# Infraestructures del Transport Aeri

# Introduction to air navigation services and air traffic management performance

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Escola d'Enginyeria de Telecomunicació i Aeroespacial de Castelldefels

UNIVERSITAT POLITÈCNICA DE CATALUNYA

# Aviation stakeholders

## Aircraft operators





# Aviation stakeholders

## Aircraft manufacturers



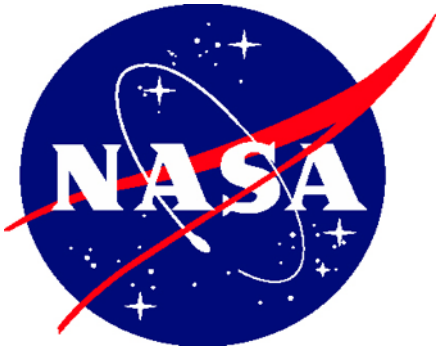




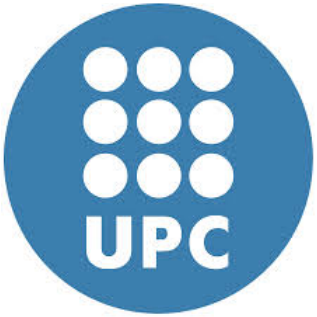



# Aviation stakeholders

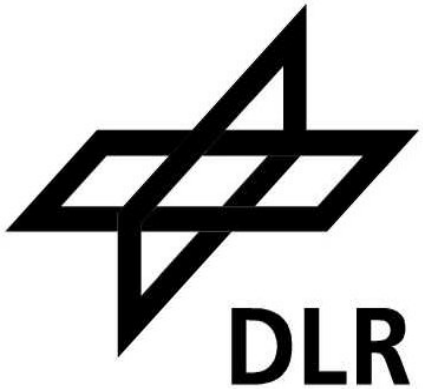
## Research and development agencies or institutions












Massachusetts Institute of Technology

# Aviation stakeholders

## National and international authorities or safety agencies





# Aviation stakeholders

## Airports

aena

AÉROPORTS DE PARIS

Amsterdam Airport Schiphol

CCIT
CHAMBRE DE COMMERCE ET D'INDUSTRIE DE TOULOUSE

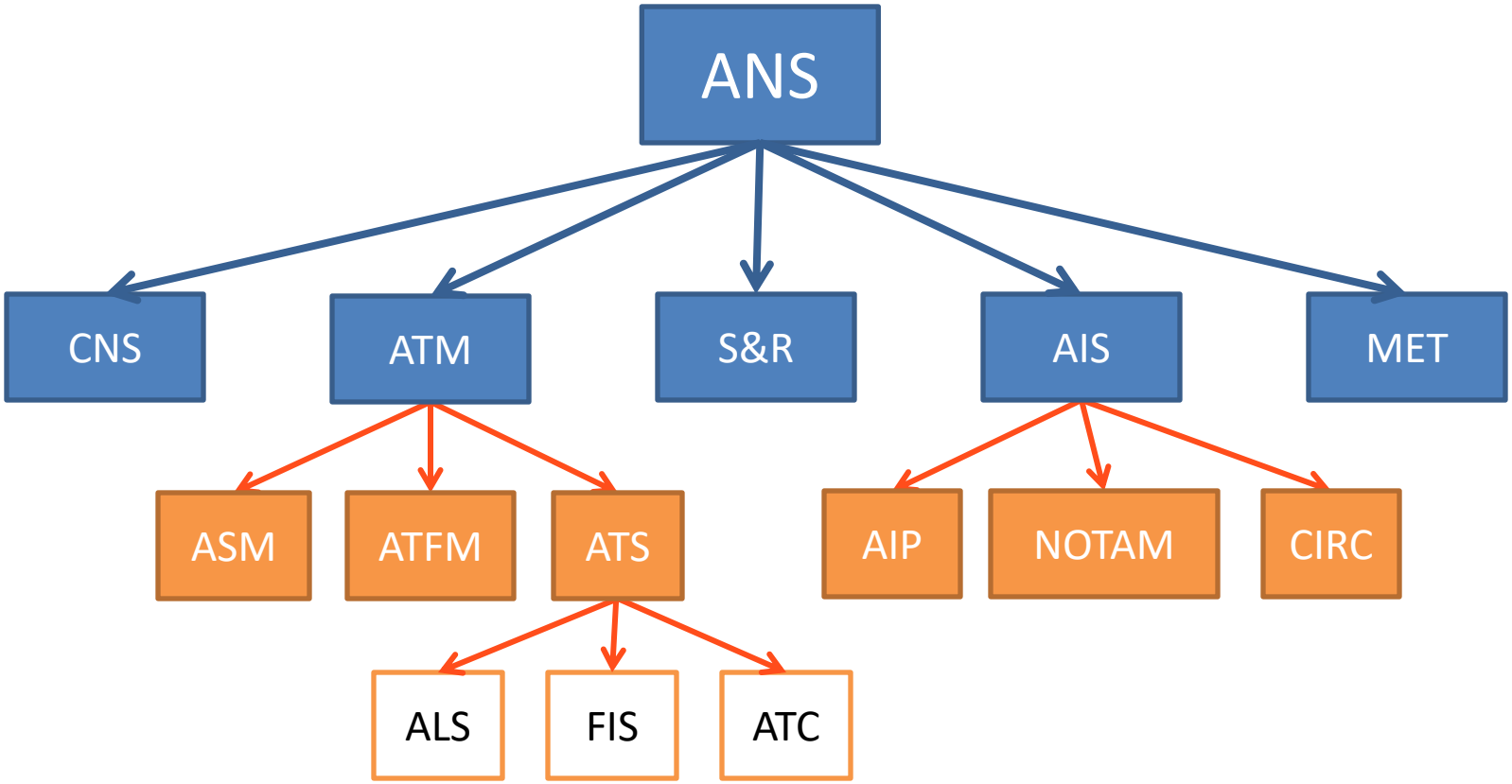
# Aviation stakeholders

## Air navigation service providers






# Air Navigation Services



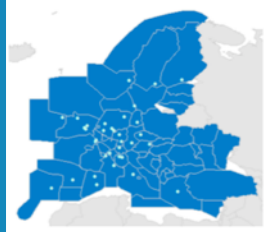

ANS: Air Navigation Services
CNS: Communications, Navigation and Surveillance
ATM: Air Traffic Management
S&R: Search and Rescue
AIS: Air Information Services
MET: Meteorological Services

ASM: AirSpace Management
ATFM: Air Traffic Flow Management
ATS: Air Traffic Services
AIP: Aeronautical Information Publications
NOTAM: Notices to Airmen
CIRC: Circulars

ALS: Alert Services
FIS: Flight Information Services
ATC: Air Traffic Control

# U.S./Europe comparison

## EUROCONTROL area



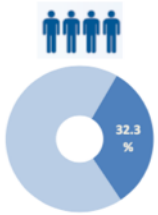
- **11.5** million km²
- **37** service providers
- **16** stand alone approach control facilities
- **62** en-route facilities
- **406** airports with ATC services

AVERAGE DAILY FLIGHTS
**28 475**

**3.5%**
share of general aviation (IFR)

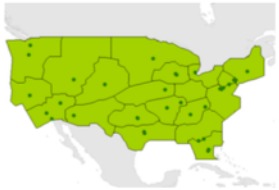
Relative density (flight hours per km²) = 1.4

TOTAL STAFF
**55 130**



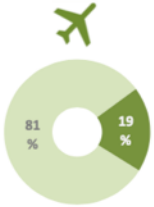

ATCOs in OPS
**17 794**
(32.3% of total staff)

## FAA/ATO (CONUS) area



- **10.4** million km²
- **1** service provider
- **26** stand alone approach control facilities
- **20** en-route facilities
- **517** airports with ATC services

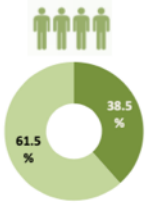
AVERAGE DAILY FLIGHTS
**41 874**




**19%**
share of general aviation (IFR)

Relative density (flight hours per km²) = 2.3

TOTAL STAFF
**31 647**




ATCOs in OPS
**12 170**
(38.5% of total staff)

| U.S. vs. Europe |
|---|
| ≈ -10% |
| +10 x |
| -42 |
| +111 |
| ≈ +47% |
| ≈ x1.6 |
| Staff: ≈ -43% |
| ATCOs: ≈ -32% |

Source: FAA and Eurocontrol. 2019 (Apr) *"U.S./Europe comparison of air traffic management-related operational performance for 2017"*, Tech. Report Issue 6

