DOI: 10.13009/EUCASS2019-846

Meeting Future European Aviation Societal and Market Needs

Raquel Martínez Arnáiz and Pablo Lázaro Galán
FerroNATS Air Traffic Services
Albasanz 14, 28037 Madrid (Spain), rmmartinez@ferrovial.com
Albasanz 14, 28037 Madrid (Spain), plazaro@ferrovial.com

Abstract

For decades, as the world has become more global, air traffic has experienced a sharp growth due to its privileged situation as a global industry. This growth is expected to continue increasing during the following years and, as air transport plays a key role within transport network, both current and future requirements of all agents involved must be accomplished. This paper addresses the evolution along the past decades, current context and future situation of air transport and how the requirements mentioned above could be fulfilled from the point of view of two main topics: accommodation of demand and overall travel time.

1. Introduction

Since the Airline Deregulation Act came into force in 1978 in the United States, and subsequently since similar measures were taken in Europe during the 90s, air traffic has experienced a sharp growth. Indeed, over the 20 years before the economic crisis, the number of IFR movements in Europe doubled from 5 million IFR movements in 1988 to 10 million in 2008. Providing that current IFR traffic in Europe is around 10 million IFR flights per year (10,6 million IFR flights in 2017), an increase by a factor of 2,5 is expected by 2050. Considering a homogeneous not restricted traffic grow, high density airports, surrounded TMAs and congested en route control centres will have to accommodate, respectively, about 3500, 7500 and 12500 daily movements.

This expected growth will lead the industry to face two big challenges: the accommodation of demand and reducing the overall time spent by the passengers. Regarding the first of them, it will be necessary to increase the capacity (including both airports and airspace capacity). Airports capacity are mainly set by their runways throughput which is directly related to the time needed to accommodate each flight safely. In this manner, the challenge to achieve a maximum throughput is to optimize final approach spacing in line with wake vortex, prevailing atmospheric conditions and radar separation requirements so that the spacing is close to minimum runway occupancy time. On the other hand, terminal area airspace (TMA) is the most restrictive airspace in terms of capacity. TMA is the managed airspace where a number of large and complex airports operate in close proximity to smaller, local airports and the operations within them are dynamic and heavily influenced by demand, regularly resulting in the need to delay aircraft in established vertical holding stacks and causing other delays in the air and on the ground. Finally, regarding the other big challenge, minimizing the overall time implies that all elements of the chain should perform nominally: no take-off queue, no holding pattern at landing, no major weather or ATM disruptions; efficient check-in, passport and security checks; fast luggage handling; efficient airport ground movements and operations; and uncongested local transport to and from home or work.

These two challenges are intimately related to 5 of all of the Flightpath 2050 Goals set by ACARE (Advisory Council for Aeronautics Research in Europe). For example, Goal 1 aims at achieving a system that is able to handle at least 25 million flights a year, including the integration of unmanned and autonomous systems, whilst Goal 2 aims at developing the ground infrastructure which include airports, vertiports and heliports. Rest of goals aim at improving the mobility between means of transport, the speed of operations and the punctuality.

Therefore it is important to identify how the aeronautical industry is facing these challenges nowadays and how it will face them in the future in order to set the guidelines needed to accomplish all the goals.

DOI: 10.13009/EUCASS2019-846

2. Accommodation of demand

2.1. Air traffic capacity

The Flightpath 2050 Goal 1 states: ***"An air traffic management system in place that provides a range of services to handle at least 25 million flights a year of all types of air vehicles, including unmanned and autonomous systems integrated into and interoperable with the overall air transport system with 24-hour operation of airports. European airspace is used flexibly to facilitate reduced environmental impact from aircraft operation".***

The present section addresses the main issue of air traffic capacity (25 million flights per year) and flexibility of operation including runway and airways terminal capacity, airport ground infrastructure and air traffic management.

The expected demand of 25 Million of flights will challenge three main elements in the transport system: a) the capacity of the runway system, b) the capacity of the TMA (Terminal Manoeuvring Area), c) the en route capacity. The accommodation of such a growth in flights will be determined by the most restrictive of these 3 capacity limits.

The European air traffic network contains some 170,000 links between airports. Over a network of more than 2100 airports, just 25 out of Europe's 2100 airports generate 44% of all flights. For all airports in Europe, 44% of all departures come from the 25 largest airports in Europe, two-thirds of departures from the top 75 and 90% of all traffic comes from the largest 250 airports (*Eurocontrol Trends in Air Traffic Volume 3*). There is a geographical concentration of airports in the region London-Amsterdam-Munich- Milan. This creates dense air traffic, with large numbers of climbing and descending aircraft: a significant challenge for Terminal Area and en route capacity.

Regarding airports, due to its condition, its operations depend upon a number of factors as well as on interactions between them which all affect runway capacity to some degree. Nevertheless, most often the main limit on airport capacity is the availability of runways. The simultaneous operation of runways is permitted if they are parallel (no crossing flights) and spaced more than 400 meters (the vortex wakes of aircraft operating from one runway do not affect operations from other runways). A standard separation of 90 seconds between flights would allow 40 movements (take-off or landings) per hour from a single runway. Careful planning can increase this figure up to 60 movements per hour per runway, depending on the safe separation between aircraft, which is the critical safety factor.

In addition to physical constraints, such as airport layout, there are "strategic" factors such as airport scheduling and "tactical" factors which include, inter alia, the sequencing of aircraft and the sustainability of throughput during specific weather conditions. The runway throughput is directly related to the time needed to accommodate each flight safely. The separation requirements in segregated mode depend on the most constraining of any one of the three parameters: (1) wake vortex separation, (2) radar separation, or (3) runway occupancy time. From the technological and operational perspectives of the runway operation, the challenge to achieve a maximum throughput is to optimize final approach spacing in line with wake vortex, prevailing atmospheric conditions and radar separation requirements so that the spacing is close to minimum runway occupancy time. The maximization of runway capacity would be achieved by "dynamic separation" (which sets the separation distance or time appropriate to the characteristics of each pair of aircraft and the prevailing atmospheric conditions), and state of the art in wake vortex, radar separation and runway occupancy time technology and procedures.

Once the maximum runway throughput has been achieved, the only way to increase capacity at congested airports will be airport expansion through additional new runways and infrastructures. This affects basically to the social/human dimension of the target as the growth of airports is severally constrained by social restrictions. Besides the plans for airport expansions, by 2030 no fewer than 19 European airports will be operating at full capacity eight hours a day, every day of the year. This will mean 50 % of all flights affected by delays; a system more vulnerable to disruption due to airport congestion and less able to recover from crisis situations; and delays that will persist in the system for longer and will propagate more rapidly and widely.

Besides runway capacity, the other important factor to accommodate the expected traffic demand is to manage take-offs and landings with the minimum safe separation without: (a) having aircraft circling above in holding patterns; (b) queuing on the ground to reach a runway position. The maximum use of available runway capacity requires four-dimensional space-time navigation, so that successive aircraft land and take-off at precise times with the minimum safe separation. This requires not only efficient management of ground movements but mainly efficient air traffic management in the terminal area around airports that is the most congested. The issues to be resolved include: (i) the organization of incoming flights into a landing sequence with optimal separations; (ii) the management of the take-off sequence without waiting or idle times on the ground; (iii) the merging of the take-off (ii) and landing (i) sequences without holding patterns in the air; (iv) the compatibility of terminal area traffic (take-offs and landings) with another airways traffic. These items (i) to (iv) are among the most important aspects of Air Traffic Management (ATM) often with greatest impact on capacity.

