reduction of 35% in Regulation and Growth. In this most-likely scenario, the combination has a good impact on the congestion hotspots in North-West Europe with a reduction of 40%. With the use of capacity benchmark for small airports, it is also efficient to solve some capacity issues in ESRA East. On the other hand, it only reduces the capacity hotspots in ESRA Mediterranean by 18%, much less than the benefits of the SESAR improvements that reduced unaccommodated traffic in this ESRA Mediterranean area by 32% for the most-likely scenario. Such a result justifies why the second combination includes these SESAR improvements in place of the local alternatives.

For the most likely scenario Regulation and Growth, **SESAR – Benchmark – HST** provides the greatest overall reduction of unaccommodated traffic with 45% and is more efficient at the regional level for all zones: respectively reductions of capacity issues by 49% in ESRA East, 42% in ESRA Mediterranean and 41% for ESRA North-West, which is only a marginal improvement compared to the fist combination for this latter region.

Regionally and globally, the second mitigation, **SESAR – Benchmark – HST** is significantly more effective for ESRA Mediterranean, but its impact on reducing unaccommodated traffic is lower on the scenario with the strongest expected growth, Global Growth, for ESRA North-West as the use of local alternatives would still be a significant solution there.

Gains from the different mitigations cannot be added and for this last combination that has the greatest impact and the reduction in unaccommodated demand is 7 percentage points less than the sum of their individual effects for the most-likely scenario (Regulation and Growth).

Figure 22 / *Mitigation gains from the combination of Local alternatives – Benchmark – HST*

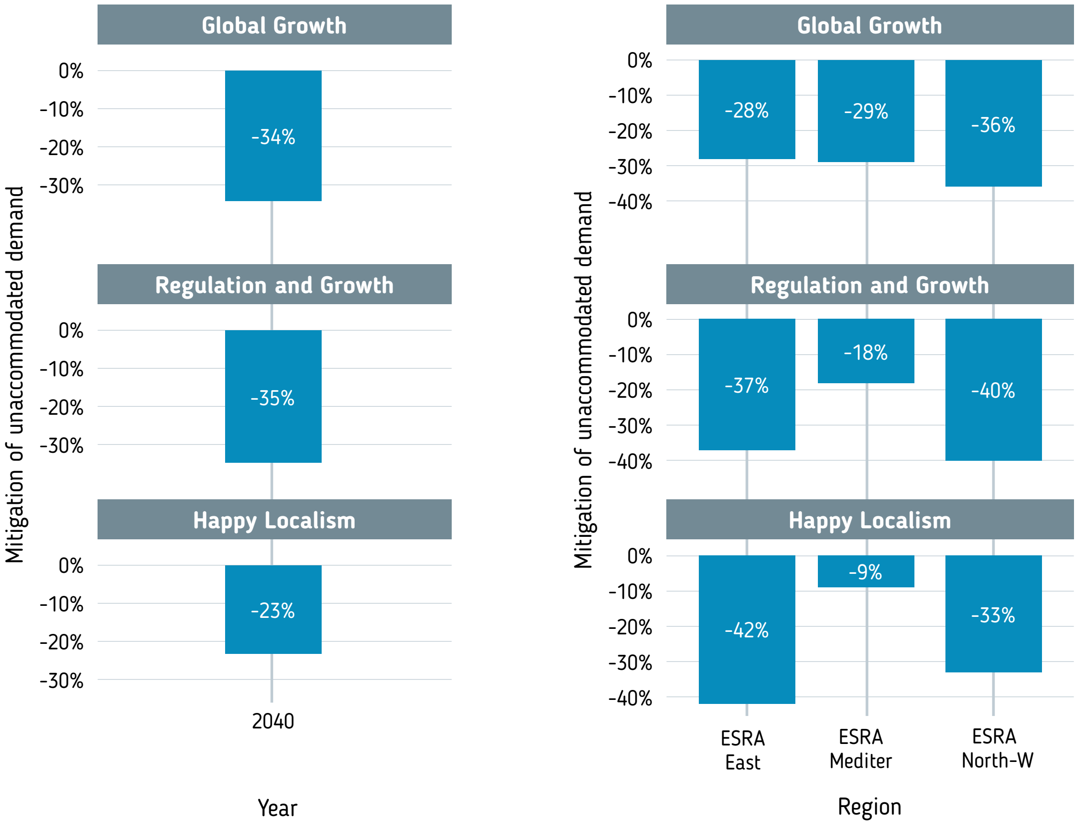
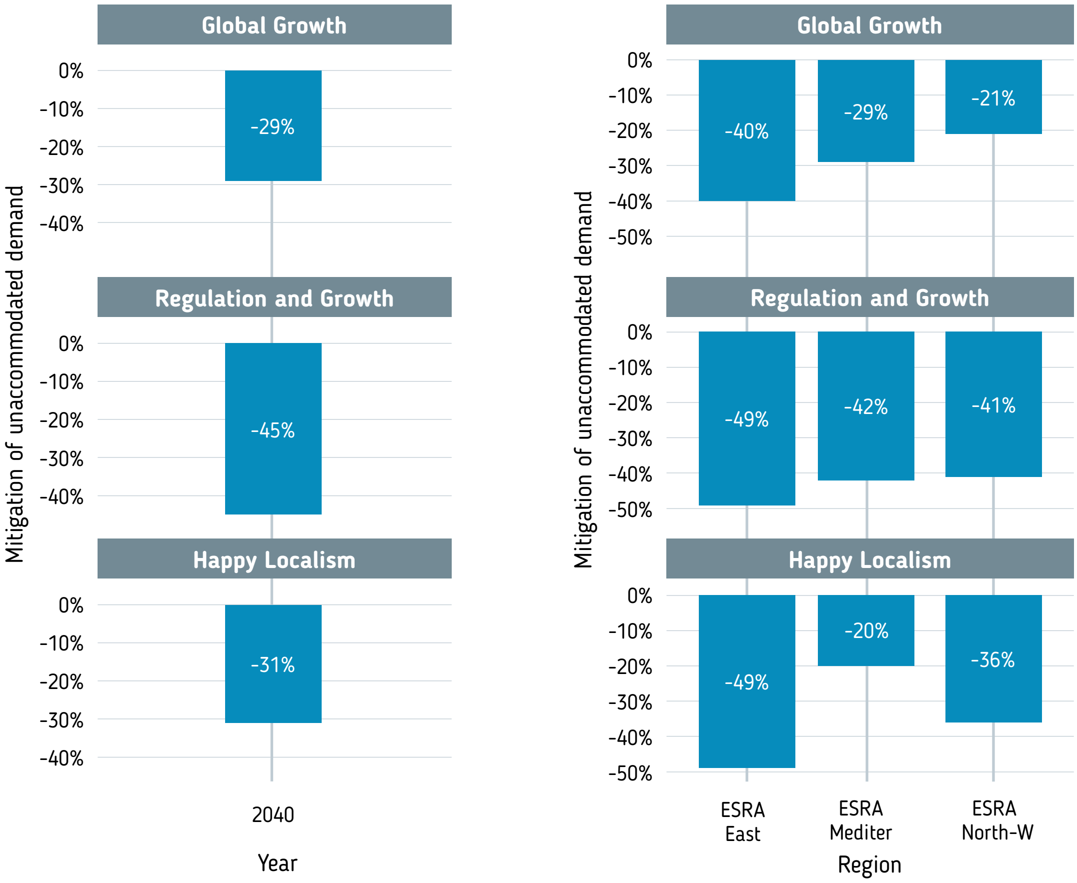