# U.S./Europe comparison

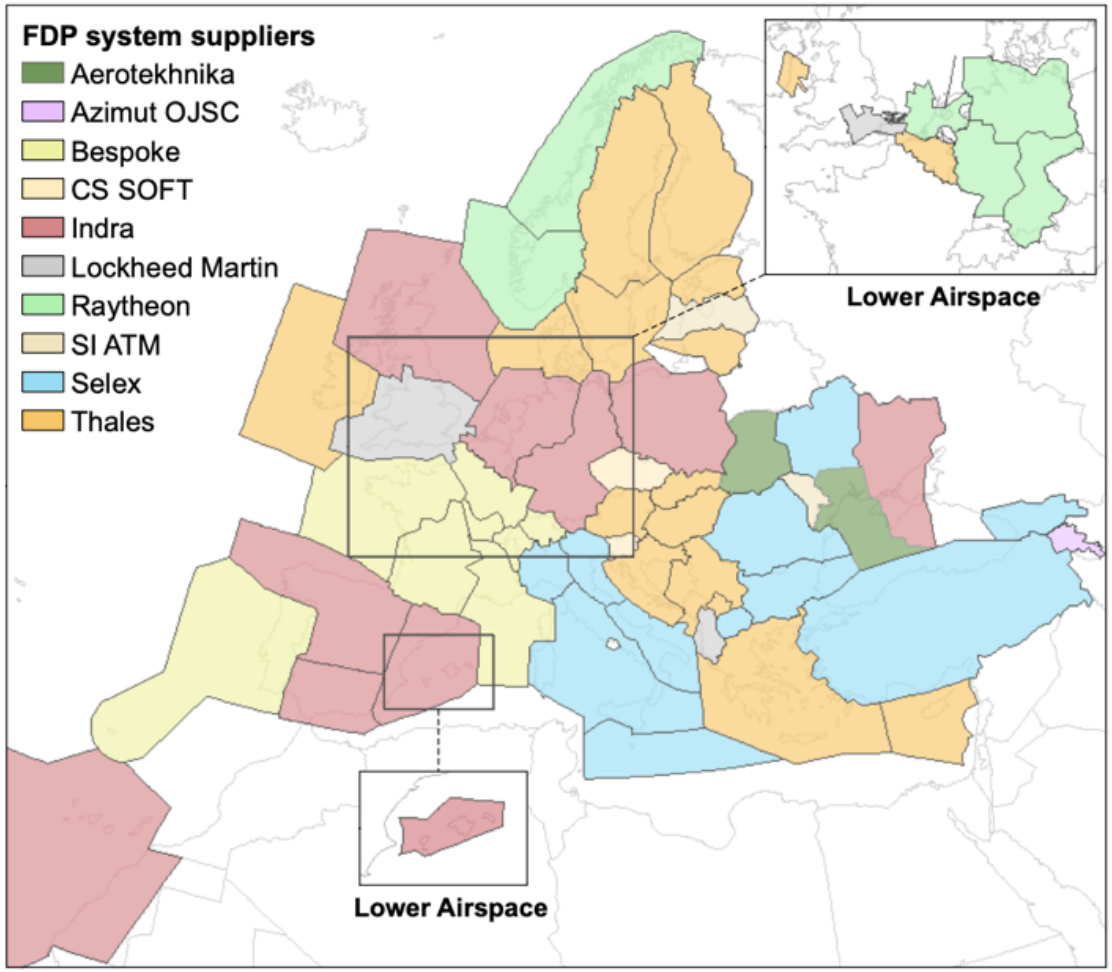
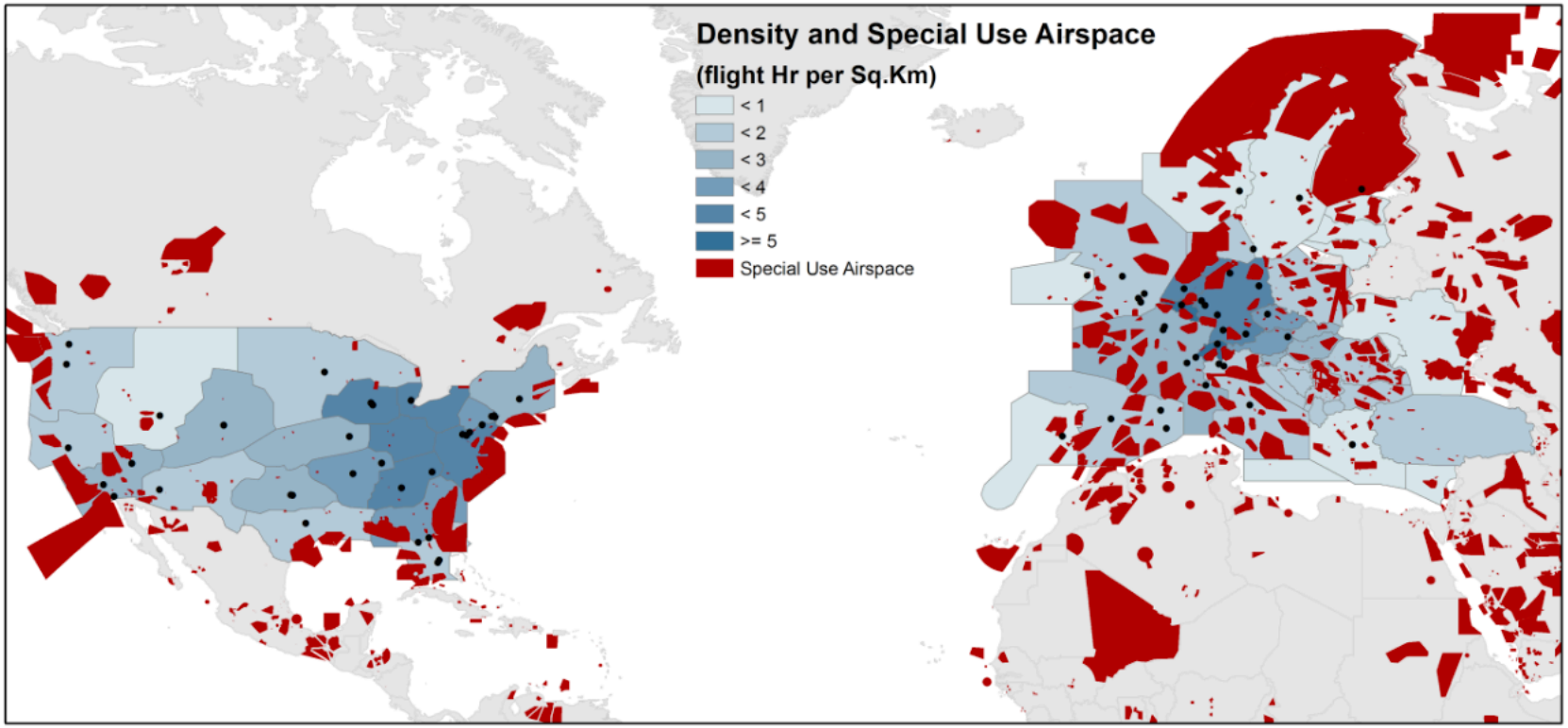



Figure 2-3: Flight data processing (FDP) systems in Europe (2016)

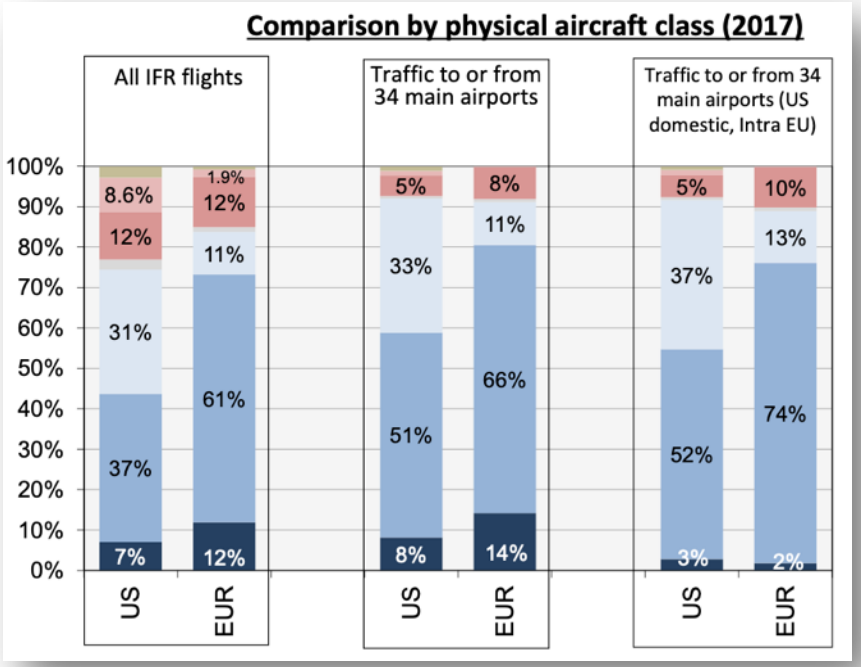
Source: FAA and Eurocontrol. 2019 (Apr) *"U.S./Europe comparison of air traffic management-related operational performance for 2017"*, Tech. Report Issue 6

# U.S./Europe comparison




Source: FAA and Eurocontrol. 2019 (Apr) *"U.S./Europe comparison of air traffic management-related operational performance for 2017"*, Tech. Report Issue 6