Accordingly, the terminal area airspace (TMA) is the managed airspace environment created to assist in achieving safety and efficiency where a number of larger, more complex airports and smaller, local airports operate in close proximity. It is characterised by high numbers of aircraft conducting climbing and descending manoeuvres in a relatively small volume of airspace. Operations within TMA airspace are dynamic and heavily influenced by demand, regularly resulting in the need to delay aircraft in established vertical holding stacks and causing other delays in the air and on the ground. Biggest TMAs in Europe are today complex and saturated scenarios where the traffic of the busiest airports in Europe is integrated with the traffic of other airports in their neighbourhood. Example of high-density TMA in Europe are Paris, London and Frankfurt.

The Paris TMA includes two major airports, i.e. Paris Charles De Gaulle or Roissy (LFPG) and Paris Orly (LFPO), some secondary airports, e.g. Le Bourget (LFPB), Pontoise (LFPT), Beauvais (LFOB) and many other general aviation aerodromes like Toussus-Le-Noble (LFPN) and Lognes (LFPL). Within the TMA, major and segregated arrival and departure flows converge and leave from the two main Paris airports, i.e. Paris CDG and Paris Orly. The two airports are close to each other (slightly less than 20 NM). Further, the vicinity of Le Bourget induces additional traffic complexity within Paris CDG approach. Considering the average daily movements at both airports (roughly 1300 at LFPG and 650 at LFPO) this TMA has to attend more than 2000 movement daily on average. The London TMA includes two major airports, i.e. Heathrow (EGLL) with 1300 movements per day and Gatwick (EGKK) with 800 movements per day, which are close to each other (slightly more than 20 NM). There are also some secondary airports (i.e. Stansted with 245 movements per day, Luton with 180 movements per day, London City), which are in expansion as low-cost airlines operate from these secondary airports. In all the TMA has to manage more than 2500 movement per day.

Regarding the en route airspace capacity, the highest concentration of en route traffic takes places In Europe in the “core area” comprising of the Benelux States, Northeast France, Germany, and Switzerland is the densest and most complex airspace. At this zone the density of fights is higher than 5 aircraft per hour and square kilometer.

Benchmarks to be achieved in en route and terminal area will require technological, operational and also social/human improvements currently under design for the future ATM system. Key to the Future ATM concept is the business trajectory principle in which the users of the airspace and controllers define together, through a collaborative process, the optimal flight path. Taking full advantage of both existing and newly developed technologies — such as Galileo — Future ATM target concept relies on a number of new key features at 3 different dimensions:

Technological and operational dimension:

- Trajectory management, reducing the constraints of airspace organization to a minimum;
- New aircraft separation modes, allowing increased safety, capacity and efficiency;
- System-wide information management, securely connecting all the ATM stakeholders which will share the same data;

Social/human dimension:

- Humans as the central decision-makers: controllers and pilots will be assisted by new automated functions to ease their workload and handle complex decision-making processes.

Network operation dimension:

- The network operation plan, a dynamic rolling plan for continuous operations that ensures a common view of the network situation;
- Full integration of airport operations as part of ATM and the planning process.

In this manner, Goal 1 about 25 million flights by 2050 needs to be accommodated by each of the Air Transport systems components: Airport runway system, Terminal Management Area airspace and en route Airspace.

Regarding the first subject, during the past years, it has been identified a growing gap between capacity and demand at a number of busy EU hubs. Congestion at these airports will remain a concern. Traffic will continue to grow in the future, as it has done over the past 50 years despite periods of economic downturn and other disruptions. Although air traffic in Europe will grow more slowly than in emerging economies, it will nevertheless nearly double by 2030 and more than double in 2050.

However, Europe will not be in position to meet a large part of this demand due to a shortage of airport capacity. A percentage of this demand will not be accommodated because of capacity shortfalls. In concrete terms, by 2030 no fewer than 19 European airports will be operating at full capacity eight hours a day, every day of the year. This will have a major impact on the entire aviation network since by 2030 congestion at these airports will mean 50% of all flights affected by delays upon departure or arrival, or both.

Therefore, due to the necessity of increasing the capacity in order to accommodate the future demand, Eurocontrol proposes a number of measures to mitigate the capacity challenges to reduce the levels of unaccommodated demand, aiming at increasing capacity at airports and also at improving operations in the airspace:

- <u>Alternative airports:</u>

Shifting to alternative airports is considered as a real option for some airline and airport operators provided that potential issues of environmental acceptance and terminal airspace congestion can both be overcome. The measure is efficient in that it would reduce unaccommodated demand by around 30%, provided passengers and carriers are willing to relocate to such airports, which in turn is linked to the quality of the ground transportation links. This mitigation measure is also much related with the goal 2, since it will be necessary an efficient mobility between airports.

- <u>SESAR improvements:</u>

The SESAR programme to increase system capacity by developing and implementing new technologies, approaches, and procedures is perceived as the strongest enabler for sustaining future long-term demand. SESAR plus investments to bring airports to the performance level of the best-in-class has the potential to increase airport capacity by a significant margin, reducing unaccommodated demand by 40%.

- <u>Reducing runway occupancy time</u>

A key indicator for runway capacity is Runway Occupancy Time (ROT).

During the arrival of an aircraft, ROT is defined as the time interval between the aircraft crossing the threshold of the runway and the tail of the aircraft leaving the runway. Runway capacity is often limited by ROT because only one aircraft can use the runway at any given time. The leading aircraft must first vacate the runway before the trailing aircraft is allowed to cross the threshold.

ROT can be reduced through the use of high-speed exits. These exits are not perpendicular to the runway, but instead use a smaller angle allowing aircraft to vacate sooner and at higher speeds, reducing ROT.

In addition, the SESAR project will investigate the use of satellite navigation and augmentation capabilities, such as GBAS and satellite-based augmentation systems (SBAS), to enhance landing performance and to facilitate advanced arrival procedures (e.g. curved approaches, glide slope increase, displaced runway threshold). By doing so, noise is reduced while runway occupancy time (ROT) is optimised. The aim is to also reduce the need for separation for wake vortex avoidance.

- <u>Time-based separation</u>

When there are strong headwinds, aircraft ground speed is reduced on final approach. This results in a reduced landing rate, causing delays and even flight cancellations.

The concept of time spacing is based on the performance of an aircraft in strong headwinds conditions, where wake vortex is quickly dispersed, permitting then to reduce the distance between aircraft, while maintaining safety levels. Consequently, airports can operate with the same landing and capacity rates as in light wind conditions.

TBS aims at reducing the gap in landing rates in light and strong headwind conditions. It will help maintain airport capacity at the same level in all wind conditions.

