D2.1: CURRENT TBO CONCEPTS AND DERIVATION OF THE GREEN AIR TRAFFIC MANAGEMENT CONCEPTS

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E-mail:	Michael.Finke@dlr.de
Project website address:	www.project-great.eu

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AUTHORS	Michael Finke (DLR), Marco-Michael Temme (DLR), Rabeb Abdellaoui (DLR), Eszes Zoltán (HC), Gergely Csaba (HC), Mavrák Gábor (HC), Pásztor Attila Barna (HC), Tormási Péter (HC), Szalóky Péter (HC), Hu Haoliang (CARERI), Li Guang (CAAC TC), Yuan Peng (CAAC TC), Yang Lei (NUAA), et al.
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	NAME	ORGANISATION	DATE
COORDINATOR	Michael Finke	DLR	15/12/2020
WP LEADER	Rabeb Abdellaoui	DLR	15/12/2020
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OTHER (QUALITY)	Jetta Keranen	L-UP	15/12/2020

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EXECUTIVE SUMMARY

Addressing environmental challenges, especially global warming, is more than ever an issue for the community. This matter is becoming an increasing priority at regional and global level. Commitments have been made to reduce the aviation's environmental footprint. Global air traffic is contributing to climate change, affecting local air quality and, consequently, affecting the health and quality of life of all citizens. The air traffic is growing and expected to continue growing significantly in the future to cope with the increasing demand for mobility and connectivity. A long-term effect on the environment from aviation sector, mainly caused by aircraft noise and exhaust gases (especially CO_2, nitrogen oxides NO_x and methane), make it a clear target for mitigation efforts. The future growth of aviation shall go hand in hand with environment sustainability policies. Therefore, studies and research are being conducted worldwide exploring possible optimization of the aircraft technologies as well as Air Traffic Management (ATM) operations. Given the close interdependency between several flight parameters, including the route of flight, and environmental impact, optimization in flight trajectory design and air traffic control (ATC) operations are an appropriate means to reduce the emissions in short- and medium-term time frames.

The international project "Greener Air Traffic Operations" (GreAT) has been launched in line with this objective. This Horizon 2020 project is conducted in cooperation between 6 Chinese and 7 European partners.

Within this concept document on hand, the foundation is created for investigating and validating 'greener ATM concepts' in the project, which aim to reduce aviation's environmental impact and its contribution to the climate change. The focus lies on the possibilities offered by the air traffic management (ATM) and flight operations, without technically changing the aircraft.

This is done by performing a detailed analysis and comparison of the current ATM principles (baselines) in Europe and China, as well as considering the requirements for ATM concepts from the International Civil Aviation Organization (ICAO). Future ATM research programs and initiatives are considered, setting the focus on activities that are relevant for greener ATM, or that are undertaking first steps towards an environmental-friendly guidance of air traffic.

Then a flight-centered analysis of the most fuel-efficient way of conducting a flight as best-case scenario is described.

Based on all this information, this document derives concept elements for greener ATM, which are reflecting basic mechanisms that are enabling the modification and optimization of a part of the flight trajectory towards the described best-case scenario. These concept elements can be considered as a framework or a toolbox.

And finally, a selection of concept elements can be made, which are used to create and describe a 'greener ATM concept' for a specific use case (e.g. TMA of a medium size airport).

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GLOSSARY

Acronym	Signification
ABAS	Airborne Augmentation System
AC	Alternate Current
ACACIA	Advancing the Science for Aviation and ClimAte
ACAS	Airborne Collision Avoidance system, Air Collision Avoidance System
ACC	Area Control Center
A-CDM	Advanced Collaborative Decision Making
ADS-B	Automatic Dependent Surveillance-Broadcast
ADS-C	Automatic Dependent Surveillance-Contract
AEEC	Airlines Electronic Engineering Committee
AFP	Airspace Flow Program
AFTN	Aeronautical Fixed Telecommunication Network
AGL	Above Ground Level
AI	Artificial Intelligence
AIM	Aeronautical Information Management
AIP	Aeronautical Information Publication
AIRAC	Aeronautical Information Regulation and Control
AIS	Aeronautical Information Service
ALTERNATE	Assessment on Alternative Aviation Fuels Development
AM	Amplitude Modulation
AMAN	Arrival Manager
AMC	Airspace Management Cells
ANS	Air Navigation Services
ANSP	Air Navigation Service Provider
AO	Aircraft Operator
AOA	ACARS Over AVLC

AOC	Airline Operation Centers
AP	Arrival Procedure
APP	Approach Control Center
ARINC	Aeronautical Radio, Incorporated
AMAN	Arrival Manager
ASM	Airspace Management
A-SMGCS	Advanced Surface Movement Guidance and Control System
ASP	Aircraft Separation Points
ASR	Aerodrome Surveillance Radar
ATC	Air Traffic Control, Air traffic Control
ATCO	Air Traffic Control Operator
ATFCM	Air Traffic Flow and Capacity Management
ATFM	Air traffic flow management
ATIS	Automatic Terminal Information Service
ATM	Air Traffic Management
ATN	Aeronautical Telecommunications Network
ATP	Airport and TMA Performance
ATS	Air Traffic Service
AU	Airspace User
AVLC	Aviation VHF Link Control
CAAC	Civil Aviation Administration of China
CAAC-ATMB	The Air Traffic Management Bureau of Civil Aviation Administration of China
CAAMS	Civil Aviation ATM Modernization Strategy
CACD	Central Airspace and Capacity Database
CAMU	Central Airspace Management Unit
CAT	Category
CCO	Continuous Climb Operation
CDA	Continuous Descent Operations
CDM	Collaborative Decision Making

CDO	Continuous Descent Operation
CDR	Conditional Route
CFIT	Controlled Flight Into Terrain
CFMU	Central Flow Management Unit
CLIMOP	Climate assessment of innovative mitigation strategies towards operational improvements in aviation
CNS	Communications, Navigation and Surveillance
COBT	Calculated Off-block Time
CPDLC	Controller–Pilot Data Link Communications
CRCO	Central Route Charges Office
CRDS	Centre of Research, Development and Simulation
CTA	Controlled Time of Arrival; Calculated Time of Arrival
CTOT	Calculated Take Off Time
CTR	Controlled Traffic Region
CWP	Controller Working Position
dA	Fully Dynamic and Optimized Airspace
DC	Direct Current
DCB	Demand and Capacity Balancing
DCL/D-ATIS	Departure Clearance/ Datalink Automatic Terminal Information Service
DEMO	Demonstration
DEP	Departure Message
DFMC GBAS	Dual-frequency Multi-constellation Ground-based Augmentation System
DLS	Data Link Services
DMAN	Departure Manager
DME	Distance Measuring Equipment
DP	Departure Procedure
dS	Digital AIM and MET Service
DVOR	Doppler VOR
EAD	European AIS Database

EASA	European Union Aviation Safety Agency
EC	European Commission
ECAC	European Civil Aviation Conference
eFPL	extended flight plans
EOBT	Estimated Off-Block Time
EOC	Essential Operational Changes
E-OCVM	European Operational Concept Validation Methodology
EPP	Extended projected profile
ETFMS	Enhanced Tactical Flow Management System
EU	European Union
FAB	Functional Airspace Block
FDP	Flight Data Processing
FERA-WoC	Flexible En-route Airspace in West of China
FF-ICE	Flight and Flow Information for a Collaborative Environment
FIR	Flight Information Region
FIS	Flight Information Service/ System
FIXM	Flight Information Exchange Model
FMIT	Flight Message Transfer Protocol
FMP	Flow Management Position
FMS	Flight Management System
FMTP	Flight Message Transfer Protocol
FO IOP	Flight Object Interoperability
FPL	Flight Plan
FQIS	Fuel Quantity Indication System
FRA	Free Route Airspace
FT	Foot
FUA	Flexible Use of Airspace
GANP	Global Air Navigation Plan
GBAS	Ground Based Augmentation System

GDP	Ground delay program
GLONAS	Globalnaja Nawigazionnaja Sputnikowaja Sistema
GNSS	Global Navigation Satellite System
GOMT-PRC	General Office of Ministry of Transport of People Republic of China
GPS	Global Positioning System
GPWS	Ground-Proximity Warning Systems
GreAT	Greener Air Traffic Operations
GS	Ground Stop Program
HMI	Human Machine Interface
HUFRA	Hungarian Free Route Airspace
HUMS	Health and Usage Monitoring Systems
IAF	Initial Approach Fix
IAP	Instrument Approach Procedure
ICAO	International Civil Aviation Organization
IFPS	Initial Flight Plan Processing System
IFPUV	IFPS Validation System
IFPZ	IFPS Zone
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMA	Integrated Modular Avionics
IMC	Instrument Meteorological Conditions
iN	ATM Interconnected Network
INS	Inertial Navigation System
IPCC	Intergovernmental Panel on Climate Change
IPS	Internet Protocol Suite
IR	Implementation Rule
KPA	key performance area
KTS	Knots
LCD	Liquid-Crystal Display

LDACS	l-band Digital Aeronautical Communications System
LMP	Late Merging Point
MEL	Minimum Equipment List
MET	Meteorological
MIT	Miles In Trail
MLAT	Multilateration
MSPSR	Multi Static Primary Surveillance Radar
MSSR	Monopulse Secondary Surveillance Radar
MT	Mission Trajectory
MTCD	Medium Term Conflict Detection
MUAC	Maastricht Upper Area Control Centre
MWP	Main Work Package
M^3	Multimodal Mobility and Integration of All Airspace Users
NAA	National Aviation Authority
NDB/ADF	Non-Directional-Beacon/Automatic Direction Finder
NM	Nautical Mile
NM	Network Management
NM B2B	Network Manager Business-to-Business
NP	Network Management
NMOC	Network Manager Operations Center
NOP	Network Operation Plan
NOP	Network Operation Portal
NOTAM	Notice(s) to Airmen
NTZ	no-transgression zone
ODP	Omnidirectional departure procedures
OJTI	On-the-Job-Training Instructor
OLDI	On-Line Data Interchange
OPS	Operations/Operational
OSI	Open System Interconnection