# U.S./Europe comparison



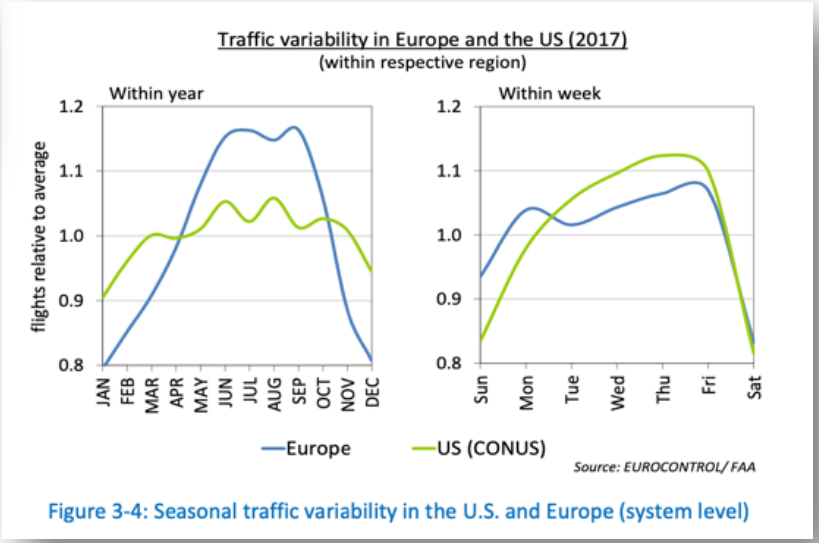
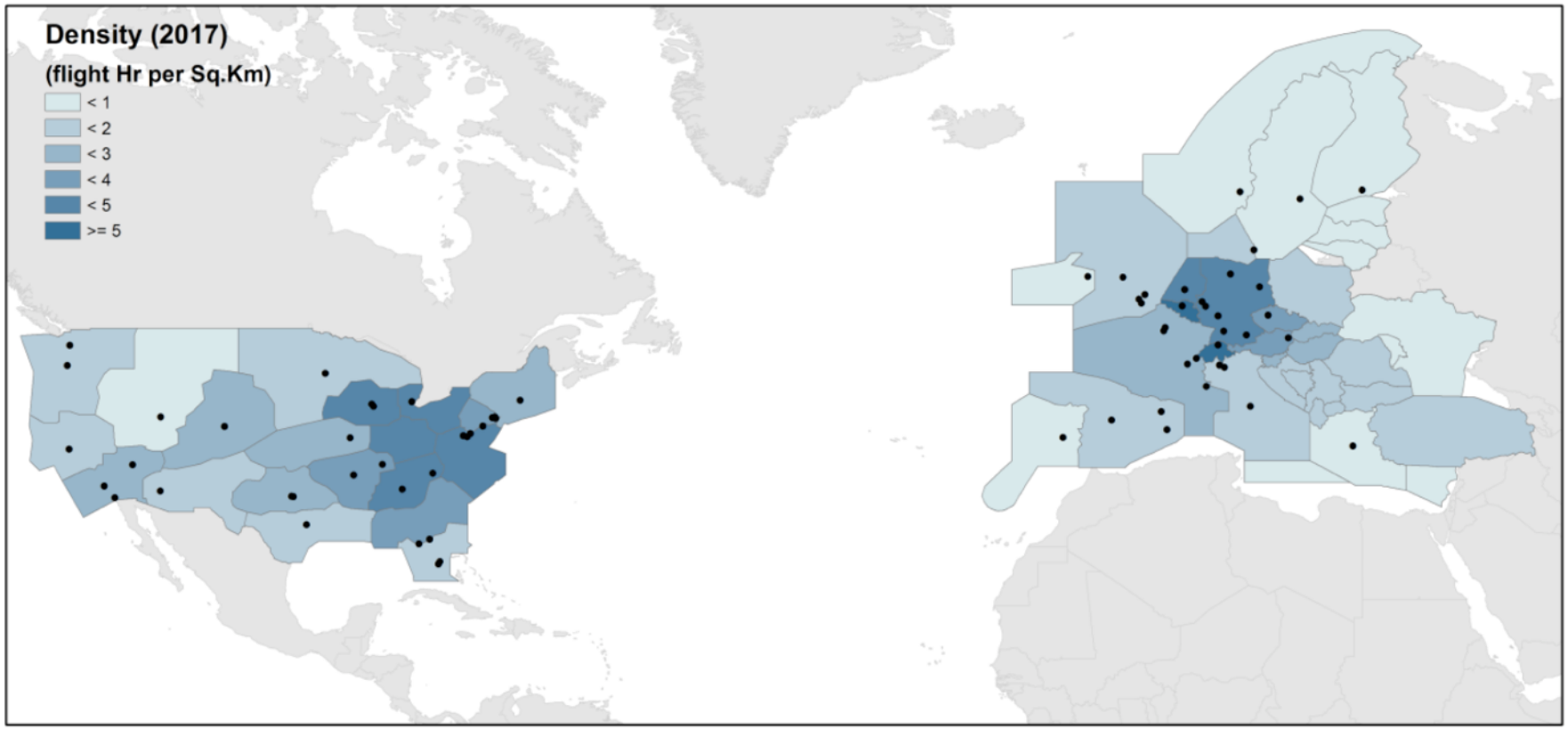




Figure 3-4: Seasonal traffic variability in the U.S. and Europe (system level)

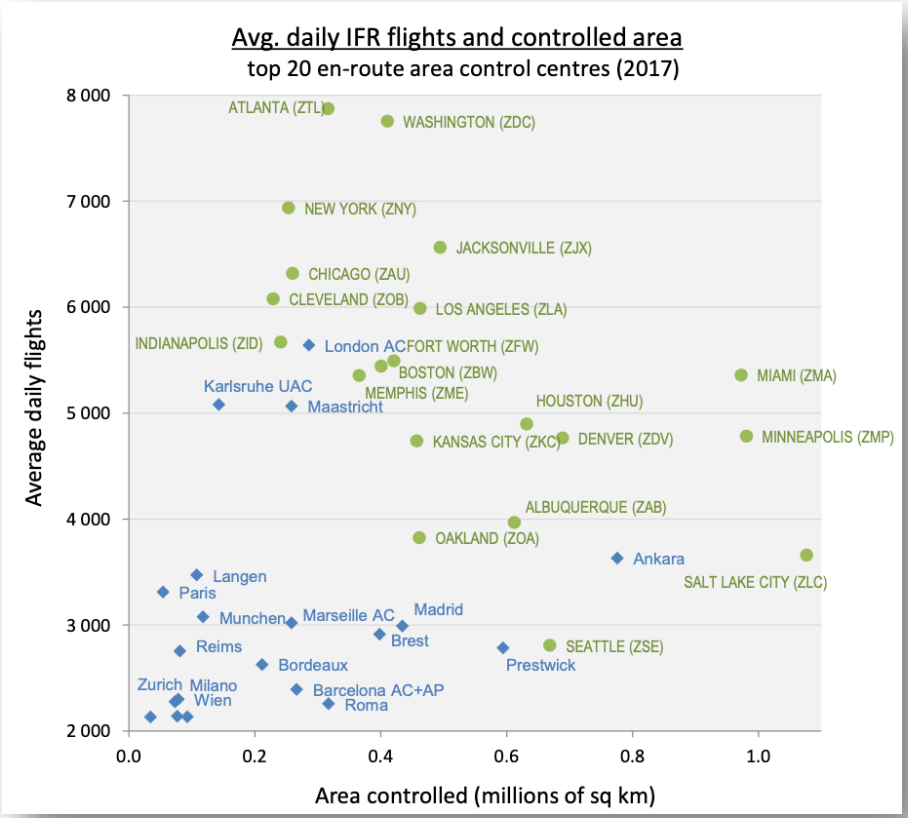
Source: FAA and Eurocontrol. 2019 (Apr) *"U.S./Europe comparison of air traffic management-related operational performance for 2017"*, Tech. Report Issue 6

# U.S./Europe comparison




Source: FAA and Eurocontrol. 2019 (Apr) *"U.S./Europe comparison of air traffic management-related operational performance for 2017"*, Tech. Report Issue 6

# U.S./Europe comparison




Source: FAA and Eurocontrol. 2019 (Apr) *"U.S./Europe comparison of air traffic management-related operational performance for 2017"*, Tech. Report Issue 6

# U.S./Europe comparison

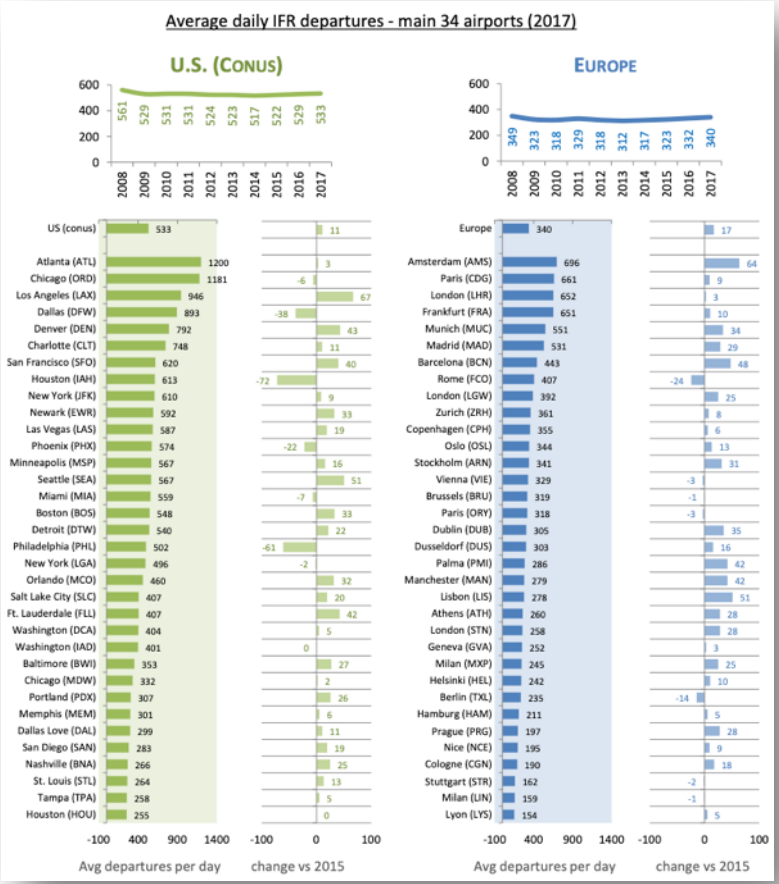



Table 3-3: Comparison of operations at the 34 main airports in the U.S. and Europe

| Main 34 airports | U.S. 2017 | U.S. vs. 2015 | Europe 2017 | Europe vs. 2015 | U.S. vs. Europe (2017) |
|---|---|---|---|---|---|
| Avg. number of annual IFR movements per airport ('000) | 390 | 2.4% | 248 | 5.2% | +57% |
| Avg. number of annual passengers per airport (million) | 38.7 | 6.8% | 31.1 | 11.4% | +24% |
| Passengers per IFR movement | 99 | 4.3% | 125 | 5.8% | -21% |
| Average number of active runways per airport | 3.4 | 0.0% | 1.9 | -1.5% | +76% |
| Annual IFR movements per runway ('000) | 114 | 2.4% | 128 | 6.8% | -11% |
| Annual passengers per runway (million) | 11.3 | 6.8% | 16.0 | 13.1% | -29% |

Source: FAA and Eurocontrol. 2019 (Apr) *"U.S./Europe comparison of air traffic management-related operational performance for 2017"*, Tech. Report Issue 6