Figure 23 / *Mitigation gains from the combination of SESAR – Benchmark – HST*

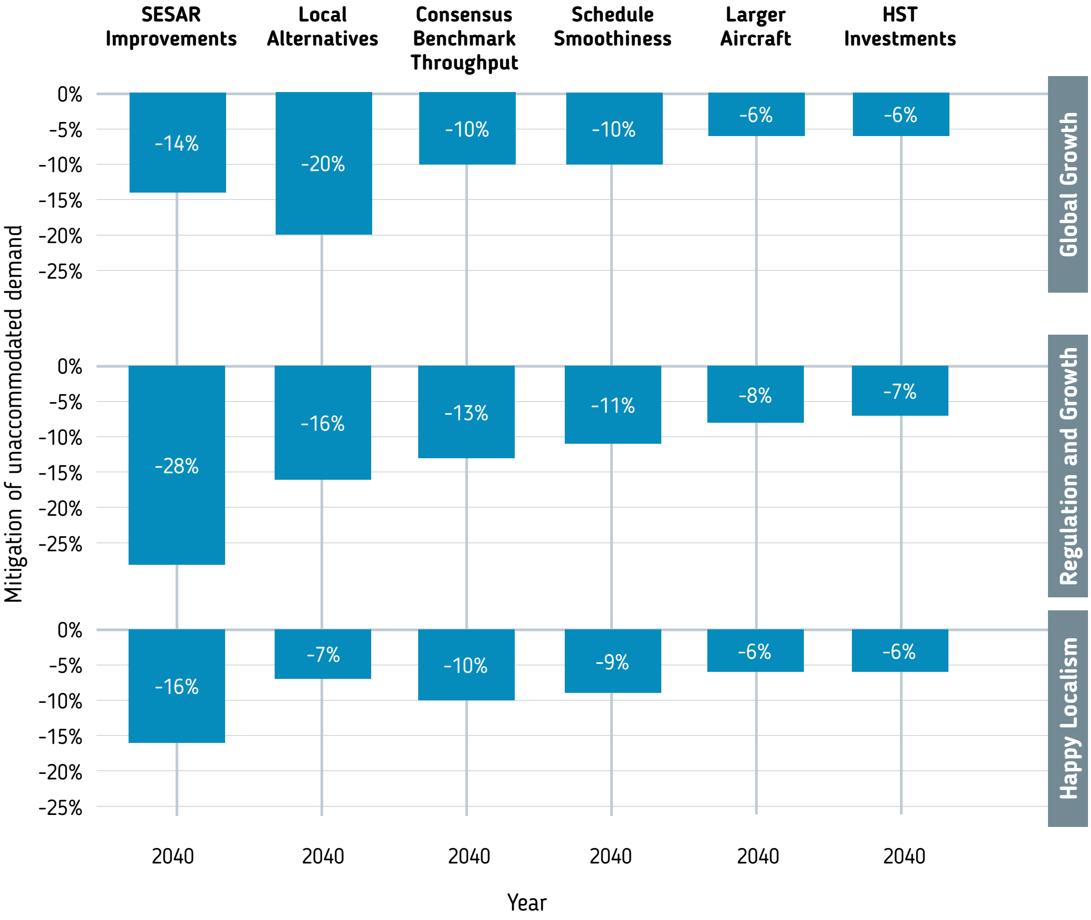


DISCUSSION

RANKING OF INDIVIDUAL MITIGATIONS

Each mitigation addresses different categories of airports: e.g. the ones expected to be the most constrained for SESAR improvements, the biggest hubs in Europe for the Local alternatives and also SESAR improvements, consensus capacity benchmark for the smallest airports. They also tend to have a different impact in the same places. As a consequence, it is difficult to compare their assessments and find a ranking that is fair. In an attempt to do that, we have ranked the overall impact of the six different methods that were assessed in this report for the most likely scenario Regulation and Growth according to their impact in 2040 on the reduction of the unaccommodated traffic. The result is available in Figure 24. As in the previous mitigation studies in CG13, the benefits are quoted to the nearest 1%. However, the modelling of the mitigations is more approximate than this and probably any difference below 5% is not significant.

Figure 24 /
Summary of the Mitigation Benefits (ordered left to right)



SESAR improvements has the greatest impact overall. It reduces unaccommodated flights by 28% for around a 1.5% capacity gain in 2040. This is in part due to the fact that the impact has been applied in priority to the airports that are forecast to be the most congested, whereas **Local alternatives** were not always available at all capacity hotspots. However, **Local Alternatives** are second when it is up to the overall impact in 2040. They are efficient to reduce congestion at the airports where alternatives do exist. The solution also appears to be the most efficient for Global Growth, the scenario with the greatest growth. This is an important outcome as Global Growth has become a likely growth scenario in view of the recent positive outlook of the traffic growth in Europe that appears likely to last. However, a viable alternative requires proper transportation to its 'mother' airport: this limits the number of available options and available alternative airports also tend to get congested. The capacity to share traffic across neighbour airports then becomes limited: it was the case around London and Istanbul where some alternatives were taken out for this study compared to CG13, which has certainly lowered the impact of **Local alternatives** in this study compared to CG13.

Consensus Benchmark and **Schedule Smoothing** come next in the list of mitigations, with very similar impacts on the amount of unaccommodated flights. However, both mitigations do not apply to the same type of airport: the first one addresses the capacity of single runway airports whereas the other applies to the busiest airports. As such, they are fully complementary mitigations rather than comparable solutions. More generally, consensus benchmark is not designed for the same airports as the other five mitigations which rather apply to the biggest European airports.

By comparison, **Schedule Smoothing** brings around the same amount of additional capacity for 2040 as **SESAR improvements** (+1.5%), but has lower benefits (-10%) as the schedule smoothing was only applied to a subset of the most congested airports that were more broadly impacted by SESAR impact.

Larger aircraft and **HST investments** come last and are effective mostly at major hubs and airports. Despite their limited impact, they still play a role in the reduction of unaccommodated traffic and are also independent of other mitigations. They could thus be applied in parallel to other solutions to bring additional impacts: HST was chosen as one of the mitigations to be kept in the combined mitigation trials.

From a geographical perspective, **Local alternatives** work well for ESRA North-West congested airports as many 'alternatives' airports could be found there, whereas **SESAR Alternatives** worked better for ESRA Mediterranean, thanks to the impact on Turkish airports, with a similar impact as **Local alternatives** for ESRA North-West. **Consensus Benchmark** impacts mostly Eastern Europe where many single-runway airports are located. The other three mitigations have relatively well-balanced effects across the other airports where there is congestion and have the advantage that they can be combined with others to further reduce unaccommodated flights. These solutions seem in particular promising options to be combined with SESAR to help solving the capacity issue in ESRA Mediterranean.

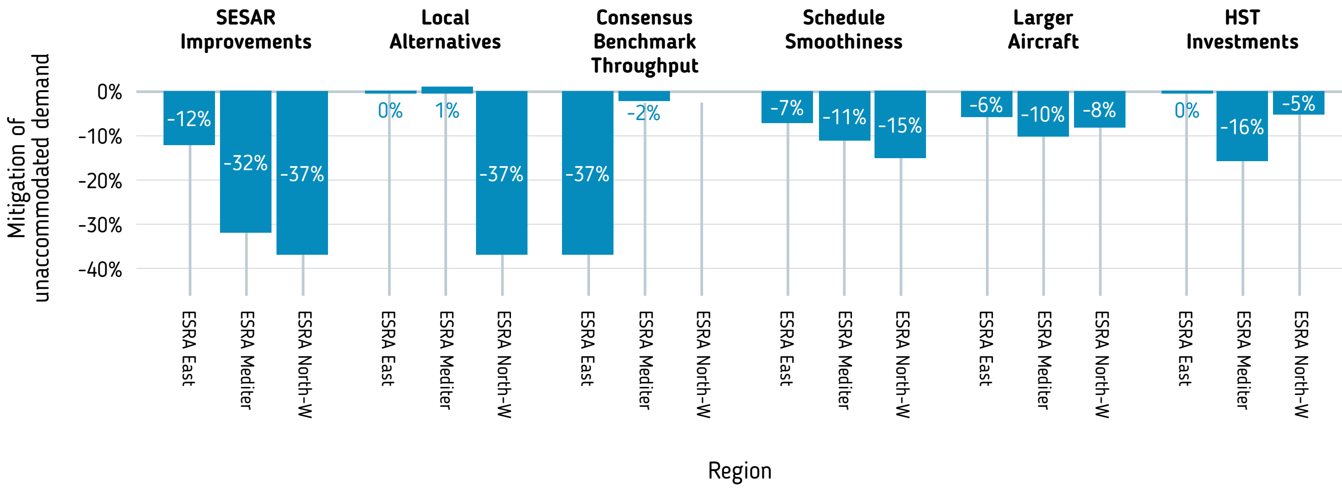


Figure 25 /
Summary of the Mitigation Benefits per ESRA Region for Regulation and Growth

COMPARISON WITH 2013

Comparison with the results from the mitigation study of Challenges of Growth 2013 (Ref.9) in 2035 for the most-likely forecast scenario gives some insight into the sensitivity of the results to the evolution of the traffic.

In CG13 for the most-likely scenario, **Local alternatives** was one of the top-ranking mitigations with a reduction of unaccommodated traffic of 21%: it is still the second most-effective but it has a lower impact with a reduction of 16% in CG18. This may be linked to the fact, also mentioned in CG13, that these alternative airports are also with time becoming more congested themselves, this all the more that we are now looking at 2040 instead of 2035 in CG13. In CG18, some alternatives have been taken out of the list of CG13 as these airports were expected to operate close to their own capacity themselves and thus no longer fit for hosting additional traffic. This, in particular, reduced the benefits of the mitigation in ESRA Mediterranean. This reduction is also coherent with the decline in effectiveness already pointed out in CG13 compared to CG08. Or, in brief, we are running short of obvious local alternatives.

Schedule smoothing was also one of the most efficient mitigations in CG13, this is no longer the case with a reduction from 20% in unaccommodated traffic in 2013 to 7% in the 2018 study. This is in part due to the fact that schedule smoothing could only be applied to 6 airports, compared to 11 in CG13: with that respect, the reduction in efficiency looks proportional. If some airports might be too pessimistic in their declared hourly capacity, which has reduced the number of airports to which the mitigation could be applied, there might also be environmental, operational and especially commercial factors that limit the approach and will limit the feasibility of schedule smoothing. As a consequence of this result, 'Schedule smoothing' is no longer in the list of the most efficient mitigations.

SESAR improvements in CG13 was also on the list of the most efficient mitigations. It is definitively the case as it ranks now first in CG18, but the assessment is more focused on peak hours in CG18 and results are thus not fully comparable with CG13. Compared to CG13, CG18 assumed 'SESAR improvements' would be implemented first on the expected most-constrained airports according to the forecast to 2040 (Ref. 2), which has 'optimised' the gains. In this update, 'SESAR improvements' go for a reduction by 28% of unaccommodated traffic, greater than the gains estimated in CG13 of 19%. We shall also note that for CG18 'SESAR improvements' could be considered in Turkey, whereas it was not the case in CG13: this certainly has boosted the impact on unaccommodated traffic as some Turkish airports will be amongst the congestion hotspots by 2040.

Consensus Benchmark, called Small Benchmark in CG13, is amongst the three mitigations with the most significant overall impact for 2040 with a reduction of unaccommodated traffic by 13%, which is similar to what was estimated in CG13 (10%). This impact follows the confirmation of the future congestion in ESRA East in the 2040 forecast that is expected to hit several single runway airports in the region by 2040.