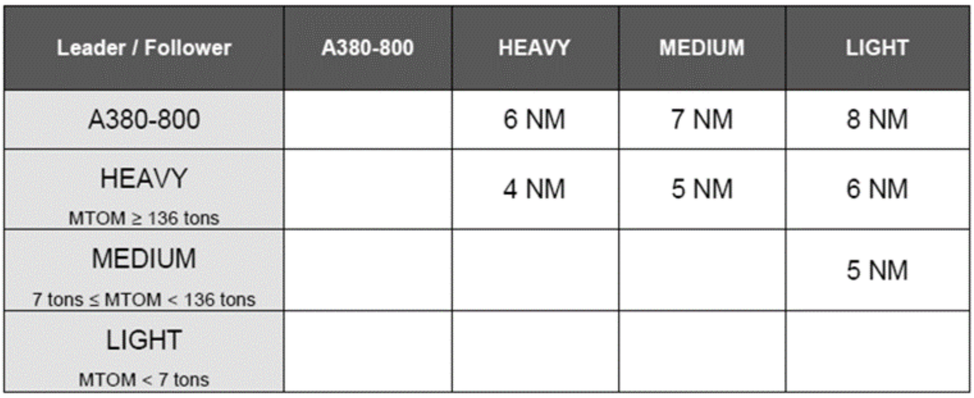
TBS brings numerous benefits for airports, airlines and passengers, including:

- Increase of resilience of runway throughput and efficiency, due to space reduction between aircraft in strong headwind conditions while maintaining the same safety levels;
- a reduction in delays, cancellations and consequent operating costs
- shorter overall flight times
- advanced information for controllers, as TBS needs wind profile measurement in the final approach area and this information can be used by the controllers.

- <u>Re-categorization of wake turbulence categories</u>

Runway capacity and efficiency use is often directly linked with the minimum separation between aircraft. These minima are constrained by ATS surveillance capabilities and wake turbulence.

During recent years, knowledge about wake vortex behaviour in the operational environment has increased thanks to recorded data and improved understanding of physical processes. It is mainly for this reason that it was possible to revise wake turbulence categorisation and corresponding separation minima to enable optimisation of airport capacity and efficiency whilst maintaining acceptable levels of safety. A safe separation minimum implies to consider wake vortex generated by an aircraft but also the wake encounter impact and resistance of the following aircraft on departure or final approach. Existing ICAO wake vortex separation rules (Figure 1) were implemented over 40 years ago and they have become outdated. These separations are based on certificated Maximum Take-off Mass (MTOM) and it includes three categories (HEAVY, MEDIUM or LIGHT) allocating all aircraft into one of them. Because the separations are defined based on the worst case in each category, this leads to over separation in many instances.



Leader / Follower	A380-800	HEAVY	MEDIUM	LIGHT
A380-800		6 NM	7 NM	8 NM
HEAVY MTOM ≥ 136 tons		4 NM	5 NM	6 NM
MEDIUM 7 tons ≤ MTOM < 136 tons				5 NM
LIGHT MTOM < 7 tons				

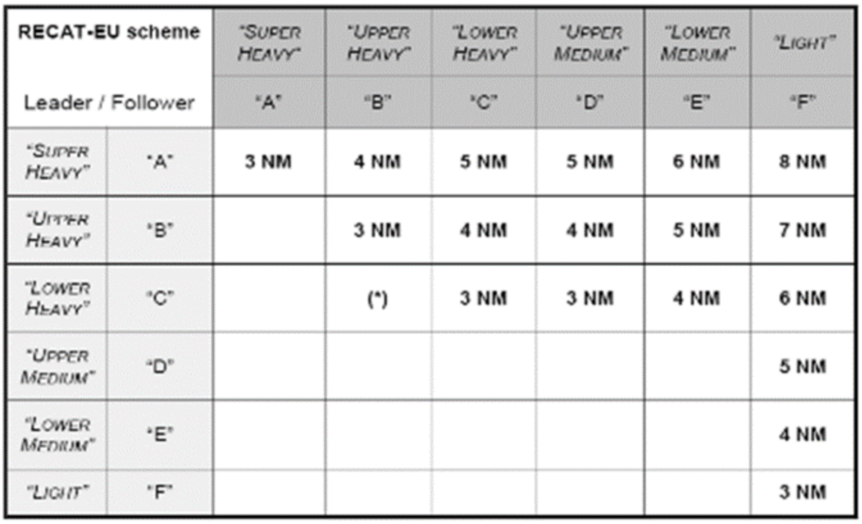
Figure 1: ICAO wake turbulence categories and separation minima

This means that each category may cover a wide range of different sized aircraft that leads to over-conservative separations in many cases, and so a loss of runway throughput.

As a result, EUROCONTROL has developed a re-categorisation of ICAO wake turbulence scheme and associated longitudinal separation minima on approach and departure, called “RECAT-EU”, to the benefits of Airports and ATM Network Performance enhancement.

European Wake Vortex Re-categorisation (RECAT-EU) is a new, much more precise categorisation of aircraft than the traditional ICAO one. It aims at safely increasing airport capacity by redefining wake turbulence categories and their associated separation minima. It divides the current Heavy and Medium categories into two sub-categories and creates a new Super Heavy one for the Airbus A380.

The separations minima applicable between the RECAT-EU wake turbulence categories are provided in the following Figure 2:



RECAT-EU scheme		"SUPER HEAVY"	"UPPER HEAVY"	"LOWER HEAVY"	"UPPER MEDIUM"	"LOWER MEDIUM"	"LIGHT"
Leader / Follower		"A"	"B"	"C"	"D"	"E"	"F"
"SUPER HEAVY"	"A"	3 NM	4 NM	5 NM	5 NM	6 NM	8 NM
"UPPER HEAVY"	"B"		3 NM	4 NM	4 NM	5 NM	7 NM
"LOWER HEAVY"	"C"		(*)	3 NM	3 NM	4 NM	6 NM
"UPPER MEDIUM"	"D"						5 NM
"LOWER MEDIUM"	"E"						4 NM
"LIGHT"	"F"						3 NM

Figure 2: RECAT-EU WT distance-based separation minima on approach and departure

Thanks to this new categorisation, several benefits are expected:

- The runway throughput benefits can reach 5% or more during peak periods depending on individual airport traffic mix
- For an equivalent throughput, RECAT-EU also allows a reduction of the overall flight time for an arrival or departure sequence of traffic, and this is beneficial to the whole traffic sequence.
- RECAT-EU will also enable more rapid recovery from adverse conditions, helping to reduce the overall delay and will also enable improvements in ATFM slot compliance through the flexibility afforded by reduced departure separations.

In this context, it is widely recognized that to increase performance, ATM modernization should look at the flights within a flow and network context rather than segmented portions of its trajectory as is the case today. Upcoming research and developments must be previously studied in order to make a wide research framework in which each project has both enough funds and duration to achieve its goals. The fact of trying that this wide framework is defined under previous studies will allow to close the gaps remaining between the goals set for 2050 and the actual improvements reached in 30 years.

2.2. Ground infrastructure

The Flightpath 2050 Goal 2 states: ***“A coherent ground infrastructure is developed including: airports, vertiports, heliports with the relevant servicing and connecting facilities, also to other modes”.***

As new airports to serve major cities tend to be built further requiring faster transport to reduce access time, vertiports and heliports could be a solution as they could be sited much closer to city centres, providing an alternative with faster access than airports, if noise and community issues can be resolved.