# U.S./Europe comparison

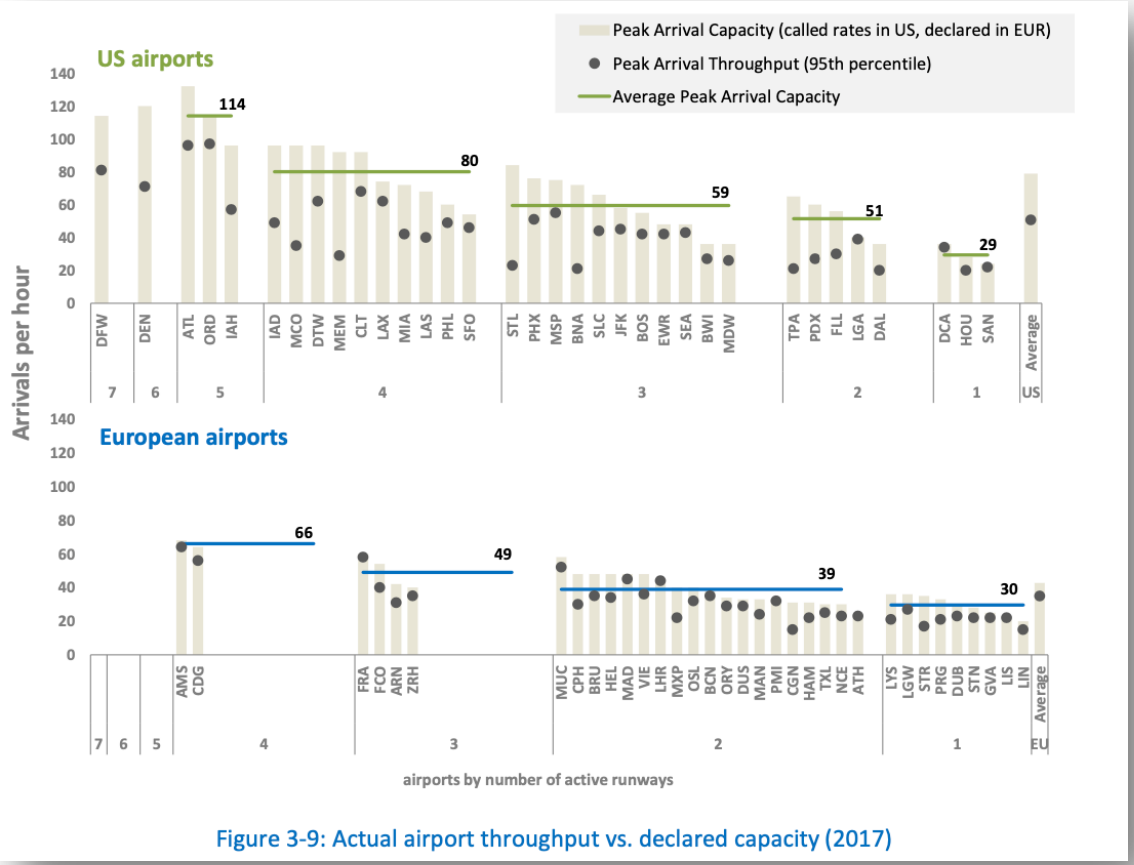



Figure 3-9: Actual airport throughput vs. declared capacity (2017)

**95th percentile airport peak arrival throughput**

The peak arrival throughput is an approximation of the operational airport capacity in ideal conditions. It is the 95th percentile of the number of aircraft in the "rolling" hours sorted from the least busy to the busiest hour.

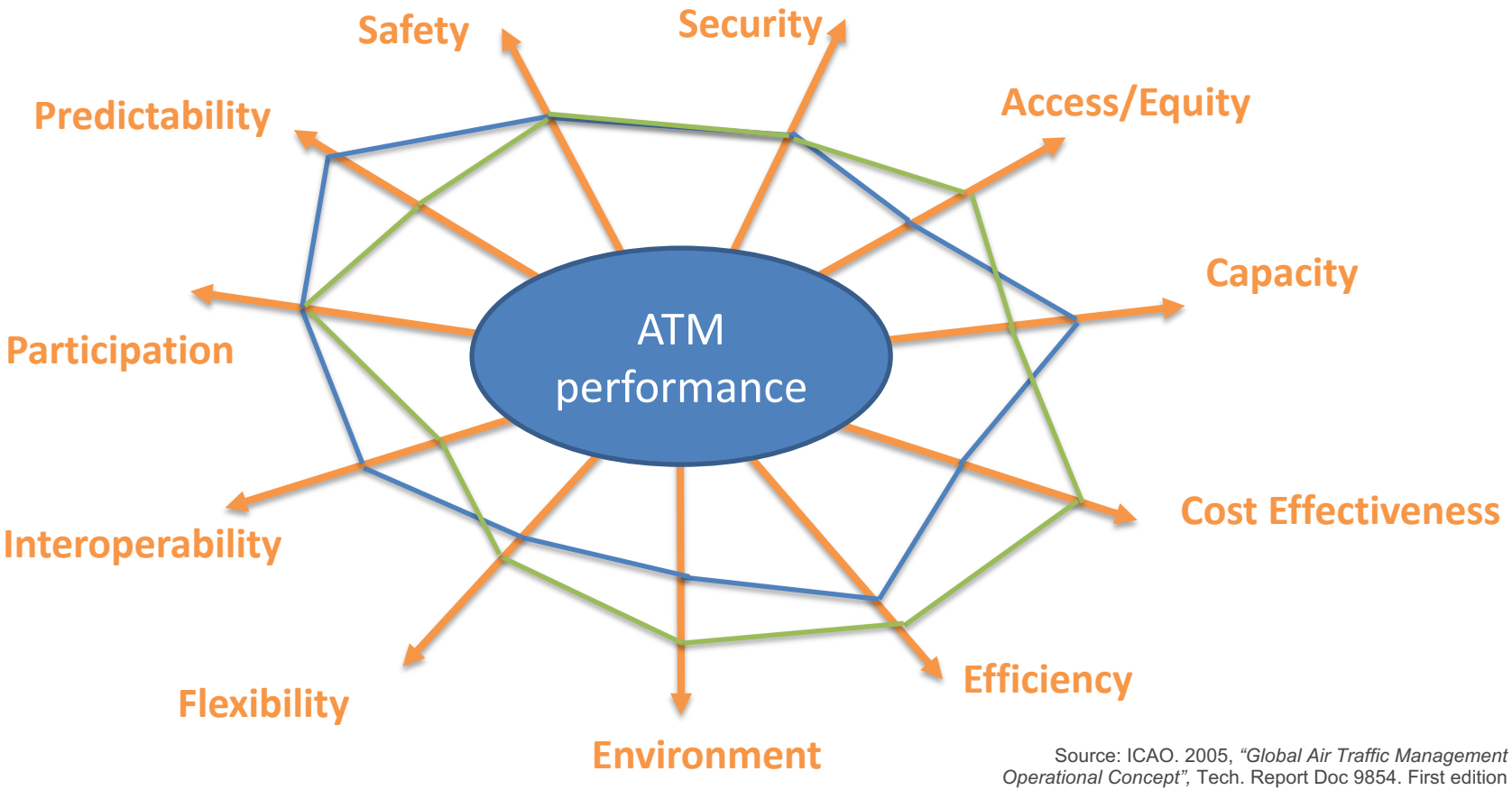
The indicator has, however, limitations when the peak throughput is lower than the peak declared capacity, in which case it is necessary to determine whether a variation in peak arrival throughput is driven by a change in demand or by a change in operational airport capacity.

Source: FAA and Eurocontrol. 2019 (Apr) *"U.S./Europe comparison of air traffic management-related operational performance for 2017"*, Tech. Report Issue 6

# ATM performance

## ICAO KPAs (Key performance areas)

Performance trade-offs!




Source: ICAO. 2005, *"Global Air Traffic Management Operational Concept"*, Tech. Report Doc 9854. First edition