For **HST investments**, HST in CG13, the benefits expected in this update are lower than in CG13 despite a very similar assessment method. In CG18, 43 city-pair links were added compared to 75 in CG13: this is associated to a more restrictive selection of the city pairs based on their distance (i.e. the 500km threshold), a restriction that is reasonable in view of the size of the HST network it still generates. It also illustrates that congestion at an airport is not always the fact of a few main routes but results for the accumulation of traffic from and to several cities. The efficiency of HST as a mitigation is also strongly linked to the geographical overlap of its network and the capacity challenge.

Larger aircraft, which contributed to a reduction of 15% of unaccommodated traffic in CG13 only brought a reduction of 8% in CG18. Such an outcome can be associated to the on-going increase of aircraft size in response to the constant economic pressure and the fuel prices constantly at risk to increase. The final margin of increase in the size of aircraft is then reduced compared to CG13 and the expected benefits are consequently lower.

For the combined mitigations, the results of CG18 are rather similar to those of CG13. One common combination was tested in CG18: the combination of HST additional investments with local alternatives and capacity consensus benchmark for the small single runway airports. The impact in the most likely scenario Regulation and Growth reduces by 35% unaccommodated traffic in CG18 compared to 39% in CG13. The impact will mainly be weaker for ESRA North-West in CG18 than in CG13 but it remains the same for ESRA East that will stay not much impacted by this combination (i.e. a reduction by 18% of the congestion in Regulation and Growth) as in CG13 (i.e. a reduction of 16% of the the congestion). The reduction in impact for CG18 compared to CG13 may also be attributed to the fact that we compare different years of forecast with 2040 seeing greater volumes of traffic than 2035 and thus a greater challenge to accommodate demand.

LOOKING BEYOND THE FIGURES

The mitigation methods analysed for this study and reported in the different sections of this annex have tried to address the lack of capacity without building new runways at airports or new airports and have analysed what can be done from the existing resources.

The methods, despite somewhat idealised, have allowed an analysis that is data-driven, airport-specific and yet takes in a Europe-wide scope, within the time and resources that are available. These methods are also inspired of what is already applied at airports to solve the capacity issue. A more precise analysis would have required discussions for individual airports with the airport, the local airlines and community. Even then, the difficulties of resolving the different perspectives on the future might not have led to a conclusive answer, a more detailed answer, but apparent precision that in reality adds little certainty. Uncertainty is inescapable in a 2040 forecast.

So the method chosen was fit for purpose even though, it probably leads to a degree of optimism in the results as it is likely to underestimate the local difficulties in implementing the methods. In particular, hosting additional aircraft, and passengers, outside of a new runway, as it is the case with the chosen mitigations, may also require new taxiways, facilities to host the passengers and the aircraft, additional maintenance equipment, new systems to assist with ATC during approach and ground handling of aircraft. These will all take time to be built, tested, certified and may necessitate new and or existing staff who will have to be adequately trained. This will have a cost that will only be invested if the return on investment is found worthwhile.

Furthermore, there are environmental and other local limits which might be under-represented in the mitigations: local air quality standards; noise restrictions; operating hour agreements; airspace constraints etc. In the future, everything points to these becoming more prevalent, to give just a few examples: local agreements to increase capacity at some times of the day in exchange for tighter curfew rules; residents' sensitivity to noise; local air quality regulations that encompass ground transport as well as ground movement of aircraft with cities growing ever closer to the airport. If several airports assumed 24/7 operation was possible, fewer hours of operations seems quite likely in the future. We can also note that one of the mitigation methods hypothesises the use of capacity elsewhere to compensate for the lack of capacity at an airport. This would expand the footprint of the environmental impact and is not a cost-free solution. Building HST railways is also not environmentally neutral and some projects, like the Lyon-Turin railway construction, have recently been delayed and questioned because of their environmental impact.

The figures highlight that no mitigation is perfect and solving the lack of capacity will only be feasible through a combination of several methods, and new runways or new airports will inevitably need to be part of the solution to bridging the capacity gap. However, any increase in traffic and change of the traffic patterns at an existing airport will only be more and more difficult for the reasons aforementioned and it is also likely to be worse for building new infrastructures. The decision will never be in the sole hands of airlines, airports and air-traffic control authorities but will also be strongly impacted by the public opinion and by the various political actors and decision-makers whose interests are sometimes far away from those of the air-traffic business. Implementing the 'ideal' solution may then take longer than expected and some projects may simply get cancelled (e.g. Notre-Dame-des-Landes in France) on the way to their completion.

CONCLUSION

For this task of Challenges of Growth we have evaluated six different ways to mitigate the capacity constraints identified in the 2040 forecast, beyond building new runways. Each is based on a different way in which the air transport industry and governments already respond when there is airport congestion.

For each mitigation method, there are limits due to business constraints such as yield and aircraft availability. There are benefits to passengers and shippers from the connectivity and quality of service that is improved. But there are also costs, from easily measurable ones such as the cost of building HST track, to the non-monetary costs such as the impact on neighbours from expanding quiet or dormant airports. As a result, none of these mitigations will be easy to achieve.

As each mitigation acts on capacity of airports in a different way, they can also be used in combination to complement their individual action. For the most-likely forecast scenario Regulation and Growth, the most effective combination analysed in this study has the potential to reduce unaccommodated demand by 45%. It is a combination of three methods: additional investment in high-speed train; assuming SESAR Wave 1 is fully available and implemented at the airports that are the most congested and the use of a consensus benchmark capacity for single runway airports whose capacity is under-estimated. However, this combination of three is not a proposal of a best option that should be implemented, but instead an indication of the scale to which unaccommodated demand can be reduced and how.

In reality not all of these gains will be achievable and the industry will have to use a little of each of the six methods, just as it has been in the past, in addition to building new infrastructure to solve the capacity issue.

ANNEX A

CITIES AND THEIR AIRPORTS

In the Local Alternative Airports Section, we mentioned the possibility to use alternative airports for operating part of the traffic that was initially directed towards the main airport. The transfers depend on the existing airports around the main airport. The following Figures illustrate the possible alternatives, amongst which have been chosen those evaluated in the Local Alternative Airports Section.

The scales vary between 1/600,000th to 1/700,000th to keep similar map sizes. In some cases, the city centre was placed off-centre to show more distance airports which are associated with the city for some flights. Only main highways (i.e. motorways and trunk roads according to Open Street Map classification[5]) are displayed on the maps. This explains why the road network sometimes looks incomplete.

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[5] *https://www.openstreetmap.org*