PBCS	Performance Based Communication and Surveillance
PBN	Performance Based Navigation
PCP	Pilot Common Project
PRC	Performance Review Commission
PSR	Primary Surveillance Radar
RBT	Reference Business Trajectory
RCA	Reduced Coordinated Airspace
RECAT	(Aircraft Wake) Reclassification
RF	Radiative Force
RNAV	Area Navigation
ROT	Runway Occupancy Time
RPAS	Remotely Piloted Aircraft System
RTC	Remote Tower Center
RTO	Remote Tower Operation
RTS	Remote Tower Service
ROT	Runway Occupancy Time
RAD	Route Availability Document
RPAS	Remotely Piloted aircraft System
RTC	Remote Tower Center
RTO	Remote Tower Operation
SAXFRA	Slovenian/Austrian Cross Border Free Route Airspace
SBAS	Space Based Augmentation System
SB-S	Inmarsat Satellite Service
SECSI FRA	Free Route Airspace of Croatia, Bosnia-Herzegovina and Serbia-Montenegro
SEEFRA	South East Europe Free Route Airspace project
SES (II)	Single European Sky (II)
SESAR	Single European Sky ATM Research Program
SID	Standard Instrument Departure
SITA	Société Internationale de Télécommunications Aéronautiques

SMAN	Surface Manager
SMR	Surface Movement Radar
SOBT	Scheduled Off-Block Time
SPO	Single Pilot Operations
SSR	Secondary Surveillance Radar
STAR	Standard Instrument Arrival
STCA	Short-Term Conflict alert
SUP	Supervisor
SVFR	Special Visual Flight Rules
SWIM	System-Wide Information Management
TAWS	Terrain Awareness Warning System
TBO	Trajectory Based Operations
TIS-B	Traffic Information Service – Broadcast
TMA	Terminal Maneuvering Area
TOBT	Target Off-block Time
TRA	Temporary Reserved Area
TRACC	Taxi Routing for Aircraft: Creation and Controlling
TRL	Technology Readiness Level
TSA	Temporary Segregated Area
TSAT	Target Start up Approval Time
TTOT	Target Take-off Time
UAC	Upper Area Control Center
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UIR	Upper Flight Information Region
U-S	U-Space Services
VDLM2	VHF Data Link Mode 2
VFR	Visual Flight Rules
VHF	Very High Frequency

VMC	Visual Meteorological Conditions
VOR	VHF Omnidirectional Range
VPN	Virtual Private Network
VS	Virtualization of Service Provision
VVP	Volume Velocity Processing
WAAS	Wide Area Augmentation System
WAM	Wide Area Multilateration

1. INTRODUCTION

Global Warming and the climate change are one of today's most serious crisis, that will constitute a significant danger for future generations [Matthews 2017]. This is even amplified by the fact that the climate change is a relatively slow process, which is caused by the accumulation of greenhouse gases over years and decades [Rahmstorf 2007]. When thinking only for the next couple of years in advance, the changes are hardly measurable; therefore, economic interests have always been prioritized in the past. The further emission of greenhouse gases by daily traffic, energy production with coal or an outdated technology used in a factory was seen as acceptable, as the individual case is always only a very small contribution to worldwide climate change. And trying to save emissions here would not noticeably change the situation within the near future and would not make a big difference.

In the last few years, this thinking started to change, as the consequences of the climate change are more and more recognizable to the public. In the same way, also the awareness increases that every emission of greenhouse gases – no matter how small it is – contributes over the years and decades and indeed makes a difference. The Intergovernmental Panel on Climate Change (IPCC) considers carbon dioxide (CO_2) as the principal greenhouse gas [IPCC 2014]. Aviation represents approximately 2 to 3% of the total annual global CO_2 emissions from human activities and, in addition to CO_2, has impacts on climate from its non-CO_2 emissions (e.g. NO_X, particles) [McCollum 2010]. Uncertainties still exists in the assessment of the impact of the aviation emissions on the environment, especially regarding effects associated with non-CO_2. Nonetheless, non-CO2 impacts cannot be ignored as they potentially represent approximately 60% of total climate impacts that are important in the shorter term[1]. Regarding the Radiative Force (RF) of all aircraft emissions, studies estimate the aviation impact to be within the range 2% to 8% [Jungbluth 2018]. The CO_2 and non-CO_2 emissions from aviation are increasing continuously. Nevertheless, CO_2 emissions are becoming of high priority considering its long-term effect. As a conclusion, it is also worth thinking about how even small gas emissions can be reduced or avoided. Although aviation only contributes to global CO_2 emissions with a very low percentage, emissions savings that can be achieved there – even if they are small – are important.

1.1. PURPOSE OF THE DOCUMENT

This document has the purpose to describe and derive greener air traffic management (ATM) fundamental concepts, which are the basis for developing detailed procedures and improvements later in the project; i.e. in MWP3 (long-haul) and MWP4 (short-haul); for developing needed avionics systems (MWP5, done by Chinese partners only); and finally, for validation activities (MWP6) and the environmental impact assessment (MWP7). These detailed procedures and improvements will lead to an advanced ATM in specific use cases (e.g. terminal maneuvering area (TMA) of a medium-size airport), capable of handling the same or preferably even a higher amount of traffic with less fuel consumption and greenhouse gas emissions.

However, another important purpose of this document is to summarize the ATM features and ATM research basics in Europe and China for all scientists working in GreAT, who are probably only familiar with one of the two ATM systems. This document serves as a handbook and encyclopedia, and shall provide the same knowledge basis to all involved scientists.

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[1] https://www.easa.europa.eu/eaer/climate-change/aviation-environmental-impacts

This document has been created in direct cooperation between European and Chinese partners of GreAT. Several tutorial sessions were held to further promote the common understanding of each other's ATM system and research actions. Several online workshop sessions with all involved partners followed to clarify any questions and to work on the EU-China comparison.

1.2. SCOPE

This document will analyze the current ATM practices for supporting environmentally friendly flying in Europe and in China. This serves as a baseline for developing the greener ATM concepts, as well as for comparing it with solution scenarios during validation activities later in the project. Further, existing developments, achievements and intentions regarding greener ATM in both world regions are considered, as well as requirements on ATM concepts defined by the International Civil Aviation Organization (ICAO). As current research activities and future roadmaps are very much pointing at realizing trajectory-based operations (TBO), this document is also focused on this new approach, being the way to advance the Air Traffic Management System.

Based on this, a flight-centered analysis of the most fuel-efficient way of conducting a flight, which serves as a best-case scenario, will follow. This best-case scenario will reflect the maximum possible achievement that can be realized with trajectory optimization, and will also be used to assess the progress that can be achieved with the new concepts later.

Finally, concept elements will be derived that can serve as building blocks for constructing greener ATM concepts for a detailed use case. Several examples how these building blocks can be assembled to a whole concept will be provided, which are the basic concepts for later activities in the project.

1.3. INTENDED READERSHIP

This section describes the intended audience for this document. In general, readers of this document can be:

1) Readers internal to the project, using this document as input for their own activities;
2) Readers from the GreAT sister projects (ACACIA, CLIMOP and ALTERNATE), to follow latest developments and approaches, and to drive scientific exchange between the sister projects. This is for the purpose of aligning the activities of all four projects and to identify synergy effects. Finally, this document can also serve as reference for scientific publications.
3) Readers from the GreAT Advisory board, to provide input and to follow the developments from a stakeholder point of view.
4) Readers involved in current and future projects dealing with reducing the impact of aviation on climate change, especially to build upon the approaches described in this document; and to align other developments (e.g. modifications to aircraft propulsion and airframe) with it.
5) Readers from air navigation service providers (ANSPs) or other stakeholders not involved in the project but effected from its improvements (especially airports, airlines and air traffic control (ATC) equipment providers).

6) Standardization bodies and regulating authorities / organizations, such as ICAO, European Union Aviation Safety Agency (EASA), EUROCONTROL or Civil Aviation Administration of China (CAAC).
7) All other interested members of aviation community.

1.4. STRUCTURE OF THE DOCUMENT

This document contains the following sections:

Chapter 1 Introduction – describes the purpose and scope of the document, the intended audience and the document structure.

Chapter 2 Baseline Situation – outlines the current ATM practices in Europe and China, and identifies the current procedures already in place to guide and manage air traffic in the best way. A comparison between Europe and China is included.

Chapter 3 Future ATM Programs and Concepts – describes current research activities and initiatives before and outside of the GreAT project, and summarizes ICAO requirements for ATM concepts. Again, a comparison between Europe and China is included.

Chapter 4 Concept for Greener Air Traffic Management – this section starts with a flight-centered analysis of the best possible and most fuel-efficient way of conducting a flight. Based on this, functional building blocks for greener ATM concepts are derived. Finally, this section provides examples on how these building blocks can be used and assembled to new procedures or improvements that are enabling a greener ATM for a specific use case. These examples are the basic concepts that are the foundation for later activities in the project.

Chapter 5 References – contains the references.

Chapter 6 Annex A – contains a list of concept elements.

To ease the correlation with the work plan, the related tasks are highlighted in the headlines.

2. BASELINE SITUATION

This section outlines the current ATM practices in Europe and China, and identifies the current procedures already in place to guide and manage air traffic in the best way. A comparison between Europe and China is included. This serves on one hand as a starting point for developing greener ATM concepts, and on the other hand as reference for being compared with the solution scenarios during validation activities conducted in GreAT.

At first, the baseline situation in Europe is described. Secondly, a description of the baseline situation in China with the same structure follows. Section structures are aligned to ease the comparison, which can be found at the end of this section.

2.1. BASELINE SITUATION IN EUROPE (T2.1.1)

The two main characteristics of the European ATM system are fragmentation and monolithic ATM structures. There is a two-level system in Europe; the first one is national or state level, where you can find the ANSPs, and the other one is a supranational one, where you can find the European level institutions, like European Union (EU)[2], EUROCONTROL[3] and EASA[4]. The challenge of the European aviation industry is to manage, organize and optimize air traffic in an efficient, environmentally friendly and safe way without causing unnecessary delay. This shall preferably be achieved by common thoughts and coordinated actions.

In this chapter, a picture of the main characteristics of the European ATM baseline situation that has relevance on the objectives of the GreAT project is provided.

2.1.1. OPERATIONAL BASELINE

2.1.1.1 AIRSPACE STRUCTURE AND MANAGEMENT

Airspace Management (ASM) is a planning function basically aimed to ensure maximum utilization of available airspace as one continuum, considering real short-term needs of its various civil and military users.

According to EUROCONTROL, the primary objectives of Airspace Management are as follows [EUROCONTROL 2020b]

- to achieve the most efficient use of the airspace based on actual needs and
- where possible, to avoid permanent airspace segregation while optimizing the network performance and
- to guarantee the availability of the airspace to all airspace users and
- to place the various airspace users in the airspace structure and
- to optimize the airspace structure and configuration and
- to perform dynamic airspace management for optimal airspace configuration.