# ATM performance

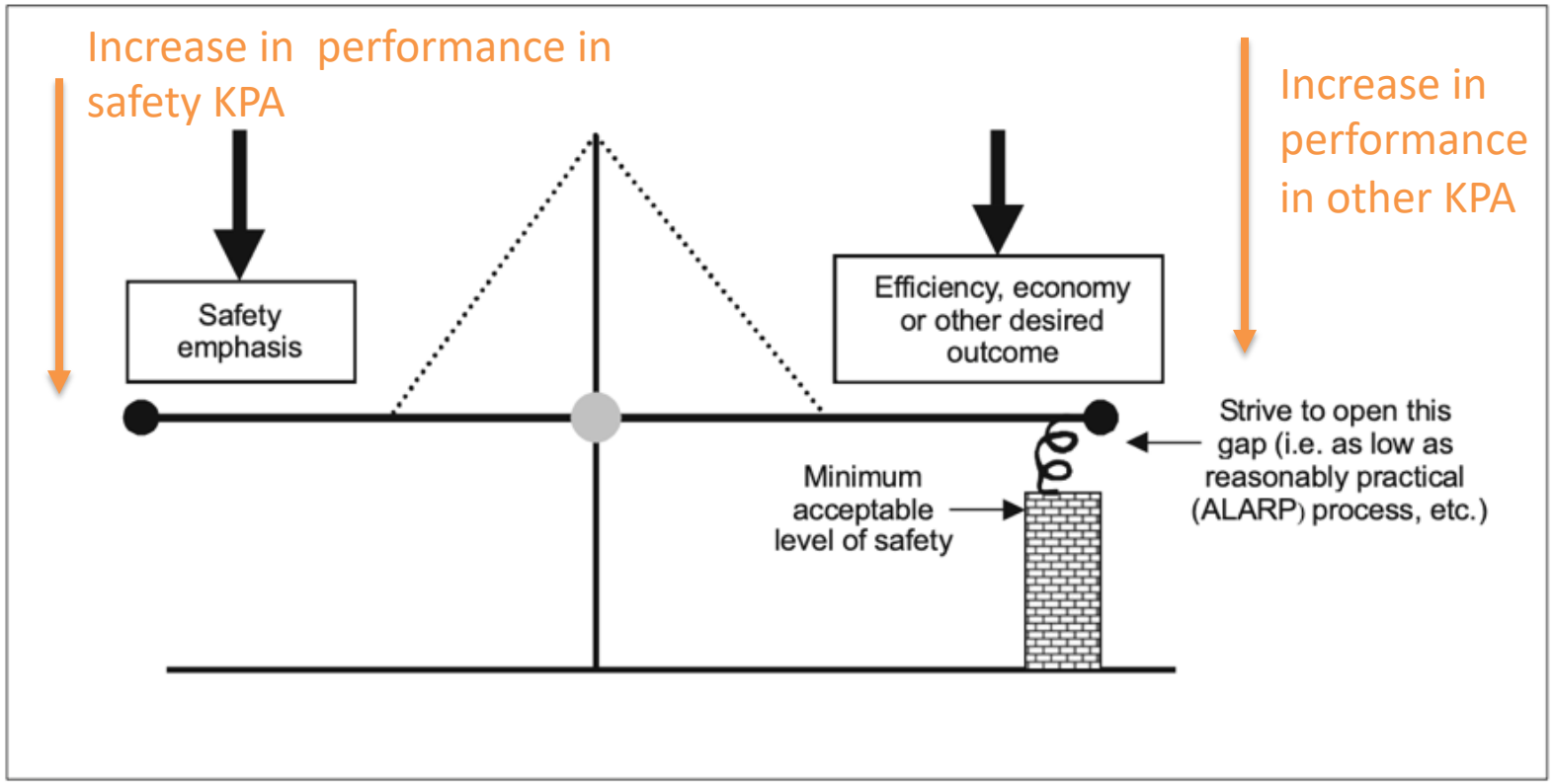



**Figure G-2. Safety balance model**

"Safety can never fall below **minimum accepted levels**. In fact, it should be argued that any change to the ATM system for an outcome not directly aimed at enhancing safety should, nonetheless, strive to achieve its net increase. This is illustrated in Figure G-2".

KPA: key performance area

Source: ICAO. 2005, *"Global Air Traffic Management Operational Concept"*, Tech. Report Doc 9854. First edition

# ATM performance

## ICAO performance framework

### KPA: Key performance area

A way of categorising performance subjects related to high level ambitions and expectations.

ICAO KPAs

1. **Access and equity**: All airspace users must have access to the ATM resources needed to achieve operational objectives. Shared use of airspace by the different users must be accomplished in a safe manner. Also, the global ATM system must ensure equity of all users who require access to a particular part of the airspace or the particular service;

2. **Capacity**: The global ATM system should exploit its capacity to meet airspace user demands at peak times and locations, while minimizing restrictions on traffic flow. To respond to future growth, capacity must increase, along with corresponding increase in efficiency, flexibility and predictability, while ensuring that there are no adverse impacts on safety and giving due consideration to the environment. ATM system must be resistant to any potential service disruptions and temporary capacity reductions;

3. **Cost-effectiveness:** The ATM system should be cost-effective, while balancing the different interests of the ATM community. The cost of service to airspace users must always be taken into account when considering proposals for improving the ATM performance and quality of service. Also, ICAO policies and principles regarding user charges should be followed;

4. **Efficiency:** Efficiency addresses the operational and economic cost-effectiveness of flight operations. In all phases of flight, airspace users want to depart and arrive at the times they select and fly the trajectory they consider optimum;

- **Source:** ICAO. 2005, *"Global Air Traffic Management Operational Concept"*, Tech. Report Doc 9854. First edition.
- **Compiled in:** APACHE consortium 2018 (Jul) " Review of current KPIs and proposal for new ones". Tech. Report, APACHE project Deliveralbe D3.1. Ed. 02.00.00

# ATM performance

## ICAO performance framework

### KPA: Key performance area

A way of categorising performance subjects related to high level ambitions and expectations.

ICAO KPAs

5. **Environment:** The ATM system should contribute to the protection of the environment by reducing noise, emissions and other negative impacts;
6. **Flexibility:** Flexibility addresses the ability of all airspace users to modify flight trajectories dynamically and adjust departure and arrival times, thereby permitting them to exploit operational opportunities as they occur;
7. **Global interoperability:** The ATM system should be based on international standards and uniform principles in order to achieve the technical and operational interoperability of ATM systems and to ensure homogeneous and non-discriminatory global and regional traffic flows;
8. **Participation by the ATM community:** Aviation community should be involved in the planning, implementation and operation of the ATM system to ensure that the evolution of the global ATM system at all times fulfils its expectations;

- **Source:** ICAO. 2005, *"Global Air Traffic Management Operational Concept"*, Tech. Report Doc 9854. First edition.
- **Compiled in:** APACHE consortium 2018 (Jul) " Review of current KPIs and proposal for new ones". Tech. Report, APACHE project Deliveralbe D3.1. Ed. 02.00.00

# ATM performance

## ICAO performance framework

### KPA: Key performance area

A way of categorising performance subjects related to high level ambitions and expectations.

ICAO KPAs

9. **Predictability:** Predictability refers to the ability of airspace users and ATM service providers to provide consistent and dependable levels of performance. Predictability is of crucial importance for airspace users whose business is based on respect of the pre-defined schedules;

10. **Safety:** Safety has the highest priority in aviation and the ATM system plays an important role in ensuring overall safety of air traffic. Uniform safety standards and practices in the field of safety management should be systematically applied within the ATM system. During the implementation of the future global aviation system, safety should be assessed against appropriate criteria and in accordance with appropriate and globally standardized safety management processes and practices; and

11. **Security:** Security refers to the protection of aircraft, people, devices and systems on the ground against threats arising from intentional acts (e.g. terrorism) or unintentional acts (e.g. human error and natural disasters). Adequate security is a fundamental expectation of the ATM community and of citizens. For this reason, the ATM system should contribute to security, and the entire ATM system, as well as the information related to it, should be protected against security threats. Security risk management should balance the needs of the members of the ATM community that require access to the system, with the need to protect the ATM system. In the event of threats to aircraft or threats using aircraft, the ATM system should provide the competent authorities with appropriate assistance and information.

- **Source:** ICAO. 2005, *"Global Air Traffic Management Operational Concept"*, Tech. Report Doc 9854. First edition.
- **Compiled in:** APACHE consortium 2018 (Jul) " Review of current KPIs and proposal for new ones". Tech. Report, APACHE project Deliveralbe D3.1. Ed. 02.00.00

# ATM performance

## ICAO performance framework

**KPA: Key performance area (Example: Capacity)**
A way of categorising performance subjects related to high level ambitions and expectations.

**Focus Area (Example: Airport Capacity)**
Within each KPA, a number of more specific "Focus Areas" are identified in which there are potential intentions to establish performance management. Typically needed where performance issues have been identified.

**Performance Objective or Ambition (Example: Increase Airport Capacity by 50% in 2025)**
Qualitative (but focused) definition of a desired trend from today's performance (e.g. improvement).

**PI: Performance Indicator (Example: Peak departure throughput per hour)**
Measure to monitor performance in a given Focus Area or KPA. No validation targets are assigned.

**KPI: Key Performance Indicator**
PI with an associated validation target derived from the corresponding Performance Ambition.

**Influence factor (Example: Taxiway throughput)**
Particular characteristic or parameter that helps determining performance. Improvements to the identification of these factors drive performance to higher levels

**Metric (Example: Number of take-offs from runway 25L)**
Used to calculate the values of (key) performance indicators.

ICAO. 2005, *"Global Air Traffic Management Operational Concept"*, Tech. Report Doc 9854. First edition

# ATM performance

## ICAO performance framework

| KPAs | KPIs identified |
|---|---|
| Access and equity | • unsatisfied demand versus overall demand |
| Capacity | *System-wide:*<br>• number of flights, flight hours and flight distance that can be accommodated<br>• number of flights, available plane miles etc<br>*Airspace*<br>• number of IFR flights able to enter an airspace volume<br>• number of IFR flights able to be present in sectors at any one time (airspace capacity rates)<br>*Airport*<br>• Hourly number of IFR movements (departures plus arrivals) as possible during low visibility conditions (IMC)<br>• Daily number of IFR movements (departures plus arrivals) as possible during a 15-hour day between 7:00 and 22:00 local time during low visibility (IMC) conditions<br>• Average daily airport capacity for a group of 35 airports measured as a 5-year moving average<br>• Average daily airport capacity for a group of seven major metropolitan areas |
| Cost-effectiveness | • Average cost per flight at a system wide annual level<br>• Total operating cost plus cost of capital divided by IFR flights<br>• Total labour obligations to deliver one forecast IFR flight in the system, measured monthly and year-to-date |
| Efficiency | • Percent of flights departing on-time<br>• Average departure delay of delayed flights<br>• Percent of flights with normal flight duration<br>• Average flight duration extension of flights with an extended flight duration<br>• Percent of flights with on-time arrival at a predetermined set of airports<br>• Total number of minutes actual gate arrival time exceeding planned arrival time on a per flight basis at the predetermined set of airports |
| Environment | • Amount of emissions (CO2, NOx, H2O and particulate) which are attributable to inefficiencies in ATM service provision<br>• Number of people exposed to significant noise as measured by a three-year moving average<br>• Fuel efficiency per revenue plane-mile as measured by a three-year moving average |

Delay

ICAO KPIs

Source (and more information): APACHE consortium 2018 (Jul) " Review of current KPIs and proposal for new ones". Tech. Report, APACHE project Deliveralbe D3.1. Ed. 02.00.00

# ATM performance

## ICAO performance framework

| | |
|---|---|
| **Flexibility** | • Number of rejected changes to the number of proposed changes (during any and all phases of flight) to the number of flight plans initially filed each year.<br>• Proportion of rejected changes for which an alternative was offered and taken. |
| **Global interoperability** | • The number of filed differences with ICAO Standards and Recommended Practices |
| | • Level of compliance of ATM operations with ICAO CNS/ATM plans and global interoperability requirements |
| **Participation by the ATM Community** | • Number of yearly meetings covering planning, implementation and operation, and covering a significant estimated proportion (e.g. 90%) of the whole of the regional aviation activity<br>• Number of yearly meetings for planning<br>• Number of yearly meetings for Implementation<br>• Number of year meetings for Operation |
| **Predictability** | Some delay measures included in the efficiency KPA are considered to be measures of predictability by certain organizations. |

| | |
|---|---|
| **Safety** | • count of accidents normalized through either the number of operations or the total flight hours |
| **Security** | • Number of acts of unlawful interference reported against air traffic service provider fixed infrastructure<br>• Number of incidents involving direct unlawful interference to aircraft (bomb threat, hijack, or imitative deception) that required air traffic service provider response<br>• Number of incidents due to unintentional factors, such as human error, natural disasters etc. that have led to an unacceptable reduction in Air Navigation System capacity. |

**Other performance frameworks (!!!):**

- **CANSO**: Civil Air Navigation Services Organisation
- **SES**: Single European Sky (through the PRB: Performance Review Body and Eurocontrol)
- **SESAR** performance framework
- **FAA** (Federal Aviation administration)
- …

ICAO KPIs

Source (and more information): APACHE consortium 2018 (Jul) " Review of current KPIs and proposal for new ones". Tech. Report, APACHE project Deliveralbe D3.1. Ed. 02.00.00

# ATM performance

## Performance trade-offs

**Capacity vs. Safety**

### Example1: close parallel PRM approaches at KSFO


Parallel approaches: Only in VMC (visual self-separation). In IMC only one landing runway used.