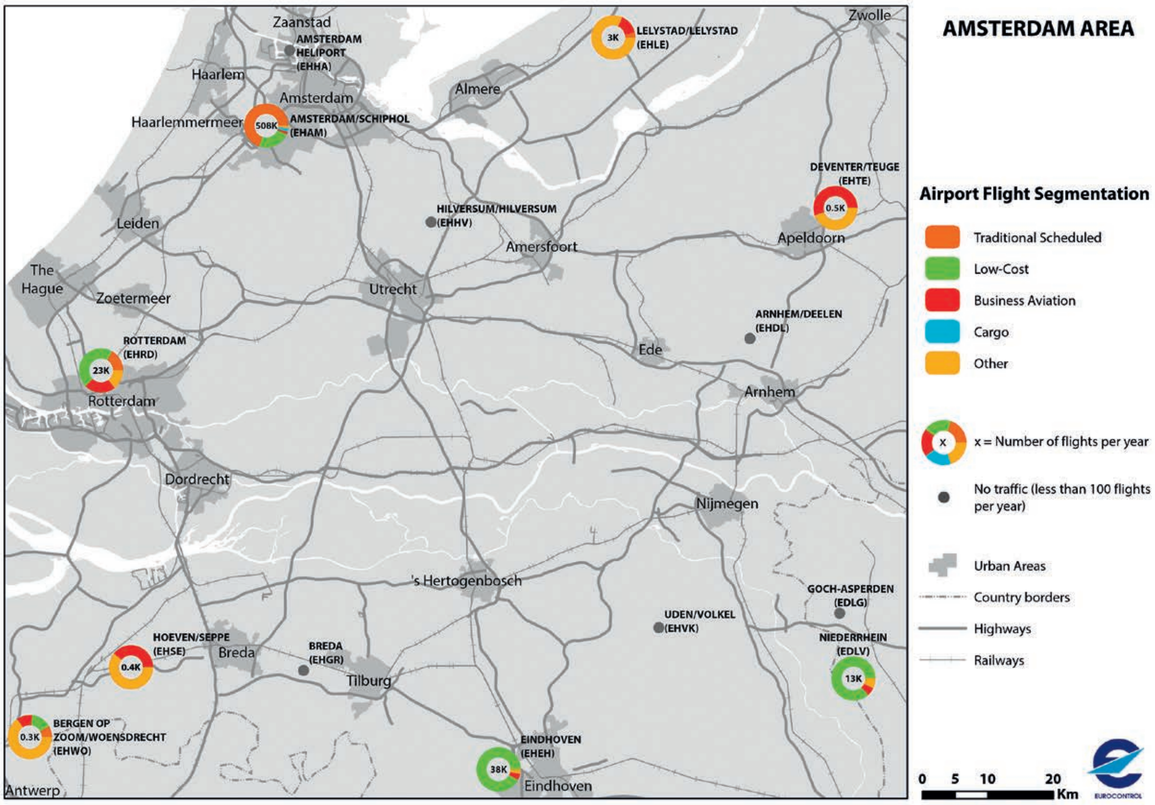


Figure 26 / *Airports around Amsterdam (Alternatives to EHAM)*

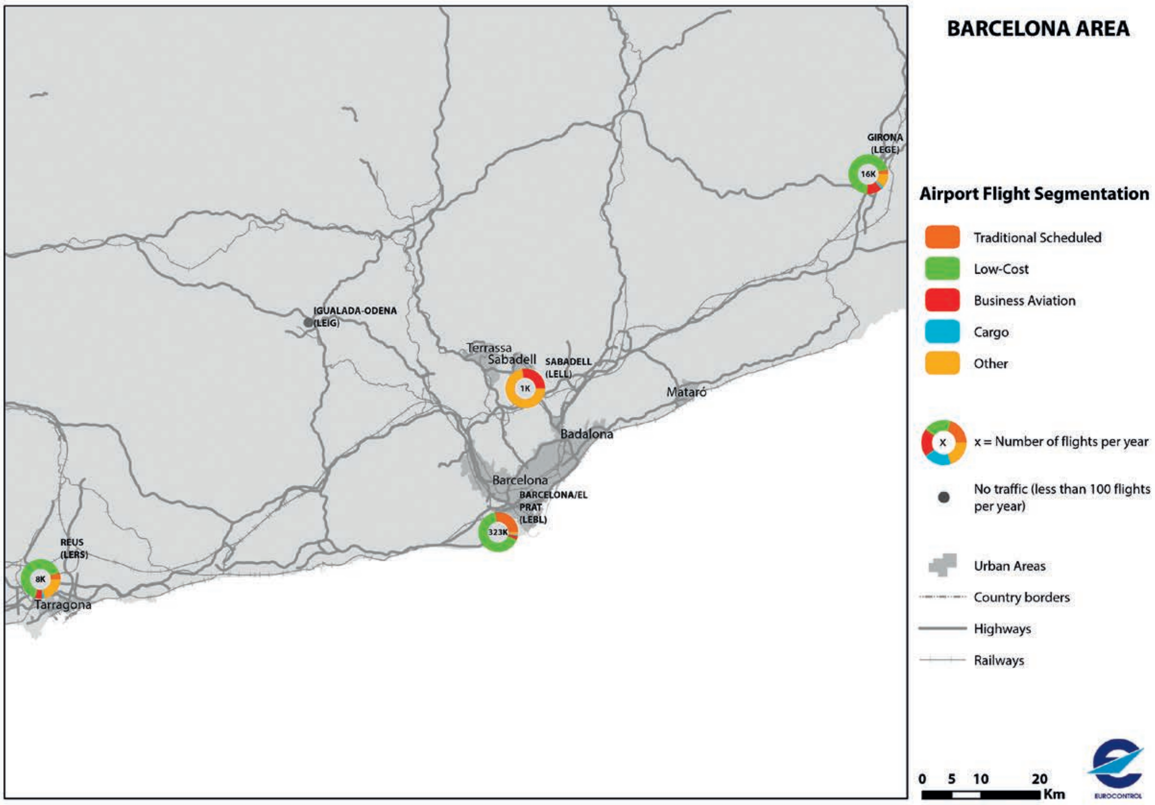


Figure 27 / *Airports around Barcelona (alternatives to LEBL)*

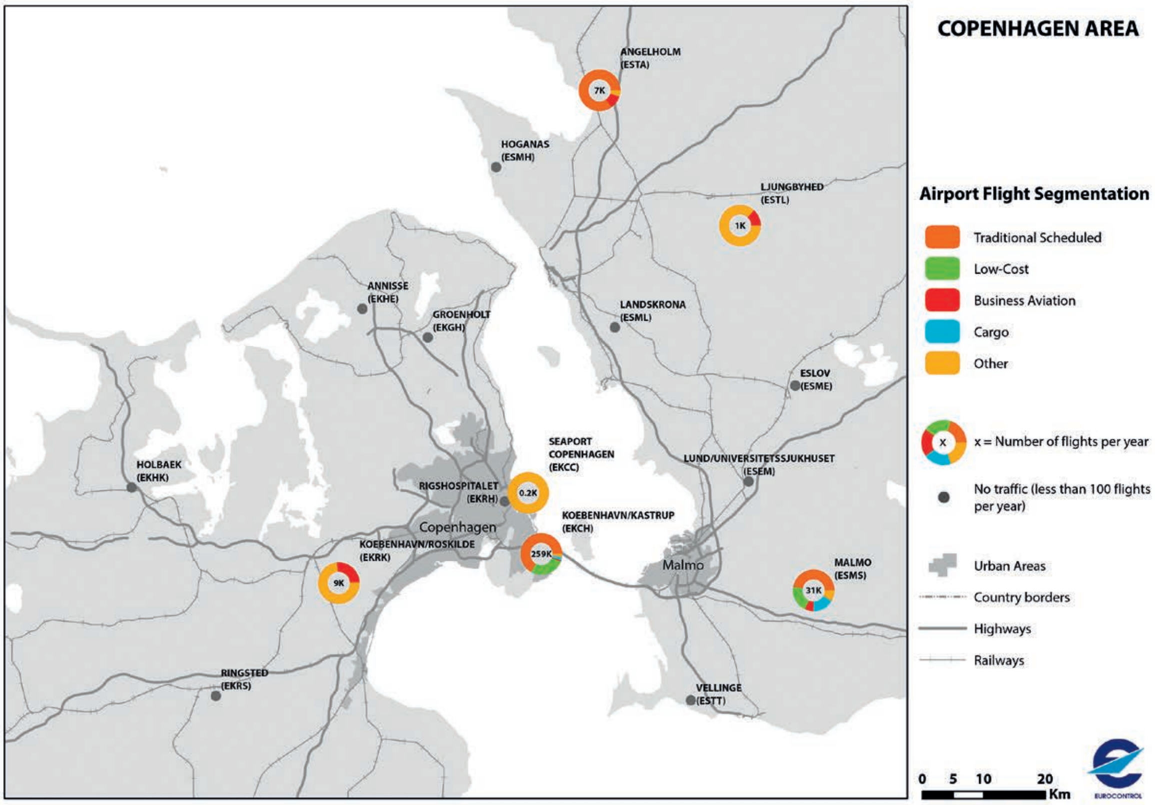


Figure 28 / *Airports around Copenhagen (alternatives to EKCH)*

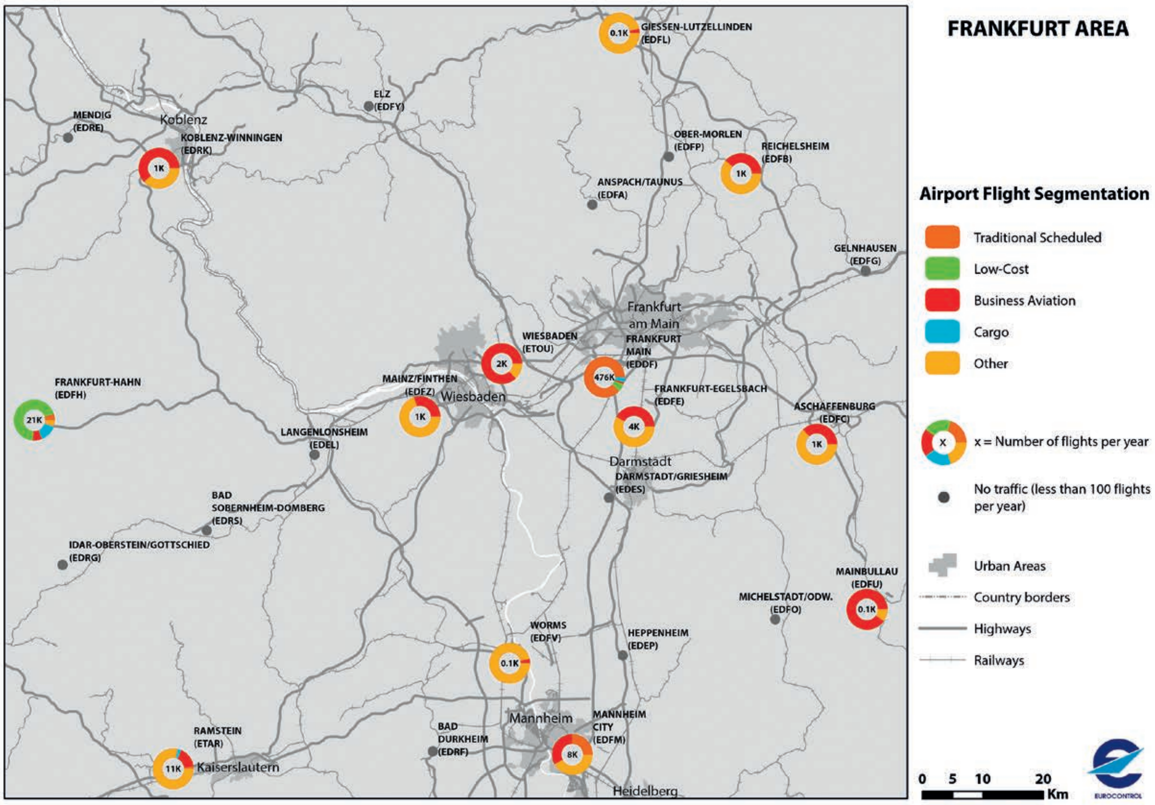


Figure 29 / *Airports around Frankfurt (alternatives to EDDF)*

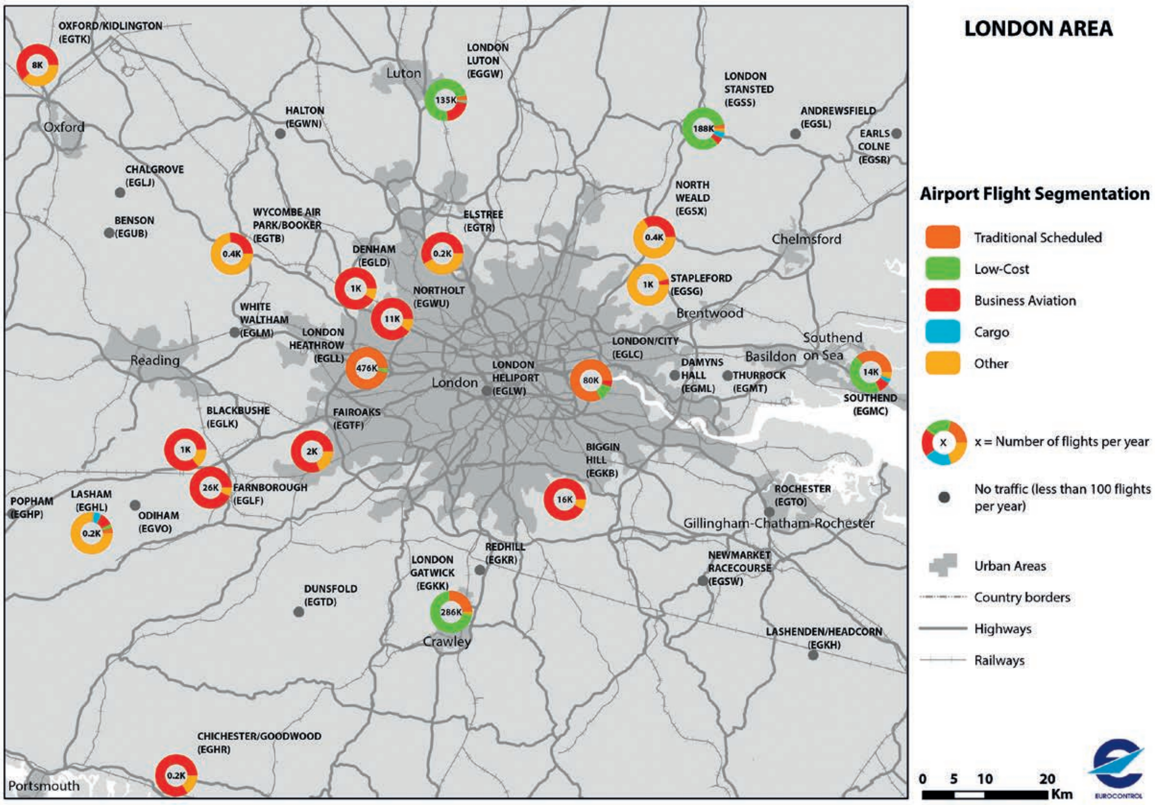


Figure 30 / *Airports around London (alternatives to EGGL)*

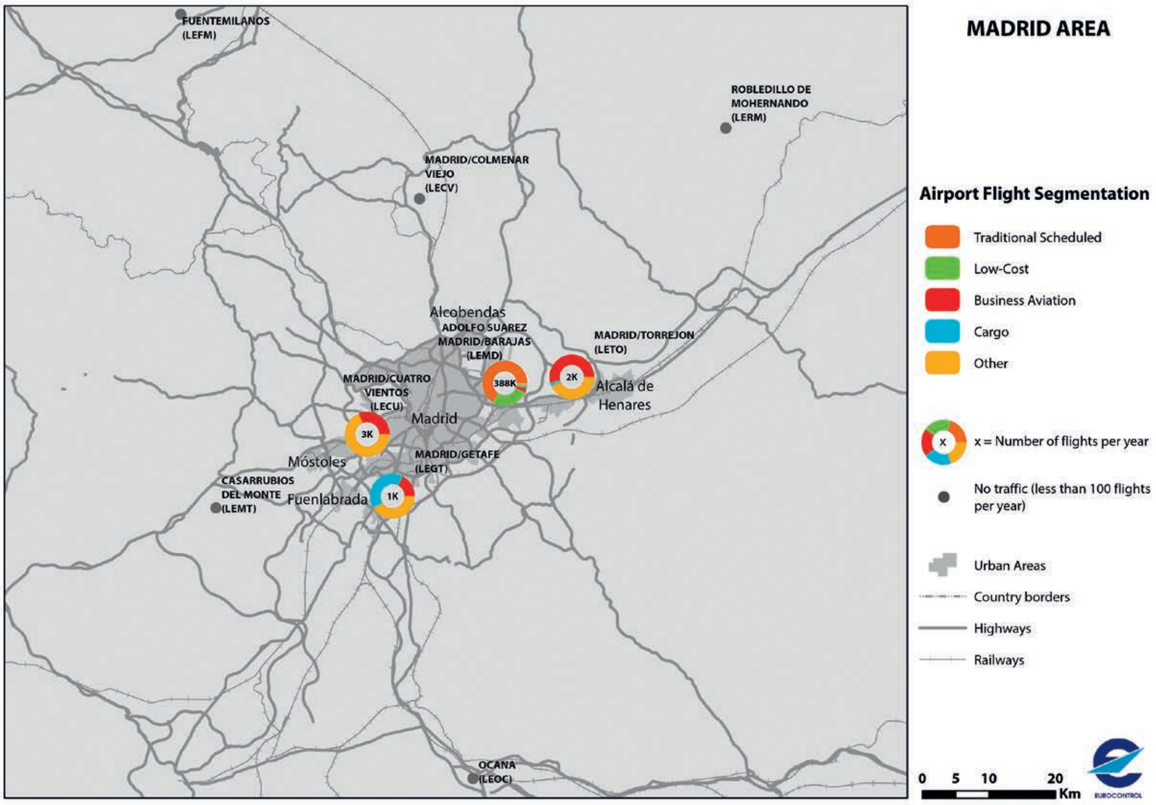

MADRID AREA
FUENTEMILANOS (LEFM)
ROBLEDILLO DE MOHERNANDO (LERM)
MADRID/COLMENAR VIEJO (LECV)
Alcobendas
ADOLFO SUAREZ MADRID/BARAJAS (LEMD) 388K
MADRID/TORREJON (LETO) 2K
Alcalá de Henares
MADRID/CUATRO VIENTOS (LECU) 3K
Madrid
Móstoles
MADRID/GETAFE (LEGT) 1K
CASARRUBIOS DEL MONTE (LEMT)
Fuenlabrada
OCANA (LEOC)
Airport Flight Segmentation
🟧 Traditional Scheduled
🟩 Low-Cost
🟥 Business Aviation
🟦 Cargo
🟨 Other
x = Number of flights per year
● No traffic (less than 100 flights per year)
Urban Areas
Country borders
Highways
Railways
0 5 10 20 Km