En-route operations

Airspace in Europe is divided into Flight Information Regions (FIR)[5]. Each member state of the European Union (EU) has one or more own FIR(s). The structure of airspace is developed by the principles laid down in ICAO ANNEX 11. The structural division of airspace provides airspace users with safe, efficient, standards-based rules and airspace blocks that are clearly applicable to all. Besides the common international rules, every European country can apply their own rules in their airspace as supplements to the international ones. In case of a diversion from the rules set in ICAO ANNEX-es, the respective state has to report it to the ICAO Council and publish its diversions from ICAO standards in the national Aeronautical Information Publication (AIP)[6]. The rules set by European Union call for unconditional enforcement.

Although there are several initiatives aimed at reducing the level of fragmentation, ATM is still largely organized according to national boundaries, which is reflected by the considerably high number of en-route centers and a diversity of ATM systems inter alia Flight Data Processing (FDP) systems. Vertical limits differ from country to country, but FL660 is the widely used as upper FIR limit. The FIR definition of a given country is published in its AIP, which is an information package issued by the authority of a state and contains aeronautical information of a lasting character essential to air navigation. FIRs are divided into an upper and a lower airspace along a variable vertical limit, which is defined individually by every European country (e.g. FL245 in Germany and FL285 in Serbia

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[2] See https://europa.eu/european-union/index_en

[3] See https://www.eurocontrol.int/about-us

[4] See https://www.easa.europa.eu/home

[5] See https://www.skybrary.aero/index.php/Flight_Information_Regions_(FIRs)

[6] See https://www.skybrary.aero/index.php/Aeronautical_Information_Publications_(AIPs)

and Montenegro). In each FIR, or across FIRs, one or several ACCs (Area Control Center) and/or UACs (Upper Area Control Center) provide en-route air traffic services. The current areas of responsibility of ACCs and UACs are designed mainly according to national boundaries. There are several examples of ACCs and UACs involving cross-border service delegations.

The lower airspace is part of the airspace below the variable vertical limit. It is controlled airspace below this level and outside the terminal or airport airspace and includes airways linking the airport with upper airspace.

On the other hand, the airspace is classified as per ICAO into different categories: A, B, C, D, E, F and G. The ICAO introduced airspace classifications in 1990. These are recommendations, as each ICAO country has the right to organize its airspace according to its own specific demands. The German airspace structure can be seen in Figure 1 as an example:

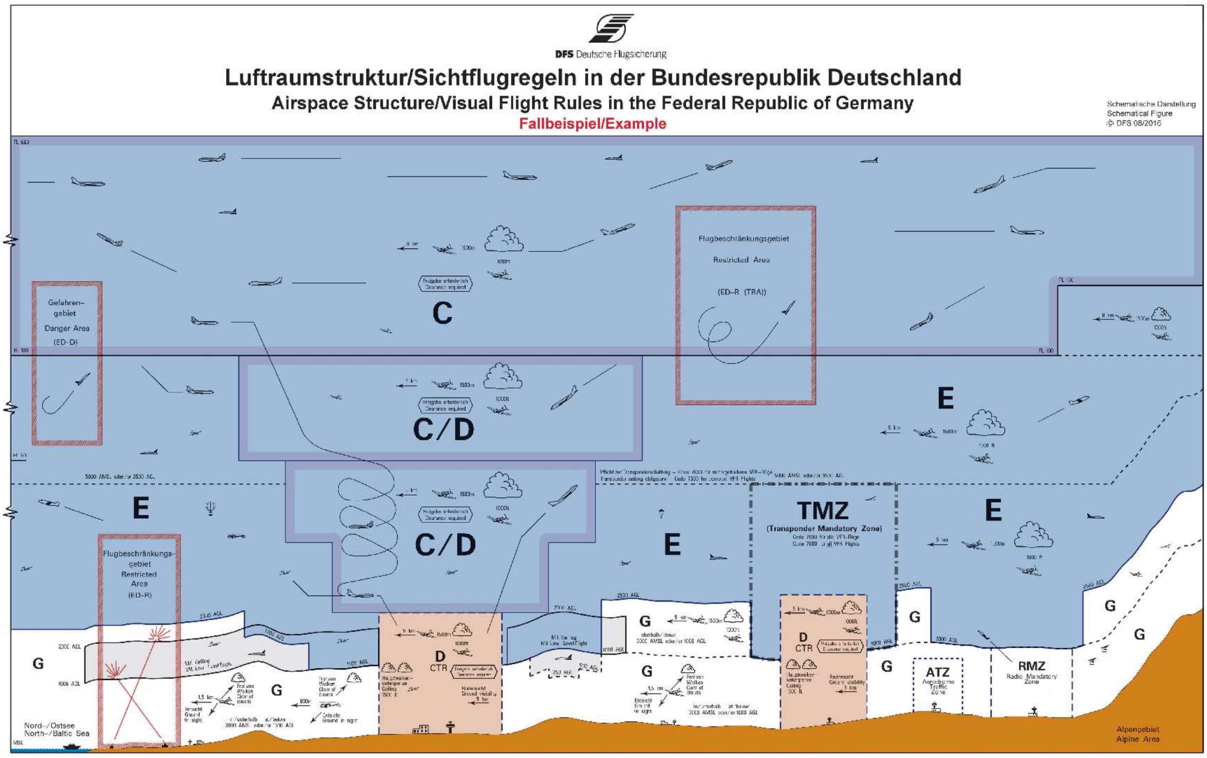

Figure 1: The three core areas of ATM[7]

Flexible use of airspace (FUA)

Due to the growing public and military demand of air transport and expanding need for air traffic services, the Flexible Use of Airspace (FUA) Concept[8] was introduced in March 1996 after development by civil and military representatives of the European Civil Aviation Conference (ECAC) States, together with representatives of aircraft operators. The introduction of the FUA Concept is based on the fundamental principle that airspace is one continuum to be allocated for use on a day-to-day basis to accommodate user requirements.

The EUROCONTROL concept of the FUA stipulates that:

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[7] https://www.dfs.de/dfs_homepage/de/Flugsicherung/Luftraum/luftraumstruktur_092016.pdf

[8] https://www.skybrary.aero/index.php/Flexible_Use_of_Airspace

- airspace is no longer designated as purely "civil" or "military" airspace, but considered as one continuum and allocated according to user requirements,
- any necessary airspace segregation is temporary, based on real-time usage within a specific time period,
- contiguous volumes of airspace are not constrained by national boundaries.

In the past, the concept of FUA was a recommendation by EUROCONTROL; therefore, compliance was not compulsory for member states. When the European Union started to coordinate the projects of EUROCONTROL, recommendations became decrees. From this point, the FUA had become a regulatory document, which is regulated by the ordinances of SES II (Single European Sky II), and have become mandatory for all member states of EUROCONTROL.

The FUA concept has increased the flexibility of airspace use and has provided ATM with the potential to increase the air traffic system performance. It allows the maximum common use of airspace by appropriate coordination between civil and/or military users.

The FUA concept is also applicable to enhancing airspace usage based on any temporary airspace structures as a function of achieving increased airspace capacity and flight efficiency.

In a cleansed FUA, there are two types of military airspaces: The Temporary Reserved Area (TRA) which is crossable during its operation time and the Temporary Segregated Area (TSA) which is absolutely closed from the other parties when it is active. In the previous type of airspaces, there is special kind of routes called Conditional Routes (CDR)[9]. The conditional routes are non-permanent ATS routes or portions thereof which can be planned and used under specified conditions. According to their foreseen availability and flight planning possibilities, CDRs can be divided into the following categories:

- Category One: Permanently Plannable CDR, which is practically usable every time.
- Category Two: Non-Permanently Plannable CDR, which is not available whenever the TRA or TSA is in operation.
- Category Three: Not Plannable CDR which has rarely useable time.

FUA calls for the creation of Airspace Management Cells (AMC) in every ATM system managed and coordinated by EUROCONTROL. An AMC is a joint civil/military cell responsible for the day-to-day management and temporary allocation of national or sub-regional airspace under the jurisdiction of one or more ECAC state(s). So, this cell is responsible for the operational airspace management (level 2), i.e. pre-tactical level. The regulatory system allows a wide range of opportunities for the application of different restrictions for each type of flight (commercial, military, etc.) in each country. Matching that with the different density and complexity of traffic, it results in big differences between the procedures of European countries. To promote the greatest possible unity, EUROCONTROL and ANSPs use special kind of solutions.

Free Route Airspace

Free Route Airspace (FRA)[10] is a specified volume of airspace where users may freely plan a route between defined entry and exit points. Subject to airspace availability, routing is possible via intermediate waypoints, without reference to the ATS route network. Inside this airspace, flights remain subject to air traffic control. FRA is a way of overcoming the aviation sector's efficiency, capacity and environmental problems by helping in the

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[9] https://www.skybrary.aero/index.php/Conditional_Route

[10] https://www.skybrary.aero/index.php/Free_Route_Airspace_(FRA)

reduction of fuel consumption and emissions, while improving flight efficiency. At the same time, it paves the way for further enhanced airspace design and ATM operational concepts.

European flights reached a record low in terms of en-route flight extension at the end of 2017. Route extension - the difference between the flight flown and the corresponding portion of the great circle distance - reached an average of 3.17% in 2012. In 2017, this fell to 2.77%, very close to the Europe-wide performance target of 2.6% by 2019, thanks in part to initiatives like free route airspace. FRA is a key landmark in achieving free routing across European airspace on the road to SESAR's business trajectories and 4D profiles. It will make possible meeting the demands of future airspace users over the next 50 years, including civil and military Unmanned Aircraft Systems (UAS), hypersonic transport, and spaceplane operations to sub-orbit, wireless network balloons and airships. Operating an FRA environment offers improved traffic predictability due to more stable trajectories. At the same time, it enhances the use of conflict detection tools. This concept can lead to a better spread of conflicts compared to the concentration of conflicts generated by the current fixed route network. EUROCONTROL studies also show a slight decrease in the workload of controllers as a result of free route airspace, in addition to a decrease in radio transmissions, as well as evaluation and coordination tasks. All Air Traffic Controllers (ATCO) working with free route airspace are adamant; they do not want to go back to a fixed-route network. Previously, aircraft were receiving direct routes, but there was no logical correlation between the fixed-route network and how aircraft actually flew. Free route airspace offers ATCOs the flexibility to handle the traffic tactically with the correct flight plans.

EUROCONTROL initiated the development and implementation of the FRA concept in cooperation with civil and military experts in airspace design, the ECAC Member States, ANSPs, airspace users, flight planning organizations and relevant international bodies. EUROCONTROL in its role as Network Manager (NM), are currently responsible for the implementation of an advanced concept of operations and free route operations, while providing the Pan-European view of FRA deployment. They ensure and coordinate the gradual implementation of FRA in a harmonized way, throughout European airspace. As NM, EUROCONTROL provides support to ANSPs in the form of airspace design, concept of operations, advice on aeronautical publication and the pre-validation of each new FRA environment to ensure that airspace users can plan flights in line with the concept. Their dedicated teams deliver appropriate solutions to further enhance operational performance and resolve any potential problems, which may arise as a result following the implementation of the FRA. They offer proactive coordination and technical and operational support for local or sub-regional free route airspace initiatives, ensuring that the requisite network improvements are in place to support those initiatives.