**Capacity:**
- 2 runways: 60 landings/h
- 1 runway: 30 landings/h

VMC: Visual meteorologic conditions
IMC: Instrument meteorologic conditions

**Special requirements on crew training and equipment** (e.g. secondary PRM Monitor frequency to protect against a blocked "breakout" instruction. The tower transmits on both. The aircraft transmits only on the tower frequency but listens to both)

**Precision Runway Monitor (PRM) approach:** independent, simultaneous operations to runways spaced less than 4,300 feet apart.
More info on PRM approaches in https://www.faa.gov/training_testing/training/prm/media/PRM_training.pdf

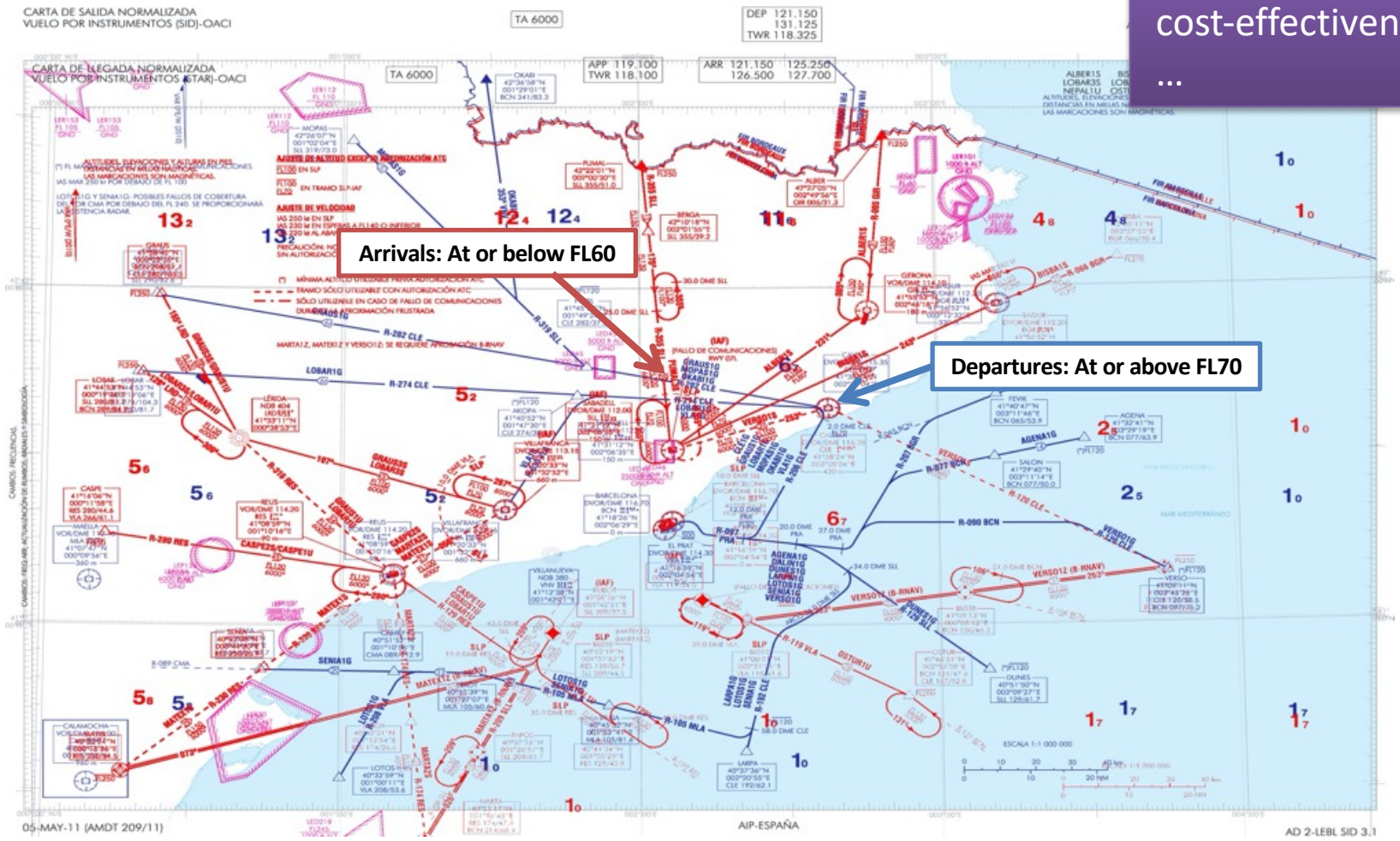
# ATM performance

Performance trade-offs

**Capacity vs.**

environment
cost-effectiveness
...

## Example2: Barcelona SIDs and STARs strategic deconfliction



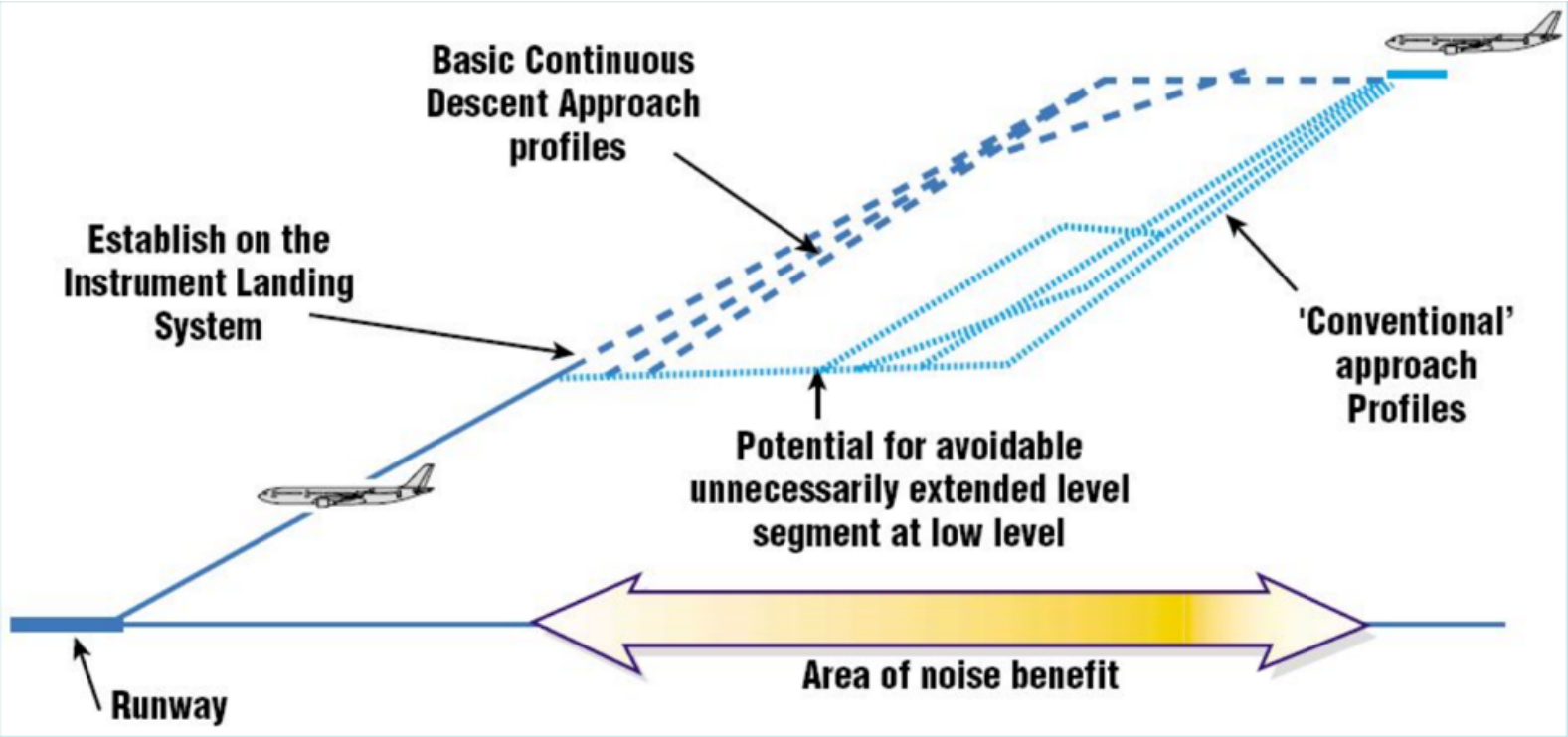
# ATM performance

Performance trade-offs

**Capacity vs.**

environment
cost-effectiveness
…

**Example3: Conventional approaches vs. Continuous descent approaches**



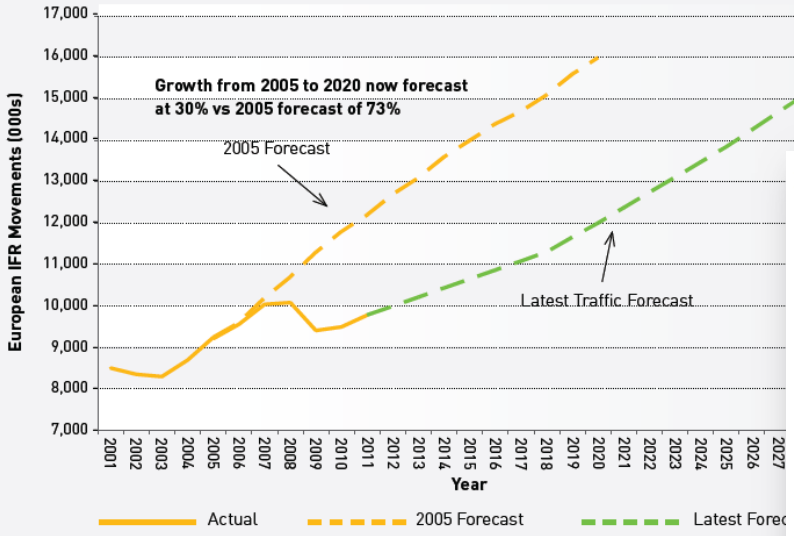
# ATM system reaching its limits

From 2003 to 2008 in Europe:
- 20% traffic increase
- 61% total delay increase

[Eurocontrol, 2008]