Figure 31 / *Airports around Madrid (alternatives to LEMD)*

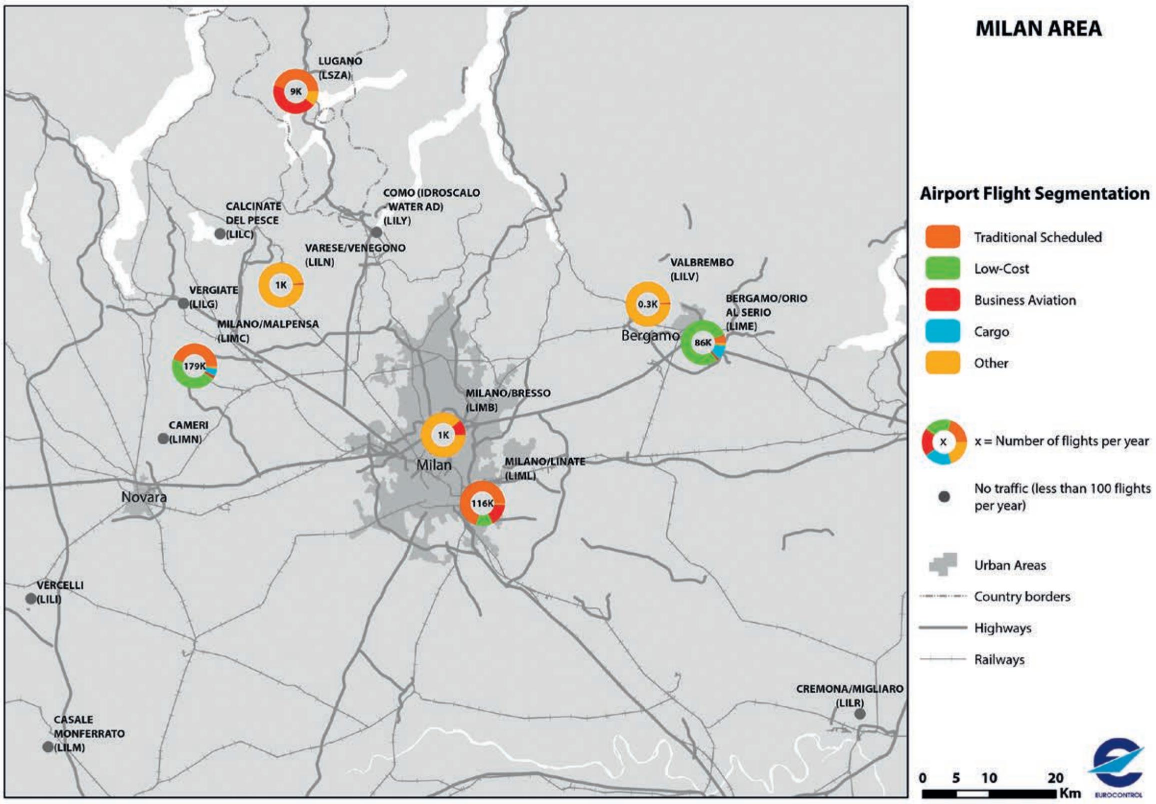


Figure 32 / *Airports around Milan (alternatives to LIMC)*

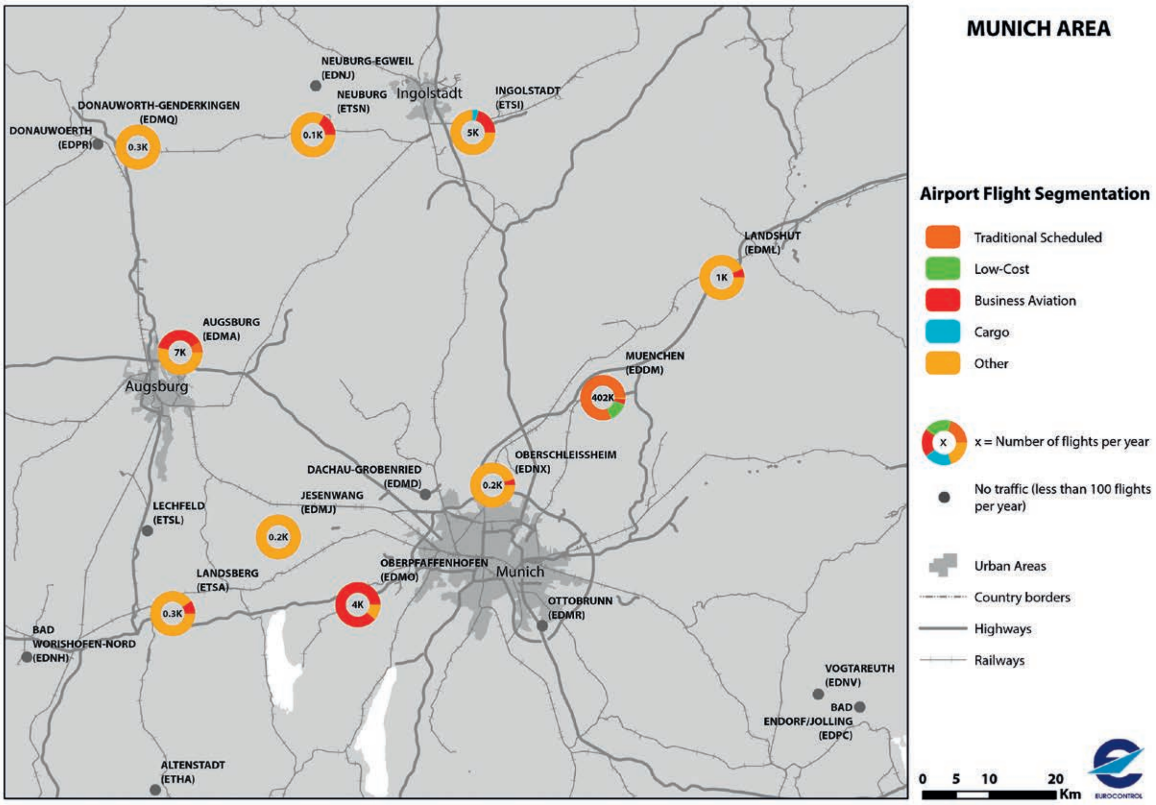


Figure 33 / *Airports around Munich (alternatives to EDDM)*

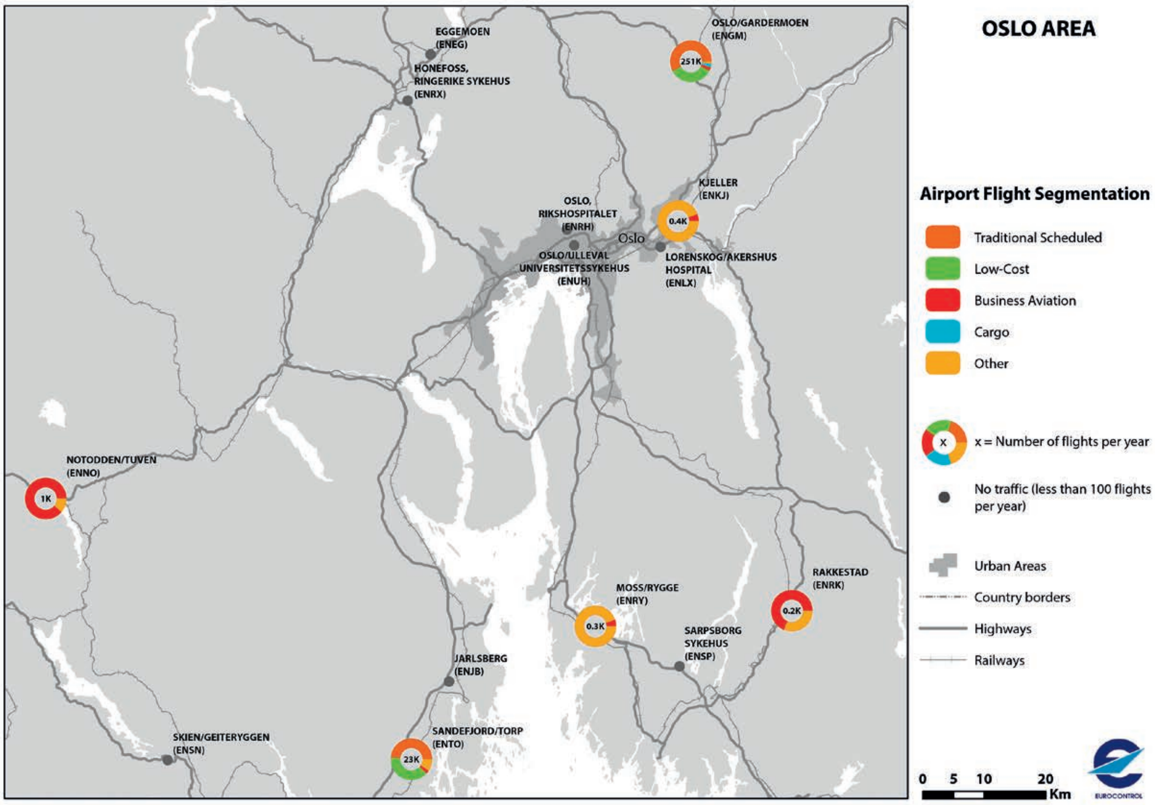


Figure 34 / *Airports around Oslo (alternatives to ENGM)*

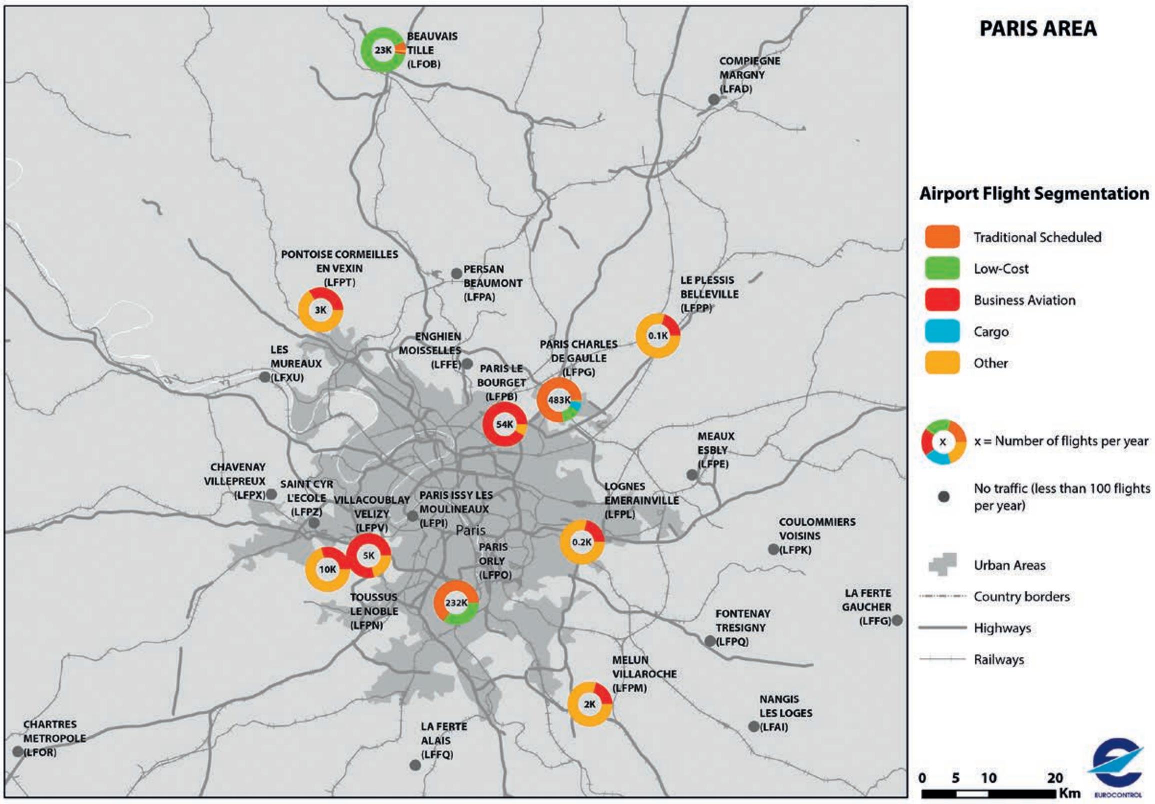


Figure 35 / *Airports around Paris (alternatives to LFPG)*

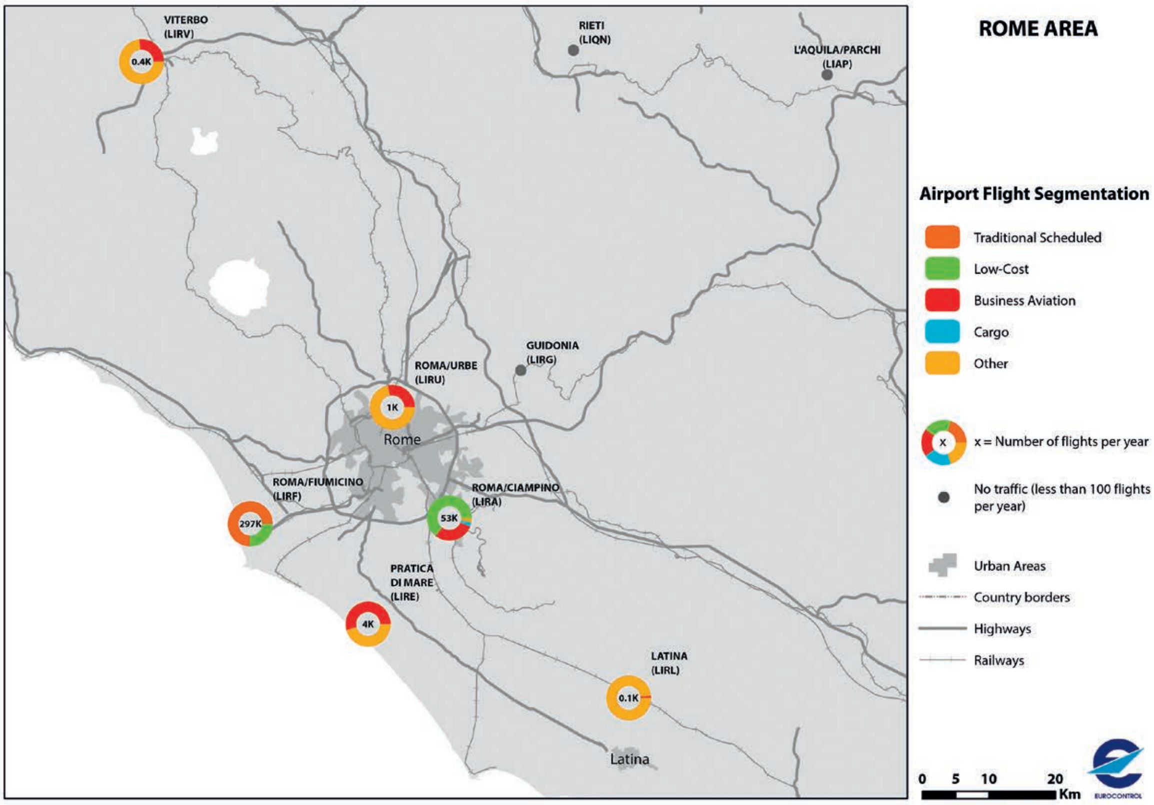


Figure 36 / *Airports around Rome (alternatives to LIRF)*

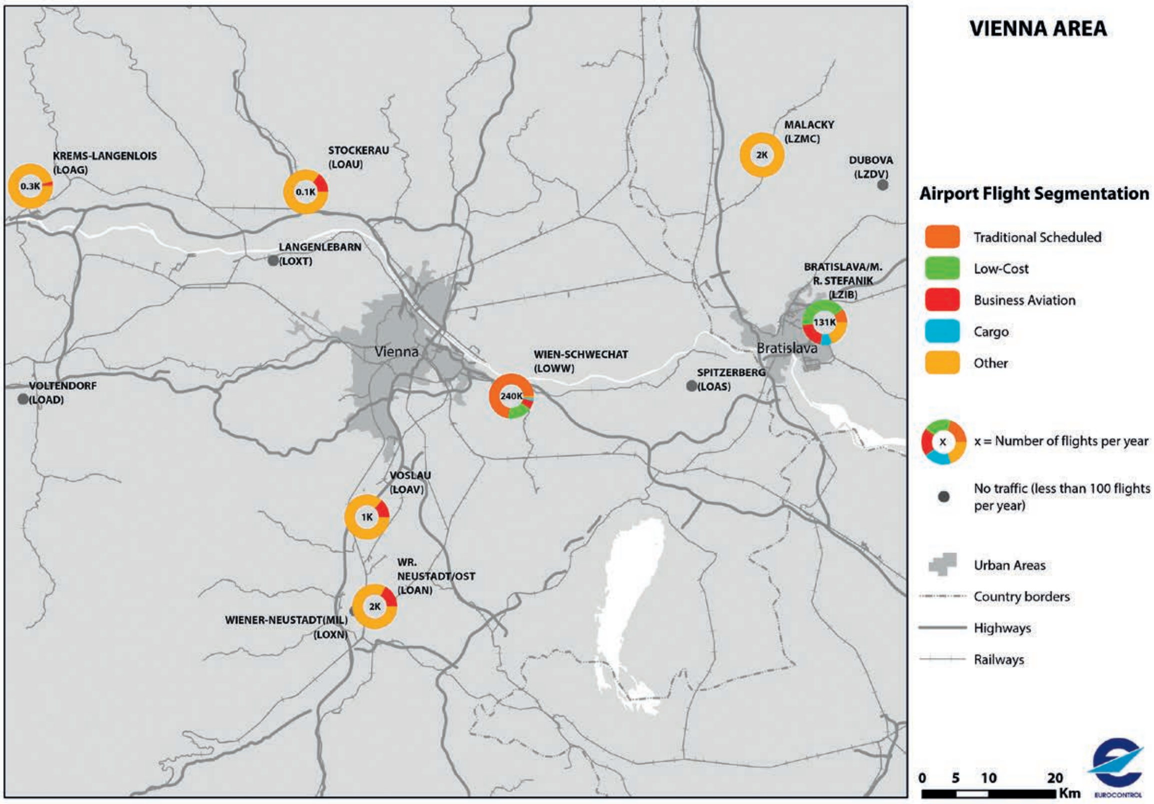


Figure 37 / *Airports around Vienna (alternatives to LOWW)*

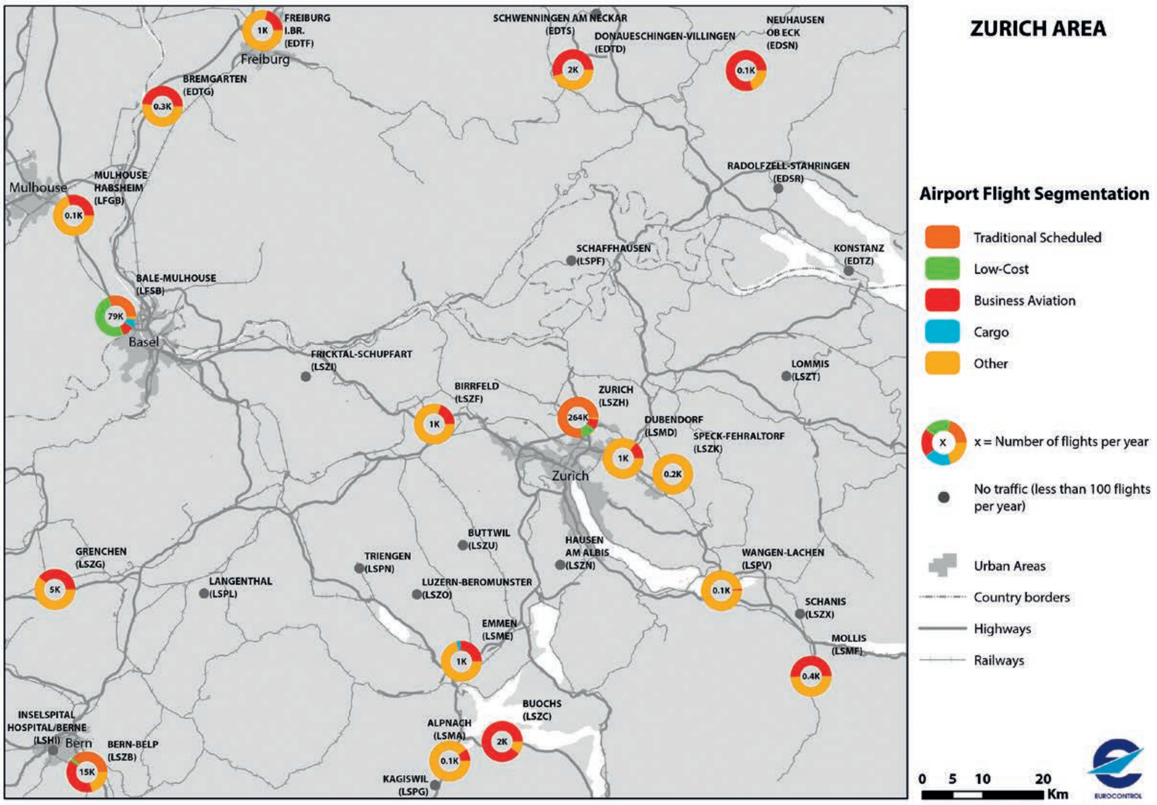


Figure 38 / *Airports around Zurich (alternatives to LSZH)*

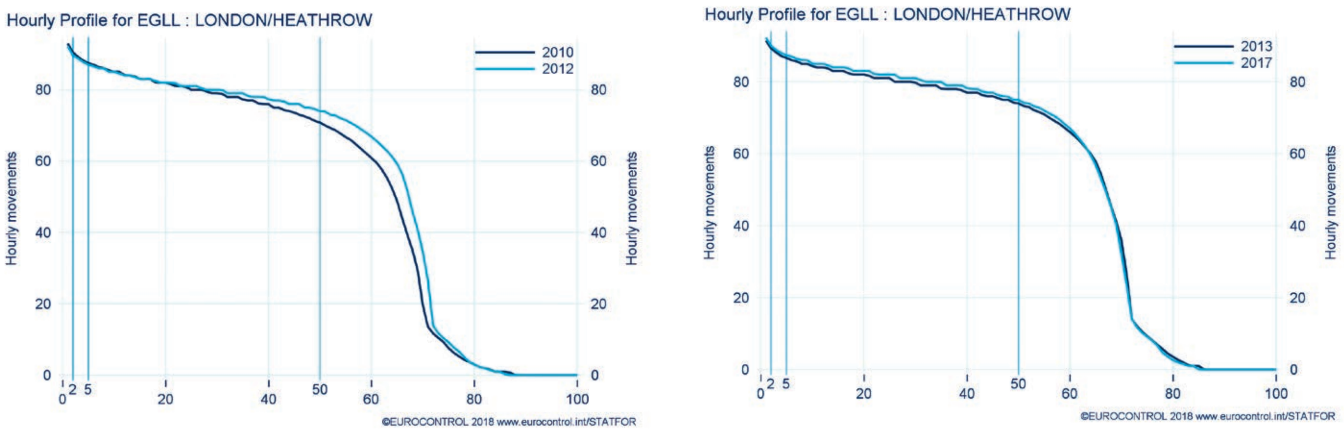
ANNEX B

CONVERTING BETWEEN HOUR AND ANNUAL CAPACITIES

One of the mitigation methods involves converting between hourly and annual capacities for some airports. This annex explains the method used for this.

In the Section about Schedule Smoothing, we showed an annual view of the hourly demand at Heathrow that grouped the hours into 100 percentiles (each containing around 86 hours) and ordered them from the most busy (percentile 1) to least busy (percentile 100). The graph is repeated in Figure 39.

Figure 39 / *An annual view of 'Schedule Smoothing' at Heathrow.*



Defining the "maximum hourly throughput" to be the average of the percentile group 2 (that is hours ranked between 88th and 176th busiest in the year), we now express each percentile as a fraction of these busy hours to normalize the airport hourly throughput and represent each airport within a same scale. Percentile 1 is close to 100% of the maximum hourly throughput: this is shown by a value close to 100 'Hourly movements' on the Y-Axis of Figure 39. The rest of the percentiles 'Hourly movements' stand below 100. For six busy airports, the results are shown in Figure 40 for 2012 and 2017.