Free route operations can be:

- Time limited (e.g. at night) – this is usually a transitional step that facilitates early implementation and allows field evaluation of the FRA while minimizing the safety risks.
- Structurally or geographically limited (e.g. restricting entry or exit points for certain traffic flows, applicable within CTAs or upper airspace only) – this could be done in complex airspaces where full implementation could have a negative impact on capacity.
- Implemented in a Functional Airspace Block (FAB) environment – a further stage in the implementation of FRA. The operators should treat the FAB as one large FIR.
- Within SES airspace – this is the ultimate goal of FRA deployment in Europe.

As of February 5th, 2015, HungaroControl was the first in Europe to abolish the entire fixed flight route network, thus enabling airlines to plan their routes through the airspace freely.

The introduction of HUFRA was preceded by a series of tests over several weeks in HungaroControl's Simulation Hub (at that time, CRDS - Centre of Research, Development and Simulation). The concept achieved its final form after specialists from the twenty most representative airlines using Hungarian airspace had provided their opinions.

Across Europe several FRA initiatives are implemented in different forms (i.e. FRA and route network mix, published direct route network, temporary FRAs, etc.).

The Slovenian/Austrian Cross Border Free Route Airspace (SAXFRA) became the first one in Central-Europe to provide 24/7 cross border free operations across the airspace of Austria and Slovenia, which was later expanded into Croatia, Bosnia-Herzegovina and Serbia-Montenegro airspaces, called SECSI FRA.

As of November 7th, 2019, the South East Europe Free Route Airspace project (SEEFRA) provides round-the-clock cross-border free route operations across the airspace of Bulgaria, Hungary and Romania[11].

The implementation of the FRA concept has brought to life a large amount of new route planning possibilities, which had not been available by the nature of the rigid route network through the airspace. Implementation of the FRA concept has finally earned the satisfaction from the airspace users' side as they have got much more overflight options. The benefit given to the airlines is a wider choice of the optional routings, and consequently, the possibility to plan and file more efficient routes, reducing the environmental impact.

However, recently, in some cases, the excessive traffic density and complexity can overwrite the necessity and efficiency of FRA. In very congested airspaces, the use of routes may prove to be more effective and safer than applying a full FRA. It causes among other things, that the use of FRA is just temporary, or just above a given flight level in the most congested, so-called "Core area". That means that nowadays the European air transport to some extent clearly needs routes. Canalization of traffic in these areas still has a vital role.

Where the published routes are used for flight planning, the controllers can apply shortcuts too. 'Shortcut' means that for any reason the pilot requests a shorter direct route instead of following the planned one. If it is possible, it will be obtained. Outside the active military areas, obtaining a short cut is not subject of the prior consent of military authority.

Common TMA airspace structures and procedures

Terminal Maneuvering Areas (TMA) or Terminal Control Areas are high complexity airspaces with the least amount of airspace available whose precise organization is a key factor in ATM.

Within the TMA, both geographical and functional (arrival and departure) sectorization are needed to accommodate traffic growth. Also, an increased use of a dedicated sequencing function for final approach should be considered.

Airports are an integral part of airspace configurations within the TMA. Runway throughput, selection of the runway in use, and airport capacity in general affect the choice of airspace configuration.

The main principles of the terminal airspace structure are:

- Terminal routes, holding patterns and their associated protected airspaces are to be contained within controlled airspace.

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[11] https://www.fab-ce.eu/airspace/free-route

- To the extent possible, a terminal airspace should be compatible with the routes and holdings to be contained within it.
- To the extent possible, only the airspace necessary to contain the terminal routes should be designated as terminal airspace so as not to constrain the operation of non-participating (usually visual flight rules (VFR)) flights.
- When necessitated by operational requirements, adjacent terminal airspaces should be fused in.
- When necessitated by operational requirements, consideration should be given as to whether and to what extent, certain parts of the airspace are to be switched "on" or "off" in accordance with the flexible use of airspace concept.

Almost every European country is trying to follow the main principles of TMA design because they provide the most efficient, safe and logical construction for the appropriate operation. To have a reliable, well-built, comprehensive TMA system, it is necessary to apply some kind of procedures to ensure the efficient and safe departure and arrival operations.

There are DPs (Departure Procedures) and APs (Arrival Procedures)[12/13]. The instrument departure procedures are preplanned Instrument Flight Rules (IFR) procedures that provide obstruction clearance from the terminal area to the appropriate en-route structure, and provide the pilot with a way to depart from the airport and transit to the en-route structure safely. There are two types of DPs:

- Omnidirectional Departure Procedures (ODP), printed either textually or graphically, and
- Standard Instrument Departure (SID), always printed graphically.

SIDs and Standard Terminal Arrival Routes (STAR) are charted instrument procedure designs depicting the lateral profile that pilots must follow for landing or departing at suitably equipped aerodromes. Various level and speed restrictions apply along the route. There is a standardized system of communication for SID and STAR procedures to ensure efficient and concise communication that would otherwise require long and complex radio transmissions between the pilot and air traffic control. SID and STAR designs and standardized transmissions are an effective way of communicating a large amount of complex information for safe and efficient departures and arrivals and are in place worldwide through the ICAO.

Besides, Area Navigation/ Global Positioning System (RNAV/GPS) transitions exist at many airports in Europe. A transition is a sort of standard arrival route which leads to the downwind leg of the traffic pattern. From there on the downwind leg is extended to join the long extended runway centerline along both legs numerous waypoints are placed to facilitate traffic sequencing. Turn onto final leg may be expected earliest abeam the last waypoint before the FAP/FAF, which happens normally at the first waypoint of the downwind leg. They are mainly used in very high traffic TMA structures and very busy aerodromes (e.g.: Munich, Frankfurt, Vienna, etc.). At some places in Europe, Point Merge system is also used, which was developed by EUROCONTROL about 10 years ago. This is also very useful in terms of sequencing and it provides continuous flow. Sometimes it is easier to do sequencing with a Point Merge system, because the traffic merges into a single common point rather than being vectored along downwind (e.g.: Dublin, Oslo, London

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[12] https://www.casa.gov.au/airspace/navigation-requirements/standard-instrument-departures-and-arrivals

[13] https://www.flightliteracy.com/departure-procedures-dps/

City). At many busy airports in Europe, arrival managers (AMAN) are used to conduct of the sequencing.

More and more European airports (e.g. Cologne, Prague, Oslo, Bergen), including Budapest, have T- or Y-bar based instrument approach procedures (IAP), where the final waypoint of the STAR is the initial approach fix (IAF) of the IAP. The basic concept of that is to provide arriving aircraft with a route that reflects the daily traffic management routine of the air traffic controllers during the initial control service. This provides airlines with a more accurate arrival profile. With the introduction of the T-bar concept, the variance of flight paths in terms of navigation points (waypoints) is significantly reduced. This has a positive environmental impact, as the overall length of the aircraft route is shorter, resulting in fuel savings and consequently a reduction in CO_2 emissions. Also, due to the reduction of runway scattering, the area affected by overflight noise is concentrated in the area below the flight path, which results in significantly smaller noise emission than it was before the introduction of the T-bar concept.

Control zone (CTR) structures and procedures

In general, the main feature of European airspace is short distances. Due to high population, airports in Europe are close to each other, on average 2 to 3 hours flight distance. Consequently, aircraft rotate about 3 to 5 times a day, which causes a very high traffic demand. High service continuity (24/7) is needed to accommodate to this high traffic demand and besides, contingency features must be taken into consideration as well. Airport design is crucial in an appropriate CTR traffic management. In Europe, for efficient air traffic management at the busy airports, independent parallel runways are required with rapid exit taxiways. Advanced ATM systems are used in Europe covering 3 major areas:

- integrated radar and flight data processing system,
- integrated decision support tools like arrival or departure manager, CDM, and
- automatization (e.g. digital ATC clearances, digital ATIS, alerts).

The next key aspect is the staff who can deliver the service at high level. The tower air traffic controllers are highly educated, continuously trained and often have radar ratings. Tower controller working positions are defined according to the local circumstances. In Budapest for example, the aerodrome control tower has a conventional layout. We can find a tower supervisor, aerodrome controller, tower planning controller, ground controller and clearance delivery controller at the working positions. At some European airports, with more traffic, aerodrome controllers might be assigned for dedicated runways.

Major European airports are capable of CAT I-II-III precision approach and landing operations (including Instrument Landing System (ILS)). Special systems, e.g. Advanced Surface Movement Guidance and Control System (A-SMGCS) are also widespread in Europe to enable handling air traffic under bad weather conditions as well.

2.1.1.2 MAIN TRAFFIC FLOWS

In general, the vast majority of flights in Europe are flights between European States (intra-European) and domestic flights. Currently, they account for nearly 80% of the total traffic. Arrivals and departures related to intercontinental traffic to and from Europe account for 19% whereas overflights (neither departing, nor arriving in Europe) represent a minor stake in European air traffic with less than 2% [EUROCONTROL 2018a].

As highlighted by Figure 2, the volume of European air traffic has been increasing continuously from 2013 until the outbreak of COVID-19, and this increase is exponential and follows the global trend. The cargo flights are negligibly small compared to the conventional (passenger) flights.

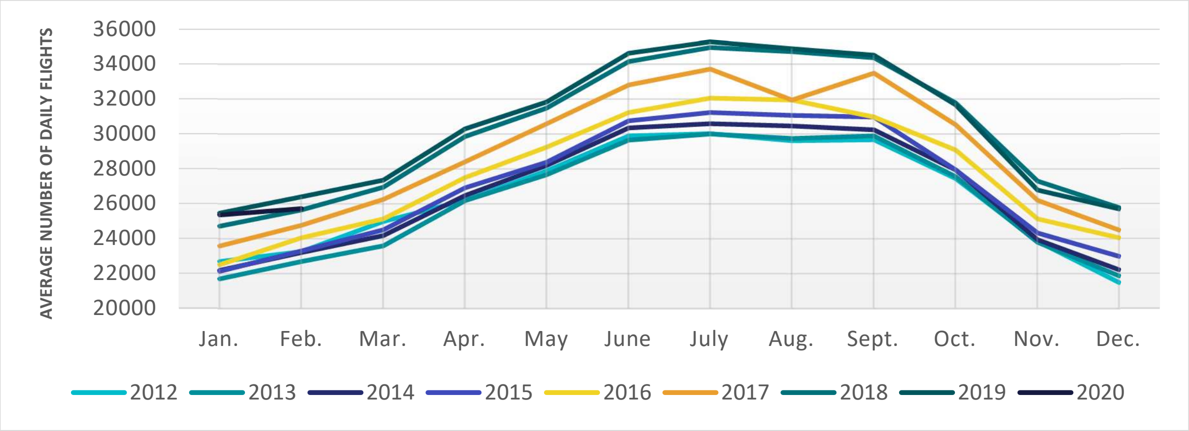

Figure 2: Average number of flights in Europe between 2012 and 2020

The statistic numbers presented in Figure 2 are extracted from own edition based on the Network Operations Portal of EUROCONTROL.