In 2010 in Europe:
- **19.4 million minutes** of total delay
- Each flight was **49km** longer (average)
- Estimated costs of **fragmentation** of airspace amounts to **€4 billion** a year.

Source : [SESAR, 2011]




Source: SESAR, European ATM Master Plan, edition 2, Oct. 2012

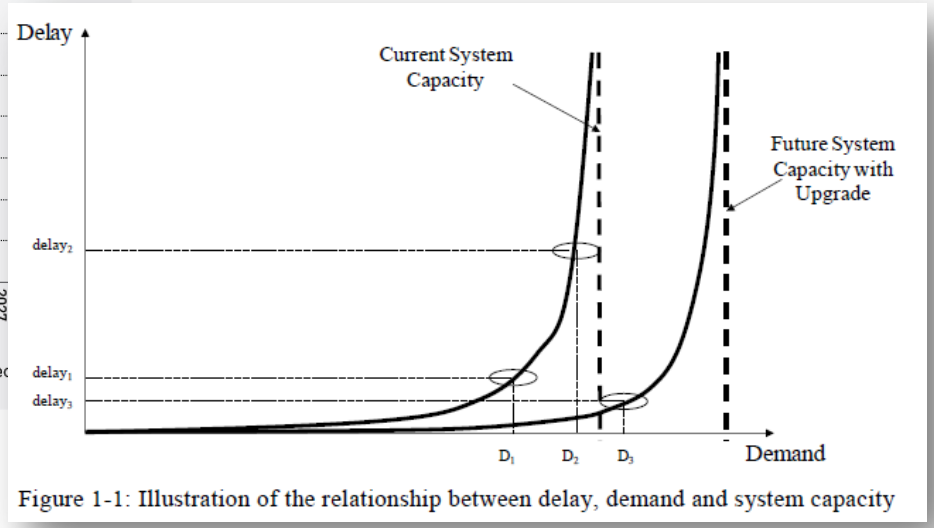
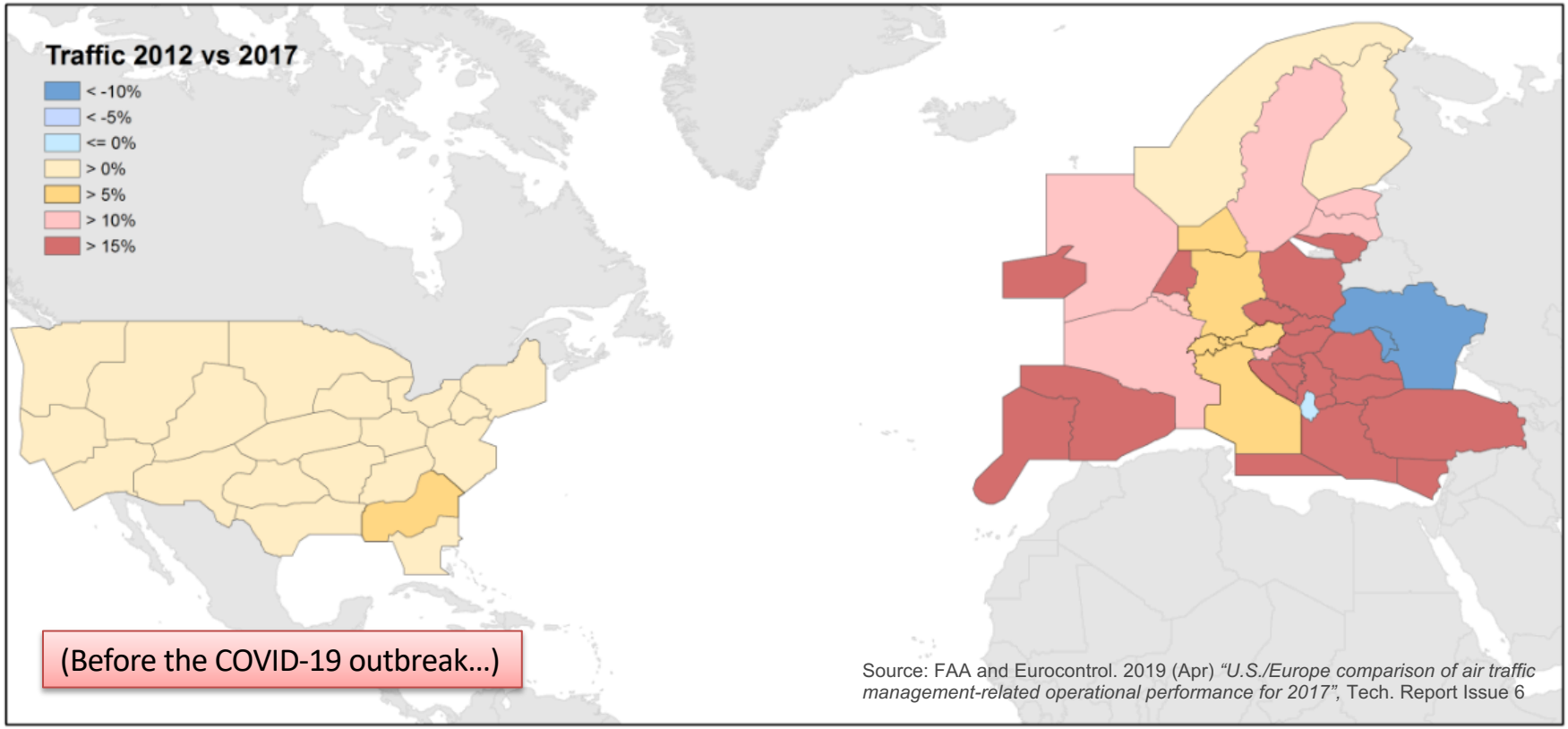



Figure 1-1: Illustration of the relationship between delay, demand and system capacity

Source: [Ball,2010]

(Before the COVID-19 outbreak…)

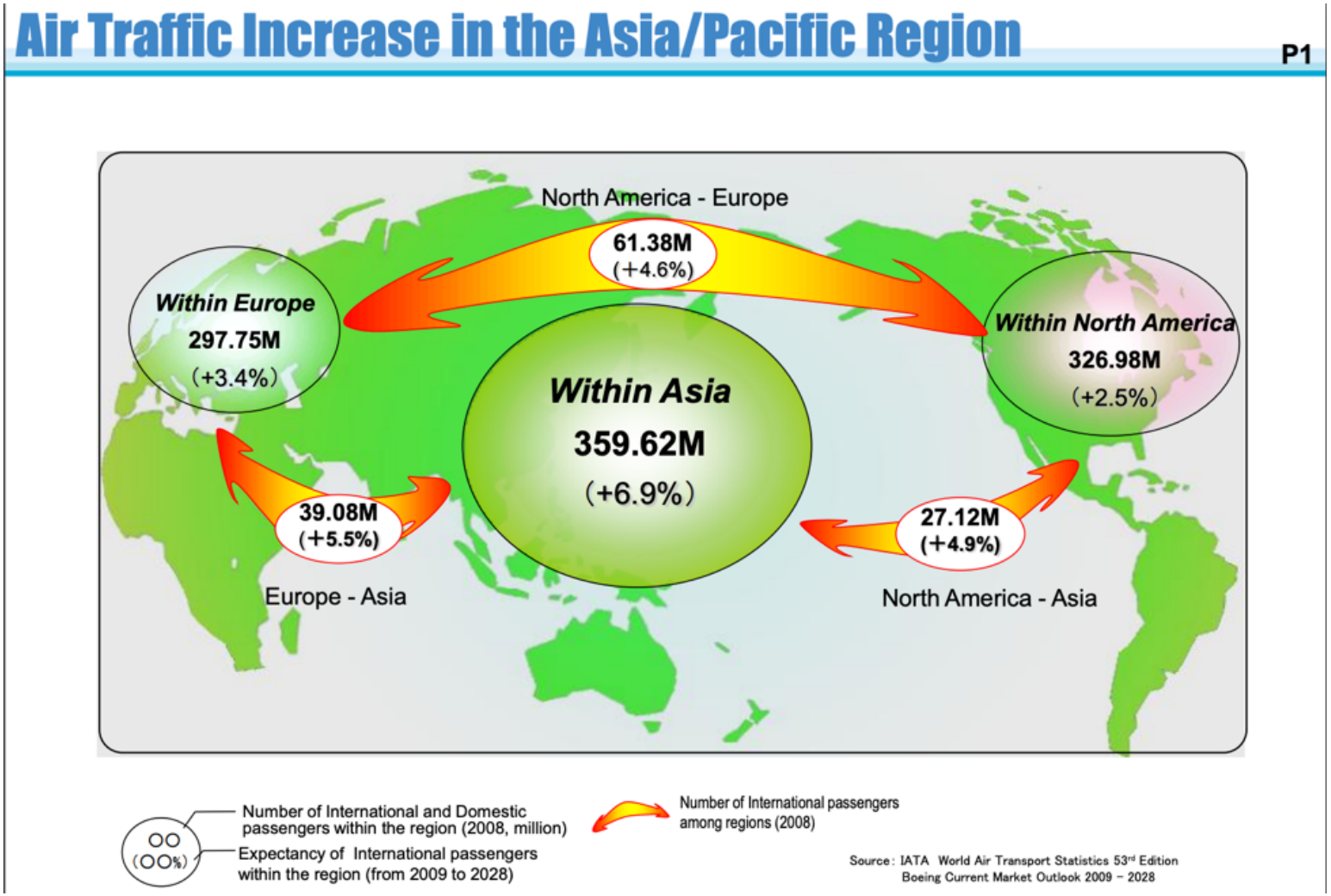
# ATM system reaching its limits




(Before the COVID-19 outbreak…)