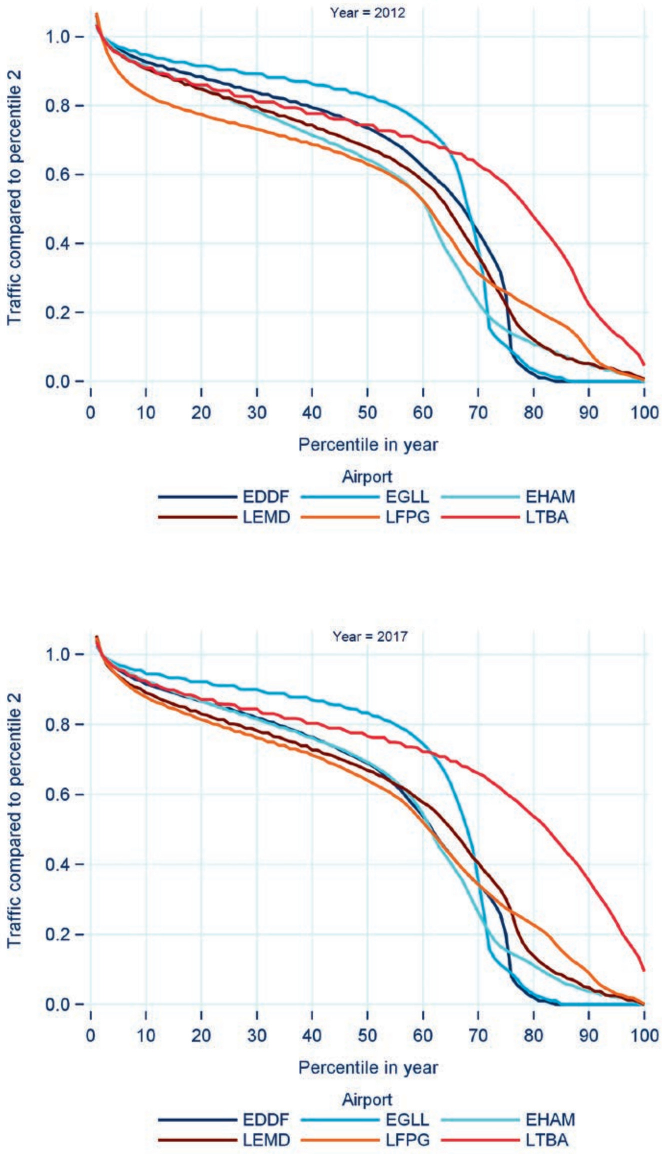
It is the area underneath the curves shown in Figure 40 that provides a conversion factor between hourly and annual capacity. If an airport operated 24/7 at the hourly throughput given by the maximum hourly throughput, Figure 24 would show a rectangle with area 1, filling the graph. In reality all the areas are less than 1. Figure 20 in the Schedule Smoothing Section shows the busy hour values and areas for 30 busy airports in 2017.

The conversion formula is yearly_capacity = hourly_capacity * area * 8,760 since there are 8,760 hours in a year (that is not a leap year).

For the 2017 data shown in Figure 41, the busy hour movements are actual traffic, not a capacity. So applying the formula gives the actual annual traffic, eg at EBBR 57.8*0.460*8,760=232,700 which was the annual traffic at Brussels (Ref. 14).

For the benchmarking by Heathrow referred to in the Schedule Smoothing Section, we use 2017 and choose to use the area between the 2nd percentile and 65th percentile as the reference that is applied to all chosen airports.

Figure 40/ *Traffic relative to busy hour (percentile 2)*



The process that defines the new capacity of each airport is then:

- The ratio between the area for Heathrow and the airport provides the potential increase in yearly capacity at the airport;
- This increase is capped at a 25%, if needed;
- Translate the new yearly capacity into an 'implied hourly capacity' and exclude the airport from the list of airports compatible with Schedule smoothing if it is greater than its declared maximum hourly capacity.

  Implied_Hourly_Capacity = Yearly_Capacity/ 8,760 is the hourly throughput that can be delivered constantly during 24/7 operations to reach the increased estimated yearly capacity.

Other airports can also be excluded:

- if an airport reported an external constraint such as an environmental cap;