Every day, millions of hours are wasted on the road worldwide. On-demand aviation, has the potential to radically improve urban mobility, giving people back time lost in their daily commutes. A network of small, traditional or electric aircraft that take off and land vertically (called VTOL aircraft for Vertical Take-off and Landing, and pronounced vee-tol), will enable rapid, reliable transportation between suburbs and cities and, ultimately, within cities.

The development of infrastructure to support an urban VTOL network will likely have significant cost advantages over heavy-infrastructure approaches such as roads, rail, bridges and tunnels. It has been proposed that the repurposed tops of parking garages, existing helipads, and even unused land surrounding highway interchanges could form the basis of

DOI: 10.13009/EUCASS2019-846

an extensive, distributed network of “vertiports” (VTOL hubs with multiple take-off and landing pads, as well as charging infrastructure) or single-aircraft “vertistops” (a single VTOL pad with minimal infrastructure).

Over the past two years NASA has studied the idea of VTOL air-taxis operating in dense urban areas (UBER, 2016). Specifically, they chose San Francisco as one metropolitan area to provide detailed geographic, land use, infrastructure, weather, and operational constraint considerations to bring real world issues into their study.

A VTOL fleet will likely be supported in a city through a mixture of both vertiports and vertistops. Vertiports would be large multi-landing locations that have support facilities (i.e., rechargers, support personnel, etc.) for multiple VTOLs and passengers. Following the heliport examples used in New York City and other locations, vertiports would be limited to a maximum capacity of around 12 VTOLs at any given time to achieve a compact infrastructure size while enabling capacity for multiple simultaneous VTOL take-off and landings to maximize trip throughput. Vertistops, on the other hand, would be single vehicle landing locations where no support facilities are provided, but where VTOLs can quickly drop off and pick up passengers without parking for an extended time. An example of a vertistop includes small helipads that are atop high-rise downtown buildings today.

3. Reducing overall travel time

3.1. Multimodal Transport

The Flightpath 2050 Goal 3 states: ***“European citizens are able to make informed mobility choices and have affordable access to one another, taking into account: economy, speed and level of service (that can be tailored to the individual customer). Continuous, secure and high-bandwidth communications are provided for added value applications”.***

The progress in mobile communications and availability of information may ensure that the passenger can make informed choices among several available travel options. A more serious constraint may come from physical limits of transportation infrastructure and the underlying issue of land planning: (i) in the expansion of existing airports or addition of more runways; (ii) in the construction of new airports, vertiports and heliports; (iii) in the road/rail infrastructure that provides fast access; (iv) in the efficient organization of ground movements within the confines of the airport.

The choice of air travel compared with other means of transport depends not only on flight time but also on the ground movements to and from the airport that is an issue addressed in this section.

A coherent ground infrastructure implies the design and implementation of an integrated, intermodal transport system as part of which airport evolve into integrated, efficient and sustainable air transport interface nodes. Airport access has been improved accordingly trough an innovative approach towards safe, efficient, frequent, comfortable transport systems and services and connections with other modes of transport must facilitate an easy and quick access to the plain.

According to Eurocontrol the average flight length of 80% of the flights within Europe is 504NM while the average flight length of the flight outside the regions (20%) is 878NM. That means that the average flight time of 80% of the flights in Europe does not exceed an hour. This will leave a maximum of 3 hours for the passenger to arrive from its departing point to the plane and to get from the plane to its final destination, including the processing times at the airport and all the connections with other modes of transport.

Technological and operational dimensions will be of high relevance to achieve the average 3 hours target time of connection and processing time. However, the social dimension of such integration will become very relevant as the main impact of an airport on the surrounding community comes not only from aircraft operations but also from ground infrastructure required to access to the airport and to connect the airport with other modes of transport.

In this context, the airport of the future is conceived as the central link of intermodal transport. Inter-modality is understood as the transport of goods and passengers using several transport modes in one trip and involves the inter-coordination of those different transport modes. This coordination is made thanks adequate intermodal infrastructure, and to intermodal agreements concluded by transport operators. Agreements allow for common reservation for the whole trip, coordinated timetables, a common checking, and the certainty to travel to the final destination despite delays faced by one or several transport modes during the trip, etc. These agreements aims at satisfying the customer´s needs and assuring a positive and seamless travel experience is central to the success of intermodal passenger transport.

Regarding the airports accessibility, all of the airports serving commercial air transport during the first decade of XXI century could be accessed by car. 97%, 525 airports out of 543 were being served by taxi. 70%, 379 airports were served by regular bus services. Only 10%, 56 airports were served by local rail and light rail/tram to nearby cities or regions. At that moment there were a few high-speed rail lines (HST) in Europe, focused on massive volumes of passengers and connections between major cities.

The interconnectivity at European airports is often still limited to urban transport, with very few (high-speed) train stations located at airports. Some of the existing intermodal links do not fully meet the passengers’ expectations, leading to low usage. As an example, in the UK train stations at regional airports have been closed due to the small number of passengers that made use of the facility.

Air/rail intermodality seems to offer promising opportunities for the future of the transport system by limiting the isolated use of road or air traffic (both responsible for congestion and air pollution) and providing combined trips, generally with rail. However, so far intermodal agreements are not very numerous in Europe. Funding and the possibility of signing exclusive agreements between airlines and other means of transport are essential enablers to foster intermodality. This multimodal transport may include high-speed trains for the national or international network, trains, subways, tramways or suburban trains at regional airports, electric ground vehicles, environmentally friendly ships or even air-buses.

One of the most important challenges will be achieving public confidence in automation, although this will demand significant advances in technology. Automation will mean that users are informed about the current status of their journey and alternative options, periodically or on demand. Information points will be distributed around the terminals and interactive devices embedded in transport systems so that passengers can access travel information at any time using smart phones or interactive panels/screens situated along the intermodal transport network.

Furthermore, a main goal for the future intermodal transport system is to reduce dependence on the automobile as the major mode of ground transportation and increase use of public transport, especially in the case of the future air transport system.

Breakthrough technologies should be taken into account as well. On-demand aviation, has the potential to radically improve urban mobility, giving people back time lost in their daily commutes. For all these reasons, it tries to introduce new technologies in order to get the best option to go from home to the airport. Urban air transportation will use three-dimensional airspace to alleviate transportation congestion on the ground.

A possibility is the use of VTOL (Vertical Take-off and Landing) aircraft and electric aircraft that take off and land vertically. They will enable rapid, reliable transportation between suburbs and cities and, ultimately, within cities.

Several companies, with different design approaches, are working to make electric VTOL aircraft a reality. The closest equivalent technology in use today is the helicopter that has longer ranges, is more polluting and may have higher costs.

The VTOL aircraft that uses electric propulsion has zero local operational emissions and will likely be quiet enough to operate in cities without disturbing the neighbours. It is claimed that at flying altitude, noise from advanced electric vehicles will be barely audible. In fact, rotor noise is a common feature. Even during take-off and landing, the noise will be comparable to existing background noise. These VTOL designs are also claimed safer than today’s helicopters because VTOLs will not need to be dependent on any single part to stay airborne and will ultimately use autonomy technology to significantly reduce operator error.