Besides, the bell-curve nature of traffic flow highlights the habits of European passengers. It means that the European passengers travel more during summer (June, July and August) when the weather is good. In addition, the traffic significantly decreased in 2020. It is due to COVID-19 virus that causes a huge relapse in all parts of the economy and industry.

The assessments in Figure 3 were made for the period 1st July 2007 - 30th June 2008 and 1st July 2017 - 30th June 2018. The short-haul traffic pattern [distances up to 400 NM (Nautical Miles) – see Figure 3 below] shows a decrease of domestic and business traffic for short-haul flights in most of the European airspace, particularly in UK and Germany, in Spain (mainly for the city pair Barcelona & Madrid) and in Northern Italy (especially the city pair Milano & Rome). Compared to 2008, a higher density of traffic is noted predominantly in Turkey and the West Jordanland as well as along the Portuguese coast, the Riga - Tallin Axis and Aberdeen - Shetland Islands Axis.

The medium to long-haul traffic pattern (flight distances over 400 NM – see Figure 3 below) shows that the traffic further increases in the whole ECAC area and adjacent non-ECAC area, significantly on the South-East Axis, South-West Axis, North-South Axis, East-West Axis, parts of the Mediterranean area and a significant increase in Turkey, particularly for Istanbul airport [EUROCONTROL 2020c].

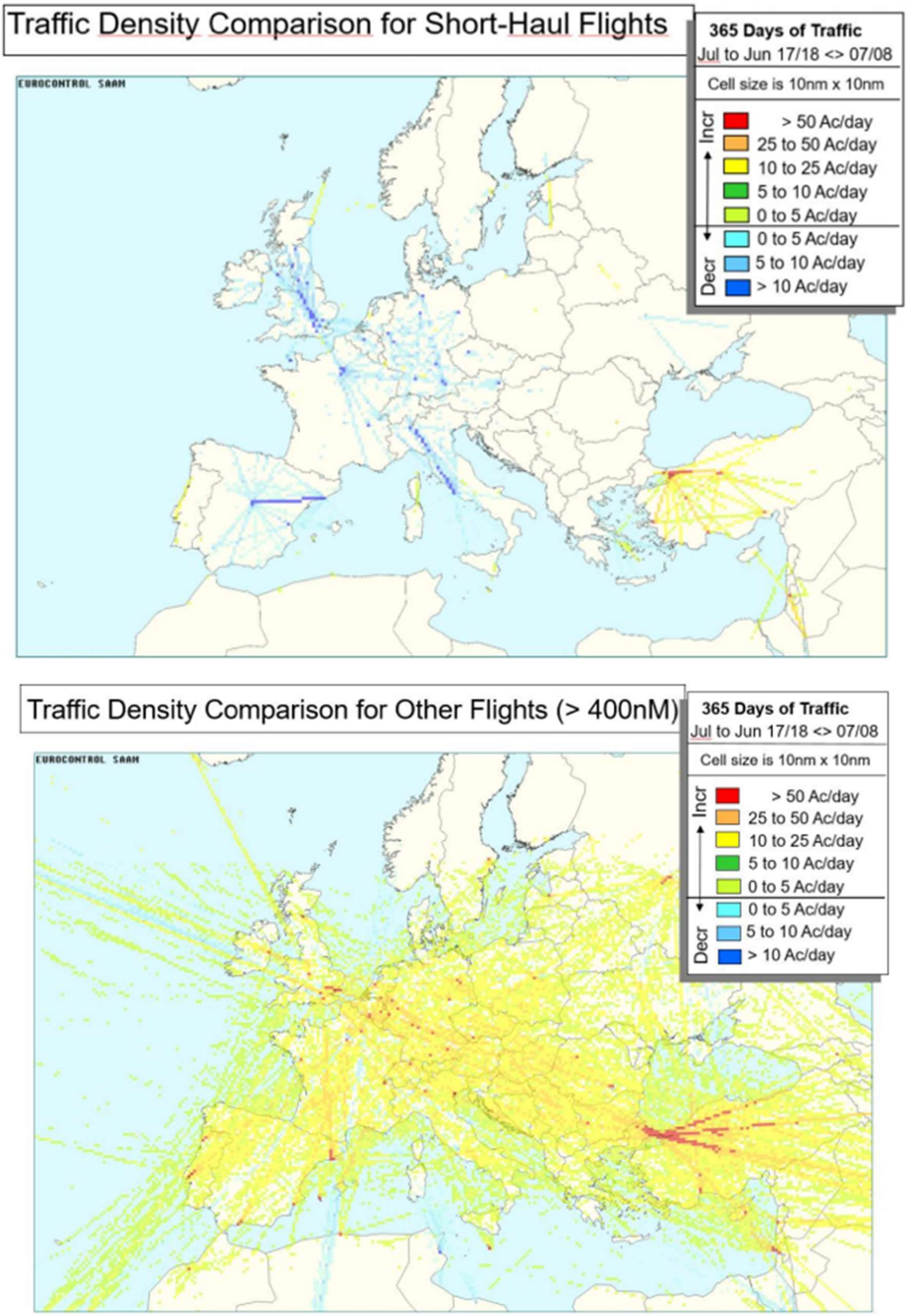

Figure 3: Short-Haul Flights (on the left) (<400 NM) and Medium-Haul Flights (on the right) (>400 NM)

Future trends in European air traffic

The general trend observed in this forecast [EUROCONTROL 2018b] is the progressive contraction of the share of the intra-European traffic (about 74% in the most-likely scenario in 2040), which is compensated by the increase of the share of the arrivals and departures (about 23%). One of the reasons is the expected slowdown of growth in the already mature markets (Western Europe). Furthermore, the lack of capacity at airports is also having an impact on the intra-European development. Moreover, the Middle- East hubs are preferred to the European ones in this scenario (except Turkey, with Istanbul playing a key role as a hub). The overflight traffic is expected to grow at a 3.9% rate per year but remains less than 3% of the total traffic.

Most congested airspaces and airports in Europe

The Performance Review Unit of EUROCONTROL, in close collaboration with ANSPs, has defined a set of complexity indicators that can be applied in ANSP benchmarking for the characterization of airspace congestion[14]. The complexity indicators are computed on a systematic basis for each day of the year, and are based on the concept of "interactions" arising when there are two aircraft in the same "place" at the same time. Hence, the complexity score is a measure of the potential number of interactions between aircraft defined as the total duration of all interactions (in minutes) per flight-hour controlled in a given volume of airspace. The complexity score is the product of two components, which are the traffic density and the structural index.

The traffic density is expressed in adjusted density, which measures the (uneven) distribution of traffic throughout the airspace (i.e. considering the relative concentration). The measure relies on dividing the airspace volume into a discrete grid of 20 nautical mile cells so the complexity depends on the size of the airspace too. An interaction is defined as the simultaneous presence of two aircraft in a cell of 20x20 nautical miles and 3,000 feet in height.

Skyguide (Meyrin-Switzerland), MUAC (Maastricht-Netherlands), NATS (United Kingdom), DFS (Langen-Germany), Skeyes (Steenokkerzeel-Belgium) and the Slovenia Control (Ljubjana-Slovenia) have controlled the most congested airspaces in Europe 2019 (refer to Figure 4 and Figure 5).