- if an airport had already based its capacity estimate on 24/7 operation, so the 2017 profile was not a good starting point for modelling;

Figure 41/ *Hour-to-year conversion values for busy airports in 2017*

AIRPORT	BUSY HOUR MOVEMENTS	AREA UNDER THE CURVE
EBBR	57.8	0.460
EDDB	25.1	0.454
EDDF	100.5	0.540
EDDL	50.9	0.495
EDDM	89.3	0.514
EFHK	50.6	0.399
EGCC	49.3	0.471
EGKK	55.8	0.585
EGLL	90.0	0.604
EGSS	44.6	0.482
EHAM	106.2	0.546
EIDW	46.4	0.546
EKCH	57.5	0.515
ENGM	65.5	0.438
ESSA	62.8	0.452
GMMN	21.5	0.467
LEBL	69.7	0.530
LEMD	79.9	0.554
LEPA	64.2	0.371
LFPG	101.3	0.544
LFPO	53.3	0.497
LGAV	44.6	0.485
LIRF	67.8	0.501
LKPR	38.3	0.429
LOWW	57.5	0.476
LPPT	42.4	0.548
LSZH	60.4	0.498
LTAI	45.5	0.387
LTBA	73.5	0.702
LTFJ	43.3	0.564

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[3] *The 4-letter ICAO codes of airports can be found on ICAO Doc 7910*

ANNEX C

GLOSSARY

4-letter airport codes (e.g. EGLL)	See ICAO Doc 7910
ATM	Air Traffic Management
CARE	Co-operative Actions of R&D in EUROCONTROL
CG08, CG13, CG18	Challenges of Growth 2008, 2013, 2018, etc.
ECAC	European Civil Aviation Conference
ESRA	EUROCONTROL Statistical Reference Area
EU	European Union
HST	high-speed train
ICAO	International Civil Aviation Organisation
SES	Single European Sky
SESAR	Single European Sky ATM Research
STATFOR	Statistics and Forecast Service of EUROCONTROL
TMA	Terminal Manoeuvring Area
Unaccommodated demand	the forecast flights that exceed an airport's reported capacity.

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For further information please contact STATFOR, the EUROCONTROL Statistics and Forecast Service
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https://www.eurocontrol.int/statfor

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2. National boundaries depicted on the chart are only indicative and have no political significance.

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