The development of infrastructure to support an urban VTOL network will likely have significant cost advantages over heavy-infrastructure approaches such as roads, rail, bridges and tunnels. Indeed, it has been proposed that the repurposed tops of parking garages, existing helipads, and even unused land surrounding highway interchanges could form the basis of an extensive, distributed network of vertiports (VTOL hubs with multiple take-off and landing pads, as well as charging infrastructure) or single-aircraft vertistops (a single VTOL pad with minimal infrastructure). As costs for traditional infrastructure options continue to increase, the lower cost and increased flexibility provided by these new approaches may provide compelling options for cities and states around the world.

Furthermore, VTOLs do not need to follow fixed routes. Trains, buses, and cars all funnel people from A to B along a limited number of dedicated routes, exposing travelers to serious delays in the event of a single interruption. VTOLs, by contrast, can travel toward their destination independently of any specific path, making route-based congestion less prevalent.

The economics of manufacturing VTOLs will become more similar to automobiles than aircraft. At first, VTOL vehicles are likely to be very expensive, but because the ridesharing model amortizes the vehicle cost efficiently over paid trips, the high cost should not end up being prohibitive to getting started.

And once the ridesharing service commences (air taxi), a positive feedback loop should ensure that ultimately reduces costs and the prices for all users. As the total number of users increases, the utilization of the aircraft increases as well. Logically, this continues with the pooling of trips to achieve higher load factors, and the lower price feeds back to drive more demand. This increases the volume of aircraft required, which in turn drives manufacturing costs down.

There is a burgeoning VTOL aircraft ecosystem, and a number of companies that are already developing and flying early vehicle prototypes, such as Zee, Aero, Joby Aviation, Airbus or Lilium. If we try to guess when these VTOL aircraft could get us from one point to other it may occur within the next ten years. For example, Lilium flew its prototype for the very first time back in 2017 and their first fully functional jet is scheduled to take off during this year in order to meet their initial prevision of being fully operative by 2025.

The VTOLs envisioned as serving within a ridesharing network (“air taxis”) will need to address four primary barriers to commercial feasibility: safety, noise, emissions, and vehicle performance. The two most important technologies to overcome these challenges are Distributed Electric Propulsion (DEP) and autonomous operation technologies.

DOI: 10.13009/EUCASS2019-846

Indeed, VTOL operations will involve the ability to take off with a rapid climb at a steep glide path angle to reach a cruising altitude up to a few thousand feet, then decelerate to land vertically at the end of the trip. There will likely be a limited need to hover for durations not exceeding one minute, with most vertical take-off and landing transitions taking place in approximately 30 seconds.

Additionally, one of the most important point to keep in mind is safety. Therefore, concerning the regulations applicable to this project, all aspects related to the safety of operations must be considered. To understand the path to improving safety for urban air transportation, it is necessary to understand the root causes of historical crashes. The main causes of air accidents are due to pilot error described, controlled flight into terrain, mid-air collisions, and loss of control. The VTOL safety is also improving with new creative ideas such as whole vehicle parachutes that can be deployed in an emergency to safely bring the vehicle to the ground. In addition to what has been mentioned above, EASA aims at establishing a complete set of dedicated technical specifications in the form of a special condition for VTOL aircraft which addresses the unique characteristics of these products and prescribes airworthiness standards for the issuance of the type certificate. This is due to the Agency considers that the current airworthiness standards for airplanes or rotorcraft are not adequate to prescribe the standard means to demonstrate compliance of such products with the essential requirements of the Basic Regulation.

3.2. Overall Ground Plus Air Travel Time

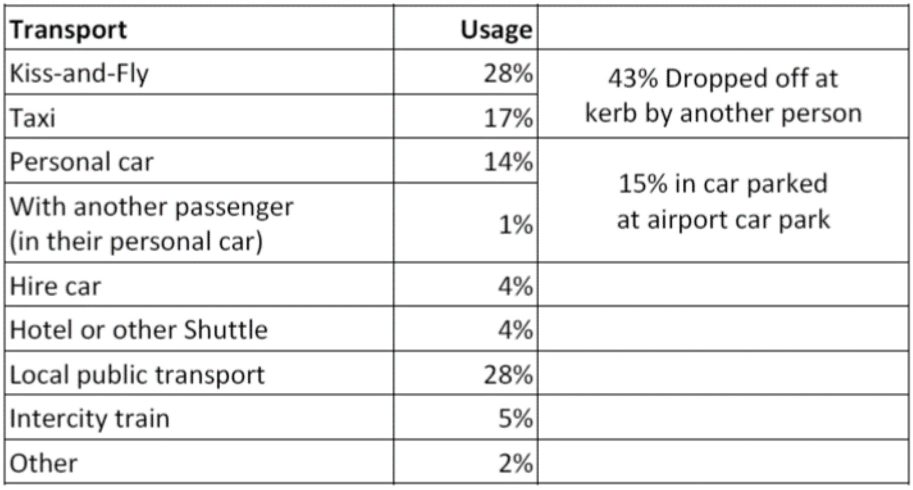
The Flightpath 2050 Goal 4 states: "***90% of passengers within Europe are able to complete their journey, door to door within 4 hours. Passenger and freight are able to transfer seamlessly between transport modes to reach the final destination smoothly, predictably and on time".***

Air travel times can vary significantly in Europe, from 1 hour in central Europe (Paris-Frankfurt) to 4 hours between extremities of the continent (Lisbon-Bucharest). Assuming that most flights do not exceed 2 hours, leaves within the four-hour total time frame, 1 hour to travel to and from the airport and go through airport services. This objective is achievable if all elements of the chain perform nominally: (i) no take-off queue, no holding pattern at landing, no major weather or ATM disruptions; (ii) efficient check-in, passport and security checks; (iii) fast luggage handling; (iv) efficient airport ground movements and operations; (v) uncongested local transport to and from home or work.

In order to assess the efficiency of the air transport system, and more particularly once considering the door-to-door time, it is also important to know, how far these airports are located from the European city centres. According to data from European Personal Air Transportation System STUDY (EPATS), it is clear that for almost 80% of the European cities the nearest airport is situated at 20 km. Such a short distance reflects that the general accessibility of the European airports is high.

In the case of the 30 largest airports in Europe, passengers have a choice between different public transport service providers for access between the centres of the respective cities and the airports. Currently, 23 out of the 30 largest airports in the European Economic Area (including Switzerland) have a direct rail access at or in the vicinity of the passenger terminal. A number of rail access projects are currently being planned or under construction.