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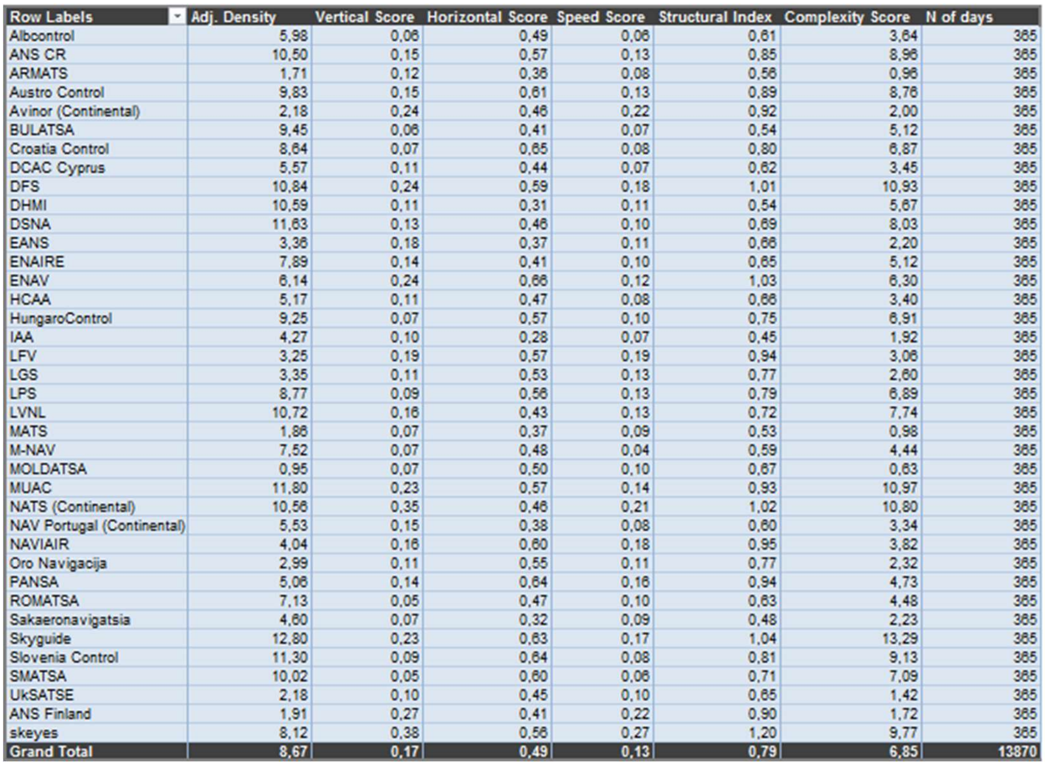
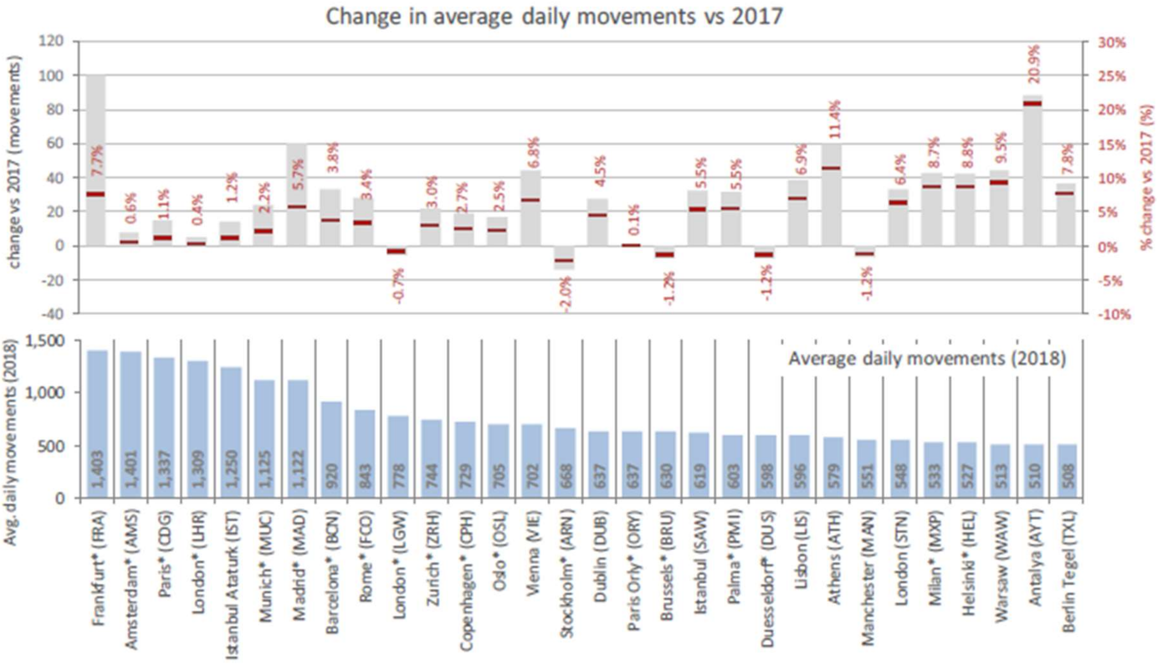
[14] https://ansperformance.eu/reference/dataset/traffic-complexity-score/



Row Labels	Adj. Density	Vertical Score	Horizontal Score	Speed Score	Structural Index	Complexity Score	N of days
Albcontrol	5,98	0,06	0,49	0,06	0,61	3,64	365
ANS CR	10,50	0,15	0,57	0,13	0,85	8,96	365
ARMATS	1,71	0,12	0,36	0,08	0,56	0,96	365
Austro Control	9,83	0,15	0,61	0,13	0,89	8,76	365
Avinor (Continental)	2,18	0,24	0,46	0,22	0,92	2,00	365
BULATSA	9,45	0,06	0,41	0,07	0,54	5,12	365
Croatia Control	8,64	0,07	0,65	0,08	0,80	6,87	365
DCAC Cyprus	5,57	0,11	0,44	0,07	0,62	3,45	365
DFS	10,84	0,24	0,59	0,18	1,01	10,93	365
DHMI	10,59	0,11	0,31	0,11	0,54	5,67	365
DSNA	11,63	0,13	0,46	0,10	0,69	8,03	365
EANS	3,36	0,18	0,37	0,11	0,66	2,20	365
ENAIRE	7,89	0,14	0,41	0,10	0,65	5,12	365
ENAV	6,14	0,24	0,66	0,12	1,03	6,30	365
HCAA	5,17	0,11	0,47	0,08	0,66	3,40	365
HungaroControl	9,25	0,07	0,57	0,10	0,75	6,91	365
IAA	4,27	0,10	0,28	0,07	0,45	1,92	365
LFV	3,25	0,19	0,57	0,19	0,94	3,06	365
LGS	3,35	0,11	0,53	0,13	0,77	2,60	365
LPS	8,77	0,09	0,56	0,13	0,79	6,89	365
LVNL	10,72	0,16	0,43	0,13	0,72	7,74	365
MATS	1,86	0,07	0,37	0,09	0,53	0,98	365
M-NAV	7,52	0,07	0,48	0,04	0,59	4,44	365
MOLDATSA	0,95	0,07	0,50	0,10	0,67	0,63	365
MUAC	11,80	0,23	0,57	0,14	0,93	10,97	365
NATS (Continental)	10,56	0,35	0,46	0,21	1,02	10,80	365
NAV Portugal (Continental)	5,53	0,15	0,38	0,08	0,60	3,34	365
NAVIAIR	4,04	0,16	0,60	0,18	0,95	3,82	365
Oro Navigacija	2,99	0,11	0,55	0,11	0,77	2,32	365
PANSA	5,06	0,14	0,64	0,16	0,94	4,73	365
ROMATSA	7,13	0,05	0,47	0,10	0,63	4,48	365
Sakaeronavigatsia	4,60	0,07	0,32	0,09	0,48	2,23	365
Skyguide	12,80	0,23	0,63	0,17	1,04	13,29	365
Slovenia Control	11,30	0,09	0,64	0,08	0,81	9,13	365
SMATSA	10,02	0,05	0,60	0,06	0,71	7,09	365
UkSATSE	2,18	0,10	0,45	0,10	0,65	1,42	365
ANS Finland	1,91	0,27	0,41	0,22	0,90	1,72	365
skeyes	8,12	0,38	0,56	0,27	1,20	9,77	365
Grand Total	8,67	0,17	0,49	0,13	0,79	6,85	13870

Figure 4: The complexity score of the Europe's member states according to the statistics of EUROCONTROL in 2019[15]



** A-CDM implemented airport*

Source: Network manager; PRC analysis

Figure 5: Traffic variation at the top 30 European airports (2017/2018)

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[15] https://ansperformance.eu/data/

Another main characteristic of the air traffic is the congestion of the airports. Obviously similar to the situation in the air, airports have increasingly lower spare capacity. Figure 5 shows the average daily movements of the top 30 European airports in 2018 and the change compared to 2017 [EUROCONTROL 2019b]. It should be also noted that the most crowded airports are mainly located in the Western side of Europe due to business activities, tourism, and the fact that they are hub airports.

Finally, it is important to mention another factor that can reduce the capacity of airports, called night flying restrictions or curfews. This is a legislative factor that aims at reducing the noise pollution caused by aviation and thus improving the home comfort of those living in the surroundings of an airport. These are rules imposed on aircraft operators that prohibit aircraft take-offs and/or landings during a specified period. Such night flight restrictions may apply to all aircraft or only to a certain number of aircraft, according to their noise performance and the intentions of the regulator. Annex 16 from the convention on International Civil Aviation sets a framework for the noise classification of aircraft. The classifications reflect the size of the aircraft and the engine type, and they are linked to a reduction in noise as technology evolves. There are no global regulations on aircraft noise, however, on local level, noise restrictions are often reflected in airport's operational license (including limits on the number of movements or the total permitted noise) or on permission to expand airport infrastructure. Annex 16 classifications are internationally recognized for use in regulation at the state or airport level. These regulations have become progressively stricter, with attention first paid to the very early jet aircraft, then to reducing 'Chapter-Two' aircraft or fitting 'hush-kits' to reduce their noise. Please find three European examples from different countries and airports of different size (only main rules, for details please refer to the page note literature) [Cook 2016]:

- Amsterdam-Schiphol: the nighttime noise exposure limits are now based on the period between 23:00 and 07:00 hour[16].
- Budapest Liszt Ferenc International Airport: no scheduled flights will be allowed to take off or land at BUD between 00:00 and 05:00.[17]
- Stuttgart Airport has a strict night flight restriction which applies to departures between 23:00 and 06:00 and arrivals between 23:30 and 06:00.[18]

2.1.1.3 FLIGHT RULES

Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) are the two sets of rules for operating any aircraft[19]. The type of flying you use, whether it is IFR or VFR, will depend mainly on the weather conditions. While there are several other factors that influence the decision, it's usually the weather and the purpose of the flight that dictates the used flight rules. The European countries basically follow the flight rules produced by ICAO, but if they have some differences from these, they have to declare that in their national AIP. VFR are the rules that govern the operation of aircraft in Visual Meteorological Conditions (VMC) [conditions in which flight solely by visual reference is possible]. Because of the limited communication and/or navigation equipment required for VFR flight, a VFR aircraft may be subject to limitations under which it is permitted to fly in controlled airspace. Any conditions

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[16] https://www.schiphol.nl/en/schiphol-as-a-neighbour/page/flight-paths-and-runway-use/

[17] https://ais.hungarocontrol.hu/aip/2020-03-26/2020-03-26-AIRAC/html/eAIP/LH-AD-2.LHBP-en-HU.html

[18] https://www.stuttgart-airport.com/fairport-str/aircraft-noise-noise-protection

[19] https://inflightpilottraining.com/2019/04/19/ifr-vs-vfr-whats-the-difference-between-these-two-flying-methods/

are detailed in national AIPs. The minimum requirements for VFR flight are detailed in EU-OPS 1 and JAR-OPS 3[20].

IFR are rules, which allow properly equipped aircraft to be flown under Instrument Meteorological Conditions (IMC) [meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling, less than the minima specified for VMC]. IFR are detailed in ICAO Annex 2: Rules of the Air, Chapter 5: Instrument Flight Rules. JAR-OPS 1.652 and associated guidance material specifies the flight and navigational instruments and associated equipment required for IFR or night operations. This may be supplemented by requirements contained in national AIPs. Minimum equipment lists (MEL) detail the conditions under which IFR flights may be commenced or continued when elements of aircraft equipment are unserviceable[21].

2.1.1.4 ATM ORGANIZATION

According to the European understanding, Air Navigation Services (ANS) as shown in Figure 6 can be divided into 5 main parts. These services are provided during all phases of operations (approach, aerodrome and en-route). In this chapter, the organization of air traffic management (ATM) in Europe is introduced especially in respect of ATS. In particular, the role of the Network Manager on European level entity is presented together with ANSPs as national level entities. The Network Manager plays a key role in the overall EU-level coordination, but the ANSPs are still responsible for the implementation of air traffic management procedures.