Source: FAA and Eurocontrol. 2019 (Apr) *"U.S./Europe comparison of air traffic management-related operational performance for 2017",* Tech. Report Issue 6

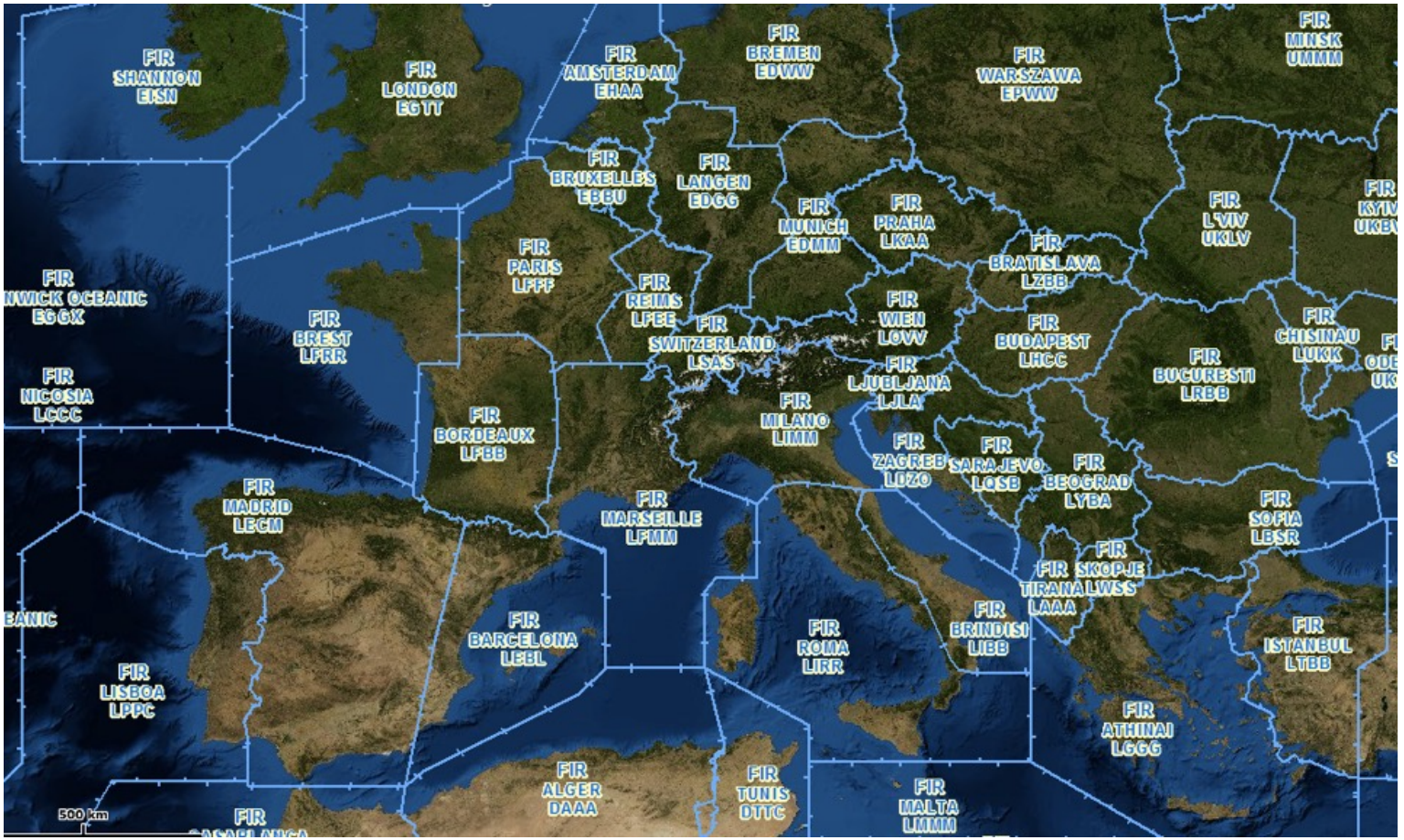
# ATM system reaching its limits




Source: T. Imagome, 2011. Seamless ATM Perspective and CARATS. ICAO Asia/Pacific Seamless ATM Symposium

# ATM system reaching its limits

**Europe:** segmentation of the airspace due to state boundaries (with some "remarkable" exceptions)



# ATM system reaching its limits

## Single European Sky (SES) ambitions (for 2035)

- Increase safety **x 10**
- Increase capacity **by 300%**
- Reduce cost per flight **by 50%**
- Reduce environmental impact **by 10%**

**SESAR: Single European Sky ATM Research**


SESAR JOINT UNDERTAKING

- The SESAR Joint Undertaking (SJU) is a public-private partnership established by the European Union together with Eurocontrol in 2007
- **Technological pillar** of Single European Sky (SES)
- Mechanism coordinating and concentrating **all EU research and development (R&D) activities in ATM**
- Unites around 3,000 experts in Europe

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## SESAR performance ambitions (2035)

PERFORMANCE AMBITIONS FOR 2035 FOR CONTROLLED AIRSPACE

| Key performance area | SES high-level goals 2005 | Key performance indicator | Performance ambition vs. baseline: Baseline value (2012) | Ambition value (2035) | Absolute improvement | Relative improvement |
|---|---|---|---|---|---|---|
| Capacity | Enable 3-fold increase in ATM capacity | Departure delay[4], min/dep | 9.5 min | 6.5-8.5 min | 1-3 min | 10-30% |
| | | IFR movements at most congested airports[5], million | 4 million | 4.2-4.4 million | 0.2-0.4 million | 5-10% |
| | | Network throughput IFR flights[5], million | 9.7 million | ~15.7 million | ~6.0 million | ~60% |
| | | Network throughput IFR flight hours[5], million | 15.2 million | ~26.7 million | ~11.5 million | ~75% |
| Cost efficiency | Reduced ATM services unit costs by 50% or more | Gate-to-gate direct ANS cost per flight[1], EUR(2012) | EUR 960 | EUR 580-670 | EUR 290-380 | 30-40% |
| Operational efficiency | | Gate-to-gate fuel burn per flight, kg/flight | 5280 kg | 4780-5030 kg | 250-500 kg | 5-10% |
| | | Additional gate-to-gate flight time per flight[2], min/ flight Within the: Gate-to-gate flight time per flight[3], min/flight | 8.2 min (111 min) | 3.7-4.1 min (116 min) | 4.1-4.5 min | 50-55% |
| Environment | Enable 10% reduction in the effects flights have on the environment | Gate-to-gate $CO_2$ emissions, tonnes/flight | 16.6 tonnes | 15-15.8 tonnes | 0.8-1.6 tonnes | 5-10% |
| Safety | Improve safety by factor 10 | Accidents with direct ATM contribution[6], #/year Includes in-flight accidents as well as accidents during surface movement (during taxi and on the runway) | 0.7 (long-term average) | no ATM related accidents | 0.7 | 100% |
| Security | - | ATM related security incidents resulting in traffic disruptions | unknown | no significant disruption due to cyber-security vulnerabilities | unknown | - |

1 Unit rate savings will be larger because the average number of Service Units per flight continues to increase.
2 "Additional" means the average flight time extension caused by ATM inefficiencies.
3 Average flight time increases because the number of long-distance flights is forecast to grow faster than the number of short-distance flights.
4 All primary and secondary (reactionary) delay, including ATM and non-ATM causes.
5 Includes all non-segregated unmanned traffic flying IFR, but not the drone traffic flying in airspace below 500 feet or the new entrants flying above FL 600
6 In accordance with the PRR definition: where at least one ATM event or item was judged to be DIRECTLY in the causal chain of events leading to the accident. Without that ATM event, it is considered that the accident would not have happened.

Source and more info:
https://www.atmmasterplan.eu/exec/overview/performance

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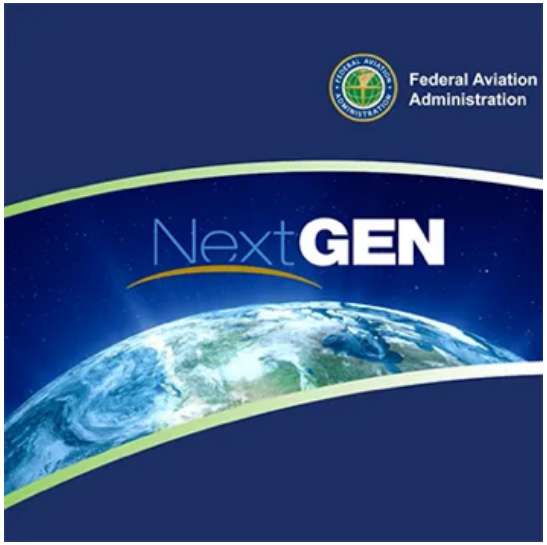


OneSKY AUSTRALIA

SESAR JOINT UNDERTAKING

中国民航空中交通管理局
Air Traffic Management Bureau

CARATS
Collaborative Actions for Renovation of Air Traffic Systems

Change of paradigm in ATM

# Thank you!!

# Gràcies!!