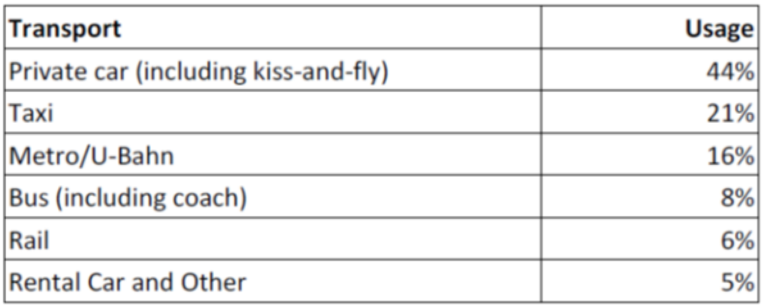
The French DGAC has studied surface access in their 2014-2015 airport passenger survey (DGAC, 2015), covering 15 airports. Unfortunately, these data have been aggregated over all 15 airports. The result of 33,655 responses by non-transfer passengers to the question of how people arrived at the airport is given below:



Transport	**Usage**	
Kiss-and-Fly	28%	43% Dropped off at kerb by another person
Taxi	17%	
Personal car	14%	15% in car parked at airport car park
With another passenger (in their personal car)	1%	
Hire car	4%	
Hotel or other Shuttle	4%	
Local public transport	28%	
Intercity train	5%	
Other	2%	

Figure 3: French airport surface access modes

The German Airports Group (ADV) also performs passenger surveys. The latest "Airport Travel Survey 2015" (ADV, 2015) includes summary data on the modes of transport used by (all) passengers to access one of the 22 airports in the study:



Transport	**Usage**
Private car (including kiss-and-fly)	44%
Taxi	21%
Metro/U-Bahn	16%
Bus (including coach)	8%
Rail	6%
Rental Car and Other	5%

Figure 4: Surface access mode share for 22 German airports

According to DLR report regarding the Flightpath 2050 goal 4 the following elements are needed for the assessment of the current state:

- European origin-destination passenger demand data matrix;
- Flight schedules;
- Train schedules (limited to air/rail code sharing);
- Ground access/egress times between NUTS regions and airports;
- Assumptions on process times (MCT, time from airport arrival to flight departure/flight arrival until exit from airport).

The minimum travel time between regions consists of the following elements:

- travel time from the point of origin to the departure airport
- the process time required from the arrival of the passenger at the departure airport to the scheduled time of departure (at)
- the flight time from the departure to the arrival airport– in case of a connecting flight, this element also contains the flight time of the first flight segment, the transfer time at the hub and the flight time of the second flight segment
- the process time required from the scheduled arrival time at the arrival airport to the point in time when the passenger leaves the arrival airport (at);
- travel time from the arrival airport to the destination point.

Using scenarios to test the desired Flightpath2050 4-hour-goal the report concludes by using data from “ETISplus“: Modelled origin-destination trip demand from EU project ETISplus and “Population product“: Theoretical situation, in which each EU citizen visits each other EU citizen that already today 91.7% of travellers can complete their journeys within 4 hours (with 60 min MCT in air transport). Only 13.1% of trips would be completed within 4 hours if every EU citizen would try to reach each other EU citizen.

The 91.7% value is due to the fact that most trips are over short distances, which can be completed within 4 hours with car/rail modes. But, if a theoretical situation in which every EU citizen should have the opportunity to visit every other EU is aspired, the goal has been achieved only to 13% (60minute MCT) or 22% (45min MCT).

The conclusion of the DLR report is that a re-phrase of the Flightpath 2050 goal is required. The proposed version states that “90% of travellers within Europe are able to complete their long-distance journey of over 200km (or 250km or 300km...), door to door, within 4 hours”.

Summarizing, what can be deduced from this paper is that regardless the progress achieved up to now in any area described above, it may be necessary that stakeholders, including authorities and companies, redesign the strategies to be followed to be in a better position to accommodate the future demand and furthermore to reduce the overall travel time spent by the passengers.

On the one hand, future demand should be accommodated within a framework in which performance-based operations are completely implemented and therefore it allow aircraft to fly the most efficient route and profile, assuring improvements in capacity. Besides, automation and advanced navigation technologies should be introduced to allow to improve accuracy, quality of the service and the system capacity. Another important matter is the necessity to address the challenges of En route capacity at the same level than the challenges on Terminal Area as well as developing airspace integration requirements for enabling safe, efficient low-altitude operations through a new airspace design, dynamic geofencing, congestion management and terrain avoidance for a UAS Traffic Management (UTM) system.

On the other hand, airports are usually located far from the city centre, resulting in long airport access times for passengers combined with buffer times for uncertainties of durations for airport processes like security checks or even unpredictability of airport access times. Therefore, key enablers to reduce overall travel times are a reduction in airport

DOI: 10.13009/EUCASS2019-846

access times, a higher predictability of times accessing the airport and process times inside the terminal. Related to that, the interconnectivity at European airports is often still limited to urban transport, with very few (high-speed) train stations located at airports. Some of the existing intermodal links do not fully meet the passengers' expectations, leading to low usage. However, air/rail intermodality seems to offer promising opportunities for the future of the transport system by limiting the isolated use of road or air traffic (both responsible for congestion and air pollution) and providing combined trips, generally with rail. In short, main challenges to overcome in order to achieve the desired framework for intermodality relate to standardisation and funding, but also to remote check-in and luggage handling and better scheduling and decreasing delays.

References

[1] DATASET2050 -Data driven approach for a Seamless Efficient European Travelling in 2050, December 2014-December 2017, Grant Agreement no: 640353, https://cordis.europa.eu/result/rcn/190323_en.html

[2] 2007, Eurocontrol trends in air traffic, volume 3-A place to stand: airports in the European air network. Eurocontrol, Brussels.

[3] 2016, Eurocontrol ANS performance monitoring, <http://www.eurocontrol.int/prudata/dashboard/rp2_2016.html>.

[4] A. Baron, M. Mączka, K. Piwek, 2010, Transactions of the Institute of Aviation, The Challenge of mobility in Europe, Scientific Quarterly 3.

[5] Abbott K & Thompson D,1990, Deregulating European aviation: the impact of bilateral liberalisation, International Journal of Industrial Organisation 9: 125–140 and Barrett S (1989) Deregulating European aviation: a case study. Transportation 16: 311–327.

[6] AFRA Best Management Practice, 2016. *Best Management Practice for Management of Used Aircraft Parts and Assemblies and for Recycling of Aircraft Materials*. Aircraft Fleet Recycling Association, Version 3.2 (March 8, 2016).

[7] Airport Collaborative Decision Making, 2010, Eurocontrol, Brussels.

[8] Aruba, Aruba Airport, KLM, VISION-BOX and Schiphol Group, 2017, *Aruba Happy Flow*, viewed 27 November 2017, <www.arubahappyflow.com>.

[9] ASSET (Aeronautical Study on Seamless Transport), 2011, *Final Report*.

[10] ATAG, 2016, Aviation benefits beyond borders, viewed on January 2018 https://aviationbenefits.org/downloads/

[11] BEUMER Group, Assessing the impact of ECAC3 on baggage handling systems, viewed 18 December 2017, <https://www.beumergroup.com/uploads/tx_bbbrochures/BEUMER_ECAC_Standard_3.pdf>.

[12] Boonstra J., Turkenburg J., de Wit J.C., 2016, Airport Capacity - Looking Beyond the Runway.

[13] Bowen, J. 2010, The Economic Geography of Air Transportation: Space, Time, and the Freedom of the Sky. Routledge, London, UK.

[14] Brasseur, G. P., M. Gupta, B. E. Anderson, S. Balasubramanian, S. Barrett, D. Duda, G. Fleming, P. M. Forster, J. Fuglestvedt, A. Gettelman, R. N. Halthore, S. D. Jacob, M. Z. Jacobson, A. Khodayari, K.-N. Liou, M. T. Lund, R. C. Miake-Lye, P. Minnis, S. Olsen, J. E. Penner, R. Prinn, U. Schumann, H. B. Selkirk, A. Sokolov, N. Unger, P. Wolfe, H.-W. Wong, D. W. Wuebbles, B. Yi, P. Yang, and C. Zhou, Impact of aviation on climate: FAA's Aviation Climate Change Research Initiative (ACCRI) Phase II, Bull. Amer. Met. Soc., 91, 461, doi: 10.1175/2009BAMS2850.1, 2015.