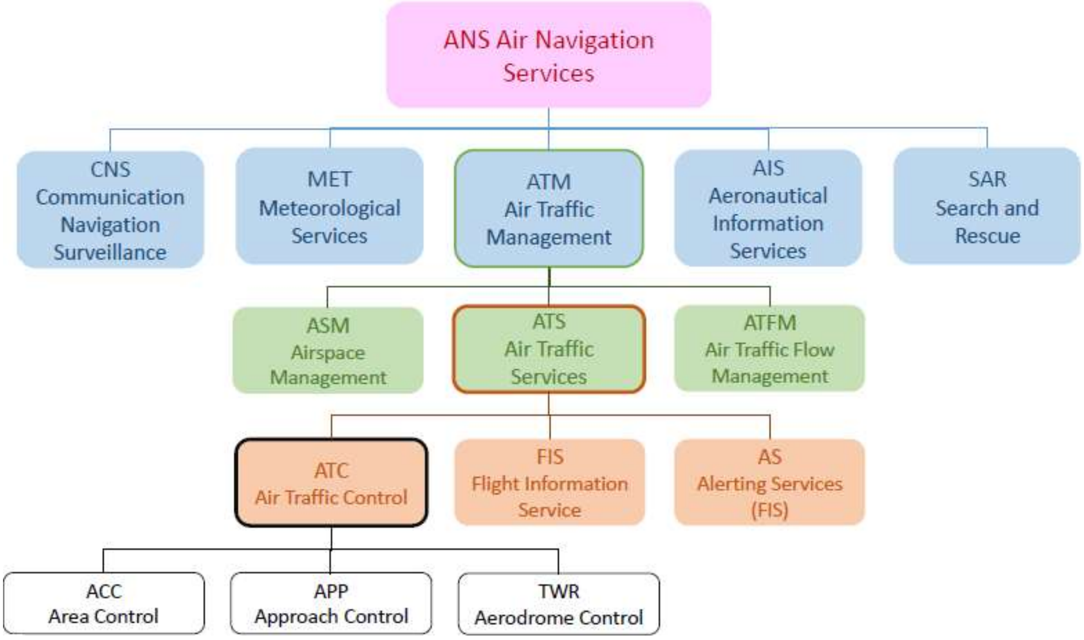

Figure 6: Structure of the ANS [22]

ANS provider, regulator, supervisor

In the European ATM system, there are regulatory, organizer and leader bodies to maintain the effective, safe, fast and seamless air transport all around Europe.

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[20] https://www.skybrary.aero/index.php/Visual_Flight_Rules_(VFR)

[21] https://www.skybrary.aero/index.php/Instrument_Flight_Rules_(IFR)

[22] https://www.vrht.bme.hu/en/

The most important objective of EUROCONTROL[23] is the development of a seamless, pan-European ATM system. Although EUROCONTROL is not an Agency of the European Union, the EU has delegated parts of its SES regulations to EUROCONTROL, making it the central organization for coordination and planning of air traffic control for the European airspace. The European Union itself is a signatory of EUROCONTROL. The main challenges are to cope with the forecasted growth in air traffic, while maintaining a high level of safety, reducing costs and respecting the environment. EUROCONTROL develops, coordinates and plans for the collective implementation of short-, medium- and long-term Pan-European air traffic management strategies and their associated action plans. this task is performed in close collaboration with national authorities, air navigation service providers, civil and military airspace users, airports, industry, professional organizations and European institutions. EUROCONTROL's core activities span the entire range of gate-to-gate air navigation service operations - from strategic and tactical flow management to controller training; from regional control of airspace to the development of leading-edge, safety-proved technologies and procedures. They include the collection of air navigation charges.

Network Management & Operating Capability

Network Manager (NM) in Europe[24;25;26] involves approximately 2000 airspace users (e.g. airlines), approximately 500 airports, 9 FABs, 40 European ANSPs, approximately 70 ACCs, approximately 700 ATC en-route sectors and handles approximately 29000 flights per day. It also deals with global and interregional operational links.

The NM is a body of EUROCONTROL, which manages ATM network functions (airspace design, flow management) as well as sparse resources (transponder code allocations, radio frequencies), as defined in EU Regulation 677/2011 and EU Regulation 2019/123.

Air Traffic Flow Management (ATFM)[27] helps in organizing and managing air traffic during the whole process. One of its purposes is to manage the traffic in dependence of demands, routes and capacity with the collection of input data, handling demands and creating new solutions. it endeavors also to increase the economic and ecologic efficiency for ANSPs, airliners, passengers, third parties and environment. Last but not least, well implemented ATFM can protect ATC controllers from sector overload, which can occur in case of high traffic, in certain sectors and certain time periods. This is beneficial for other air traffic stakeholders, especially aircraft operators and airports as well, and ultimately increases the safety of every single flight and air traffic at large. The European unit responsible for Network Management, including ATFM, is the Network Manager Operations Centre (NMOC), located in Brussels.

There are 3+2 different time-based phases of the network management. The first step of ATFM is the preliminary planning and forecasting[28]. This phase involves the collection of statistical information, surveying the structure of system (airspaces, routes and navigation points, airports, scheduling etc.), search of critical points of the system, connecting and training all participants, creating forecasts about the traffic demands, the capacity of the segments and the trends of longer term.

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[23] https://www.eurocontrol.int/about-us

[24] https://www.icao.int/MID/Documents/2019/ACAO-ICAO%20ATFM%20Workshop/1.3.1-%20EUROCONTROL%20Experience.pdf

[25] https://www.skybrary.aero/index.php/Network_Manager

[26] https://www.eurocontrol.int/network-operations

[27] https://www.icao.int/APAC/APAC-RSO/Pages/ATFM-CDM.aspx

[28] https://www.eurocontrol.int/network-operations

The mentioned 3 main time-based sections are as follows:

- **Strategic level** takes place T-1 year until T-1 week before flight. As a result, the Network Operation Plan (NOP) is produced [29] [EUROCONTROL 2019e]. This document provides a short to medium-term outlook of how the ATM Network will operate, including expected performance at network and local level. It gives details of capacity and flight efficiency enhancement measures planned at network level and by each Area Control Center (ACC), as well as a description of the airport performance assessment and improvement measures that are planned at those airports that generate a relatively high level of delay.
- **Pre-tactical level** takes place T-6 days until T-1 day before flight[29]. Main activities carried out are Collaborative Decision Making (CDM), comparison of predicted and actual traffic and capacity, preparation of a summary of ATFM measures to be proposed and their submission to the ATFM community for collaborative analysis and discussion. At an agreed-upon number of hours before the operation, a last review is conducted in consultation with the affected ATS units and other stakeholders to determine the ATFM measures that will be published.
- **Tactical level** is carried out from T-1 day. Real time operations are implemented, such as information analysis, decision making and use of ATFM measures. Measures should correct any actual imbalances of capacity and demand and shall cause minimal effects for any single flight. Typical causes of disturbances can be e.g. staffing problems, weather problems, crises and special events, precise flight plan data, unexpected opportunities of ANSPs.

In addition, there is a final task, which will be relevant after the landing of a flight. It is the Post Operation Analyses and comprises the appreciation of the working of the system, every stakeholders' report and an analysis of each step and result of every phase and every decision made, an investigation the causes and the effects of ATFM measures and recommendations for system development.

The NM prepares monthly the Network Operations Report and yearly the Annual Network Operations Report[30;31]. The monthly edition gives an overview and in-depth analysis of the performance of the European ATM network. The annual edition has a main and three sub-reports as annexes:

- The main report provides a high-level view of the performance of the European ATM network in the year of question.
- Annex I provides an airspace user's view on how the network performed.
- Annex II contains a traffic and capacity evolution of each ACC.
- Annex III focuses on airport performance and contains capacity, delay and punctuality indicators for a list of 29 airports in the network.

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[29] https://www.eurocontrol.int/network-operations-planning

[30] https://www.eurocontrol.int/publication/network-operations-report-february-2020

[31] https://www.eurocontrol.int/publication/annual-network-operations-report-2019

Aeronautical Information Service

At EUROCONTROL, aeronautical data from all countries in its area of operations are also stored in the world's largest aeronautical information service (AIS) – the European AIS Database (EAD). Also, accurate information about Europe's airspace are kept up-to-date in the Central Airspace and Capacity Database (CACD). Sharing this information improves the efficiency and accuracy of ATM systems – Integrated Initial Flight Plan Processing System (IFPS) and Enhanced Tactical Flow Management System (ETFMS) – and those of involved stakeholders. The airspace data is updated both during the current Aeronautical Information Regulation and Control (AIRAC) cycle (dynamically and semi-dynamically) as well as for the next cycle (statically).

Flight Plan Handling and Management

For every flight in European skies, pilots intending to depart from, arrive at or fly over one of the countries that are in the operational area of EUROCONTROL, Aircraft Operators must submit a flight plan to EUROCONTROL's NMOC[32]. Flight plans (FPLs) generally include basic information such as departure and arrival points, estimated time en-route, alternate airports in case of bad weather, type of flight (IFR or VFR), the pilot's information, number of people on board and information about the aircraft itself. In most countries, FPLs are required for flights under IFR, but may be optional for flying VFR unless crossing international borders. FPLs are highly recommended, especially when flying over inhospitable areas (e.g. oceans), as they provide a way of alerting rescuers if the flight is overdue. FPLs from Aircraft Operators (AO) are received by the NMOC, which validates, corrects (if necessary), and distributes them to the ANSPs and operational partners concerned. To ensure efficient flight plan management at European level, a centralized flight plan processing and distribution function is operated by the NMOC. This service is supported by the IFPS. It is a central system that collects initial flight plans, processes the related messages and distributes them to ANSPs including the FPL pre-validation service provided by the IFPUV (IFPS validation system). It covers that part of the ICAO EUR Region known as the IFPZ (IFPS zone) and is supported by fully redundant infrastructure and disaster recovery mechanisms. Regional centralizing flight plan management contributes substantially to improving both the consistency and predictability of flight demand information. It simplifies operations, improves flight efficiency and reduces overall transactional costs for both ANSPs and airspace users. Various interfaces are available to access the FPL filing and management service and to interface with the IFPS. This can be done through the Aeronautical Fixed Telecommunication Network (AFTN)/SITA (Société Internationale de Télécommunications Aéronautiques), the NOP or through the IP/VPN (Virtual Private Network) connections for accessing the NM B2B (Network Manager business-to-business) web services.

Flow Management

The FMP (Flow Management Position) is a working position established in appropriate air traffic control units to ensure the necessary interface with a central flow management unit on matters concerning the provision of the air traffic flow management service. The duties of FMP cover inter alia: consultation with the stakeholders and collecting information,

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[32] https://www.eurocontrol.int/service/flight-plan-filing-and-management

analyzing and distributing information, creating and distributing the daily plan, managing ATFM measures, logging all ATFM measures, cancelling ATFM measures, daily telephone and/or web conferences as required, and monitoring of ATM system.