[15] Brueckner J.K., 2003, Airline Traffic and Urban Economic Development.

[16] Brusow W., Klepacki Z., Majka A., 2007, Airports and Facilities Data Base, EPATS technical report, Project no: ASA6-CT-2006-044549, Rzeszow, Poland.

[17] Burghouwt G., Boonekamp T., Volta N., Pagliari R., Mason K., 2017, The impact of airport capacity constraints on air fares, Final report, SEO Amsterdam Economics.

[18] CAEP/8-WP/10. 2010. Report of the Independent Experts to CAEP/8 on the second NOx review & long-term technology goals. London, 2009.

[19] CLEAN SKY, 2014, Clean Sky socio-economic study - powering a stronger Europehttp, viewed 6 january 2018, www.cleansky.eu/news/clean-sky-socio-economic-study-powering-a-stronger-europe

[20] CODA Digest: Delays at Ari Transports in Europe, 2010, Eurocontrol, Brussels.

[21] Collin D. 2016. Overview of overview of aviation noise research effort supported by the European Union // ICAO Environmental Report 2016, p 38-41.

[22] Comparison of Air Traffic Management-Related 2015 Operational Performance: U.S./Europe, 2016, Federal Aviation Administration, European Commission, Eurocontrol.

[23] CORE-JETFUEL Report Summary. http://cordis.europa.eu/result/rcn/192392_en.html.

[24] DATASET2050 - Data driven approach for a Seamless Efficient Travelling in 2050, 2016, Deliverable 4.1, "Current Supply Profile", DATASET2050 Horizon 2020, Grant Agreement no: 640353

[25] Detandt Y. *Aeroacoustics research in Europe: The CEAS-ASC report on 2014 highlights* // Journal of Sound and Vibration Volume 357, 24 November 2015, Pages 107-127.

[26] DLR, 2010, Airport Accessibility in Europe, Analyses of the European air transport market, Topical Report, contract TREN/05/MD/S07.74176.

[27] Dobrzynski W. M., Schoning B., Leung Choi Chow, Wood C. and C.Seror. 2005. Design and testing of low noise landing gears. AIAA 2005–3008, 11th Aeroacoustics Conference, Monterey, May 2005.

[28] Dodgson, J. S., 1994, Kluwer Academic Publishers, Competition policy and the liberalisation of European aviation, Transportation 21: 355-370.

[29] EASA, 2017, *Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes CS-25*, Amendment 19, Annex to ED Decision 2017/015/R.

[30] EC, 2008, Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003 87 EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community (OJ L 8, 13.01.2009, p. 3).

[31] EEA, 2014, Focusing on environmental pressures from long-distance transport — TERM 2014: transport indicators tracking progress towards environmental targets in Europe, EEA Report No 7/2014, European Environment Agency.

[32] EEA, 2014, Transport and Environment Reporting Mechanism 2014.

[33] Eighth USA/Europe Air Traffic Management Research and Development Seminar (ATM2009) Airport CDM Network Impact Assessment, Eduardo GOÑI MODREGO, Mihai-George IAGARU, Marc DALICHAMPT, Roger LANE EUROCONTROL Experimental Centre, Bretigny s/ Orge, France.

[34] Eurocontrol Statistics and forecasts (STATFOR), <http://www.eurocontrol.int/statfor>.

[35] EUROCONTROL, 2007, A Place to Stand: Airports in the European Air Network, Trends in Air Traffic, Volume 3, *European Organisation for the Safety of Air Navigation*, Brussels, Belgium.

[36] EUROCONTROL, 2009, Mitigating the Challenges for Air Transport 2030, *European Organisation for the Safety of Air Navigation*, Brussels, Belgium.

[37] EUROCONTROL, 2010, Planning for Delay: influence of flight scheduling on airline punctuality, EUROCONTROL Trends in Air Traffic, Volume, *European Organisation for the Safety of Air Navigation*, Brussels, Belgium.

[38] EUROCONTROL, 2013, Challenges of Growth 2013. Task 6: The Effect of Air Traffic Network Congestion in 2035, *European Organisation for the Safety of Air Navigation*, Brussels, Belgium.

[39] Eurocontrol, 2013, *Challenges of growth 2013-task 7: European Air traffic in 2050*. Eurocontrol, Brussels.

[40] EUROCONTROL, 2014, *Framework for the analysis of Operational ANS Performance at airports*, viewed 18 December 2017, <https://eurocontrol.int/sites/default/files/events/presentation/140219-ans-ops-performance-framework.pdf>.

[41] EUROCONTROL, 2015, *European ATM Master Plan*, viewed 18 December 2017, https://www.atmmasterplan.eu/downloads/202.

[42] EUROCONTROL, 2016, Closing the gaps: a report on what still needs to be done for the Single European Sky, viewed 6 January 2018, http://www.eurocontrol.int/news/closing-gaps-report-what-still-needs-be-done-single-european-sky.

[43] EUROCONTROL, 2016, Flight Movements and Service Units 2016-2022, EUROCONTROL SEVEN-YEAR FORECAST FEBRUARY 2016, *European Organisation for the Safety of Air Navigation*, Brussels, Belgium.

[44] EUROCONTROL, 2017, CODA DIGEST 2016, All-Causes Delay and Cancellations to Air Transport in Europe – 2016, *European Organisation for the Safety of Air Navigation*, Brussels, Belgium.

[45] EUROCONTROL, 2017, *EUROCONTROL Annual Report 2016*, viewed 18 December 2017, http://www.eurocontrol.int/sites/default/files/publication/files/eurocontrol-annual-report-2016.pdf.

[46] EUROCONTROL, 2017a, CODA DIGEST Q3 2017, All-Causes Delay and Cancellations to Air Transport in Europe – Q3 2017, *European Organisation for the Safety of Air Navigation*, Brussels, Belgium.

[47] EUROCONTROL, *ANS performance monitoring*, viewed 18 December 2017, http://www.eurocontrol.int/prudata/dashboard/rp2_2017.html.

[48] EUROCONTROL, SESAR, 2009, *European Air Traffic Management Master Plan*, viewed 18 December 2017, <https://ec.europa.eu/transport/sites/transport/files/modes/air/sesar/doc/1-european_atm_master_plan.pdf>.

[49] EUROCONTROL, SESAR, *ATM Master Plan monitoring*, viewed 18 December 2017, https://www.atmmasterplan.eu/depl/essip_objectives/monitoring

[50] Eurocontrol. (2010). What is Airport CDM.

[51] EUROPEAN COMMISSION, Europe’s Vision for Aviation-Flightpath 2050, viewed January 2018, https://ec.europa.eu/.

[52] EY, 2016, Airport Capacity Programme, Global Comparison of Airport Mitigation Measures, *Ernst & Young LLP*, London, United Kingdom.

DOI: 10.13009/EUCASS2019-846

[53] Fleming G.G., Ziegler U. Environmental trends in aviation to 2050. // ICAO Environmental Report 2016, p 16-22.
[54] Fleuti E., 2014, Aircraft Ground Handling Emissions, Methodology and Emission Factors Zurich Airport, *Zurich Airport*, Zurich, Switzerland.
[55] FORUM-AE, 2015. Mid-Term Synthesis. D4.14, Forum-AE Coordination & Support Action, FP7 – 605506.
[56] Germa Bèl, Xavier Fageda,2008, Getting there fast: globalization, intercontinental flights and location of headquarters, Journal of Economic Geography, 72, 18.
[57] Gleave,S.D., 2015, Study on employment and working conditions in air transport and airports, Brussels, Belgium.
[58] Honeywell and Safran, EGTS - electric taxiing system. Introducing the future of aircraft taxiing, (2014).
[59] Hong Kong Airport, 2016, *Introducing advanced technologies and new facilities in the airport experience*, viewed 27 November 2017, http://www.hongkongairport.com/eng/sustainability_report/pdf/creating_a_seamless_passenger_experience.pdf.
[60] Hudda, N., Gould, T., Hartin, K., Larson, T. V., Fruin, S.A. 2014. Emissions from an international airport increase particle number of concentrations 4-fold at 10 km downwind. Environ. Sci. Technol. 48, 6628–6635. doi:10.1021/es5001566.
[61] IATA, ACI, *Smart Security Project*, viewed 27 November 2017, <http://www.iata.org/whatwedo/security/Documents/smart-security-brochure.pdf>.
[62] ICAO CAEP/7-IE/WG/3. 2007. Long Term Technology Goals for CAEP/7. WG3 and IE Chair presentation to CAEP/7, February 2007.
[63] ICAO CAEP/8-IP/11. 2010. Update on advances in emissions reduction technology: NOX // Committee on Aviation Environmental Protection (CAEP), 8TH MEETING, Montréal, 1 to 12 February 2010.
[64] ICAO Circular 303, Operational Opportunities to Minimize Fuel Use and Reduce Emissions.
[65] ICAO Document 9888, 2007. Review of Noise Abatement Procedure Research & Development and Implementation Results.
[66] ICAO Resolution A39-1. 2016. Consolidated statement of continuing ICAO policies and practices related to environmental protection – General provisions, noise and local air quality.
[67] ICAO Resolution A39-2. 2016. Consolidated statement of continuing ICAO policies and practices related to environmental protection – Climate change.
[68] ICAO Resolution A39-3. 2016. Consolidated statement of continuing ICAO policies and practices related to environmental protection – Global Market-based Measure (MBM) scheme.
[69] ICAO Secretariat. 2016. *Local Air Quality – Overview* // ICAO Environmental Report 2016, p 73-74.
[70] ICAO, 2017, Airbus Global Market Forecast, Growing_Horizons, viewed 6 January 2018, https://www.icao.int/Pages/default.aspx.
[71] ICAO, 2017, Aviation Benefits 2017.
[72] INTERACTION (INnovative TEchnologies and Researches for a new Airport Concept towards Turnaround coordinatION) project web page, <http://www.interaction-aero.eu/>.
[73] International Civil Aviation Organization (ICAO), 2016, *DOC 9626: Manual on the Regulation of International Air Transport*, Third Edition, ICAO Edition.
[74] Jiříček O. Aeroacoustics research in Europe: The CEAS-ASC report on 2015 highlights // Journal of Sound and Vibration, Volume 381, 27 October 2016, Pages 101-120.
[75] Keuken, et al. 2015. Total and size-resolved particle number and black carbon concentrations near an industrial area. Atmospheric Environment, Volume 122, Pages 1-900 (December 2015), Pp. 196-205.
[76] Lee, D. S., D. W. Fahey, P. M. Forster, P. J. Newton, R. C. N. Wit, L. L. Lim, B. Owen, and R. Sausen, Aviation and global climate change in the 21st century, Atmos. Environ., 43, 3520-3537, 2009.
[77] Maertens,S. ,Wolfgang,G., 2015,Institute for Air Transport and Airport Research, How to assess the percentage of transfer passengers at airports?,15,1-15.
[78] META-CDM project web page, Multimodal, Efficient Transportation in Airports and Collaborative Decision Making, <http://www.meta-cdm.org/>.
[79] Miake-Lye R. Et al. 2016. White Paper on air quality aviation impacts on air quality: state of the science // ICAO Environmental Report 2016, p 75-80.
[80] ModAir project web page, <https://www.indracompany.com/en/indra/modair-intermodal-airport>.
[81] Munich Airport. (2010). Collaborative Decision Making (CDM) - a new concept.
[82] NASA, 2015, *NASA UTM*, <https://utm.arc.nasa.gov/index.shtml>.
[83] Nieße, Hendrik and Grimme, Wolfgang, 2014, Minimum Travel Times between European Regions - An assessment of the ACARE 4h-Goal, Air Transport Research Society World Conference, Bordeaux, Frankreich.
[84] Nolte P. 2012, Quantitative Assessment of Technology Impact on Aviation, in Proceedings of the Third International Conference in Air Transport and Operations (published by R. Curran and L. Fischer), June 2012, Delft, Netherlands (page 525).

[85] Norin A., 2008, A*irport Logistics – Modelling and Optimizing the Turn-Around Process,* LiU-Tryck, Linköping, Sweden.

[86] Performance Review Report 2010-An Assessment of Air Traffic Management in Europe during the Calendar Year 2010, 2011, Eurocontrol, Brussels.

[87] Potential Strategies Would Redefine Federal Role in Developing Airport Intermodal Capabilities, 2005, GAO.

[88] Reichmuth, J.,2010, Topical Report Airport Accessibility in Europe, Air Transport and Airport Research, 1-32, Köln Germany.

[89] Report prepared by Oxford Economics for ATAG, 2017, Aviation: Benefits Beyond Borders.

[90] SITA, *Orlando International Airport first to adopt facial recognition technology at border*, https://www.sita.aero/pressroom/news-releases/orlando-international-airport-first-to-adopt-facial-recognition-technology-at-border.

[91] Soepnel S.M.L. 2015. Impact of electric taxi systems on airport apron operations and gate congestion at AAS // Msc. Thesis Study, Delft University of Technology.

[92] Suomalainen E., Celikel A., Vénuat P. 2014. Aircraft metals recycling: process, challenges and opportunities http://www.env-isa.com.

[93] The Association of European Research Establishments in Aeronautics (EREA), 2012, *From Air Transport System 2050 Vision to Planning for Research and Innovation.*

[94] The International Air Transport Association (IATA), 2013, *TECHNOLOGY ROADMA*, 4th Edition**,** 13-19.

[95] The International Air Transport Association (IATA), 2017, *Future of the airline industry 2035,* School of International Futures.

[96] U.S./Europe Comparison of 2010 ATM-Related Operational Performance, 2010, Federal Aviation Administration, Eurocontrol.

[97] UBER, 2016, *Fast-Forwarding to a Future of On-Demand Urban Air Transportation*, UBER Elevate.

[98] UBER, 2016, *UBER Elevate*, <https://www.uber.com/elevate.pdf>.

[99] WheelTugPLC, WheelTug: Driving Aerospace, (2014).

[100] X-NOISE 2015 Evaluation of Progress Towards ACARE Noise Targets // Aviation Noise Research Network and Coordination, X-NOISE EV, Project Number 265943, Deliverable D06.31, Date of preparation: June 2015.