Traffic Management & Operating Capability on ANSP level

Traffic management on ANSP level in en-route, TMA and CTR airspaces is strictly aligned with the ICAO provisions, no divergence from that is allowed in European environment.

ATCO Licensing, Rating and Endorsement

The requirements are set by the International Civil Aviation Organization (ICAO) and the European Aviation Safety Agency (EASA) for Air Traffic Control Operator (ATCO) training to help maintain safe airspaces[33]. ICAO's requirements apply to all ATCOs across the globe. However, EASA's requirements also apply to ATCOs who work in Europe. EASA's requirements are built on ICAO, but often go a bit further.

To provide air traffic control, different types of ATCOs[34] are required. The procedures of becoming an ATCO and getting authorization is a long and hard process. The purpose of ATCO licensing is to enable each NAA (National Aviation Authority) to regulate air traffic controllers within their state. The system includes the issue, maintenance and, where necessary, the revocation of ATCO licenses. The ATCO license:

- identifies the holder as a person who is qualified to provide ATC service,
- contains details, usually described as ratings and endorsements, of the type(s) of ATC service that the license holder may provide and
- may restrict the ATC Unit(s) where the holder may provide these services.

The acquisition of a valid license requires that specified conditions relating to professional competency and medical fitness are met and, for retention, that these are checked at specified time intervals. Competency in the use of English language may also have to be demonstrated and endorsed in an ATCO License.

In Europe, the structure for a harmonized European ATCO license has been developed to enable the license qualifications to more closely match the ATC services being provided, and to permit the recognition of additional ATC skills associated with the evolution of ATC systems and their related controlling procedures. It has not yet been adopted by all states.

Although the harmonized European ATC license retains the basic principles of the ICAO license, new ratings have been introduced.

Rating Endorsements are endorsements associated with particular ratings to indicate the type of equipment associated with the provision of an ATC service in that rating discipline. For example, the ICAO Approach Radar Control rating becomes the Approach Control Surveillance rating with a radar endorsement; the endorsement indicating that radar is the surveillance equipment used in providing the ATC service.

Unit endorsements are endorsements associated with specific ratings and rating endorsements, which indicate the ATC Unit and the individual sectors, groups of sectors or operational positions where the license holder provides an ATC service.

License endorsements are endorsements associated with the license, but not with any particular rating or rating endorsement. Currently, the only license endorsement possible

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[33] https://www.skyradar.com/blog/how-is-atco-training-structured-according-to-icao-and-easa

[34] https://www.skybrary.aero/index.php/ATCO_Licensing

on an ATCO License issued under the new European system is the OJTI (On-the-Job-Training Instructor) endorsement.

ATM financing

European air traffic management is funded by the operators of the aircraft, known as airspace users, who are charged for the services they receive, based on the type of aircraft and distance flown within the area of responsibility of each ANSP, according to the planned trajectory[35]. In 2016, airspace users paid approximately €9 billion for these services in Europe, or just above €900 per flight on average. There are different kinds of charges: route charges, terminal charges, air navigation charges, and communication charges.

The Central Route Charges Office (CRCO) runs an efficient system for the cost recovery of air traffic services made available to airspace users. All important information on this topic can be found in the annual publication of CRCO [EUROCONTROL 2020a].

2.1.2. TECHNICAL BASELINE

The technical baseline can be divided into two parts: ground side and on-board side. this chapter focuses on the European CNS equipment and highlights a couple of technical solutions, which are already available or currently being deployed. As long as on-board side is concerned, this chapter shows how avionics technology supports safe and efficient air traffic in Europe.

2.1.2.1 GROUND SIDE

Communication, Navigation, Surveillance

The communication, navigation and surveillance (CNS) infrastructure and the radio spectrum they require are the fundament of the aviation operational performance, enabling airspace capacity. Without them air transport would not exist. In this chapter[36], only the elements that are most important from our project’s point of view are presented.

Surveillance: In ATM, the most important task is the surveillance. The main systems used in Europe are as follows: PSR (Primary Surveillance Radar), MSPSR (Multi Static Primary Surveillance Radar), SSR (Secondary Surveillance Radar), MSSR (Monopulse Secondary Surveillance Radar), MLAT (Multilateration), ADS-B (Automatic Dependent Surveillance-Broadcast), WAM (Wide Area Multilateration), TIS-B (Traffic Information Service – Broadcast), and Space-based ADS-B[37].

The surveillance on the airport surface is required as well to reach higher levels of safety at any moment. The most common surveillance systems used in European airports too are SMR (Surface Movement Radar) and A-SMGCS (Advanced Surface Movement Guidance & Control System)[38].

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[35] https://www.eurocontrol.int/publication/customer-guide-route-charges

[36] https://www.eurocontrol.int/communications-navigation-and-surveillance

[37] https://www.icao.int/WACAF/Documents/Meetings/2016/Lisbon-2016/Sat-21/SAT21%20WP%2009%20%20Space%20based%20ADS-B-Airon.pdf

[38] https://www.skybrary.aero/index.php/Advanced_Surface_Movement_Guidance_and_Control_System_(A-SMGCS)

Communication: There are different channels and modes to achieve the appropriate relations between each station:

- air-ground (A/G), which is to ensure the communication between pilots and controllers, and
- ground-ground (G/G), to ensure the connection between two ATC controllers.

On the other hand, the received and transmitted information can be voice-based and text-based modes.

For voice-based communication, radio is the primary communication means between ATCOs and pilots. The secondary voice-based means of communication is the telephone used between two ATCOs. Adequate voice communication systems on board and naturally on ground side as well need to be provided. These systems can be different in the European countries, depending the given provider.

Besides voice-based communication, text-based communication is available too. The most important system is Controller Pilot Data Link Communications (CPDLC)[39]. The On-Line Data Interchange (OLDI) is a EUROCONTROL standard, which enables a point-to-point connection. It sends or receives the changes of the FPL status so it uses the data dynamically and in real-time. Flight Message Transfer Protocol (FMTP) is the next version of the OLDI messages. They use the data statically and are able to transmit technical messages, FPL related messages, messages exchanged with the IFPS, NM tactical messages and meteorological messages.

Navigation: They aim to safely, efficiently and dynamically navigate aircraft during flight. ATCOs will give instructions to pilots, while pilots maintain an appropriate situational awareness to comply with the ATCO’s instructions.

There are two types of navigational systems, ground based navigation systems and satellite-based radio navigation systems. The ground-based systems used in Europe are VHF Omnidirectional Range (VOR), Doppler VOR (D-VOR), Distance Measuring Equipment (DME), Non-Directional-Beacon/Automatic Direction Finder (NDB/ADF) and Instrument Landing System (ILS). The satellite-based systems are GPS (Global Positioning System), GLONASS, GALILEO, ABAS (Airborne Augmentation System), SBAS (Space Based Augmentation System) and GBAS (Ground Based Augmentation System).

2.1.2.2 ON-BOARD SIDE

Avionics technology supporting the operational baseline

Avionics are electronic systems used on aircraft, artificial satellites and spacecraft[40]. Avionic systems include communications, navigation, the display and management of multiple systems that are fitted into aircrafts to perform individual functions. Most European airline operators use aircrafts manufactured by major producers having global presence. Also, international standards for avionics equipment are prepared by the Airlines Electronic Engineering Committee (AEEC) and published by Aeronautical Radio, Incorporated (ARINC). Consequently, in this chapter, the specific European features are highlighted.

The VHF aviation communication system works on the frequency band of 118.000 MHz to 136.975 MHz. Each channel is spaced from the adjacent ones by 8.33 kHz in Europe, 25 kHz elsewhere. VHF is also used for line of sight communication such as aircraft-to-aircraft and aircraft-to-ATC. Amplitude modulation (AM) is used, and the conversation is

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[39] https://www.skybrary.aero/index.php/Controller_Pilot_Data_Link_Communications_(CPDLC)

[40] https://en.wikipedia.org/wiki/Avionics

performed in simplex mode. Aircraft communication can also take place using HF (especially for trans-oceanic flights) or satellite communication.

Many carriers in Europe equip their planes with instruments as shown in Table 1. These equipment often can help to improve flight safety and the pilot’s situational awareness. Besides, they are also a prerequisite to depart from and/or arrive to most European commercial airports.

Equipment	ADS	RNAV
• DME • D-FIS ACARS • PDC ACARS • ADF • GNSS • Inertial NAV • CPDLC • ILS • VOR • PBN approved • VHF RTF • RVSM APPROVED • VHF 8.33 kHz	• Transponder Mode S, a/c ID, PA, extended squitter (ADS-B) and enhanced surveillance • ADS-B 1090MHz out	• RNAV 5 all sensors • RNAV 2 all sensors • RNAV 1 all sensors • BASIC RNP 1 ALL SENSORS • RNP APCH BARO-VNAV

Table 1. Currently used on-board avionics

2.2. BASELINE SITUATION IN CHINA (T2.1.1)

In China, the use of airspace is managed by National Air Traffic Control Committee as a whole. The implementation of ATM, including ATM service provision, CNS, aviation meteorology, flight information, etc., is in the charge of Air Traffic Management Bureau of Civil Aviation Administration of China (CAAC ATMB). The national airspace is divided into seven regions, managed by a regional ATM bureau respectively.

In this chapter, a picture of the main characteristics of the Chinese ATM baseline situation that has relevance on the objectives of the GreAT project is provided.

2.2.1. OPERATIONAL BASELINE

2.2.1.1 AIRSPACE STRUCTURE AND MANAGEMENT

Overview

At present, China has 11 flight information regions with a total area of about 10.81 million square kilometers. China has set up:

- 16 high-altitude control areas
- 28 medium/low-altitude control areas
- 41 approach control areas
- 1 terminal control area

In total, 360 control sectors are set, including:

- 223 regional control sectors
- 137 approach (terminal) control sectors (see Figure 7)

In total, there are 269 various types of special airspaces:

- 1 prohibited airspace
- 66 danger airspaces
- 201 restricted airspaces
- 1 air defense identification zone are set

In total, there are 881 air ways and routes, with a total distance of 218,591 km calculated by non-repeated distance. In total, 47 entry/exit points into Chinese airspace have been set up, realizing the organic connection with the international air route network of neighboring countries and remote countries and regions. At present, 236 airports, 13,013 city pairs, and 8,542 flight air routes have been announced. The average non-linear coefficient of city-pair flight air lines is about 1.14.

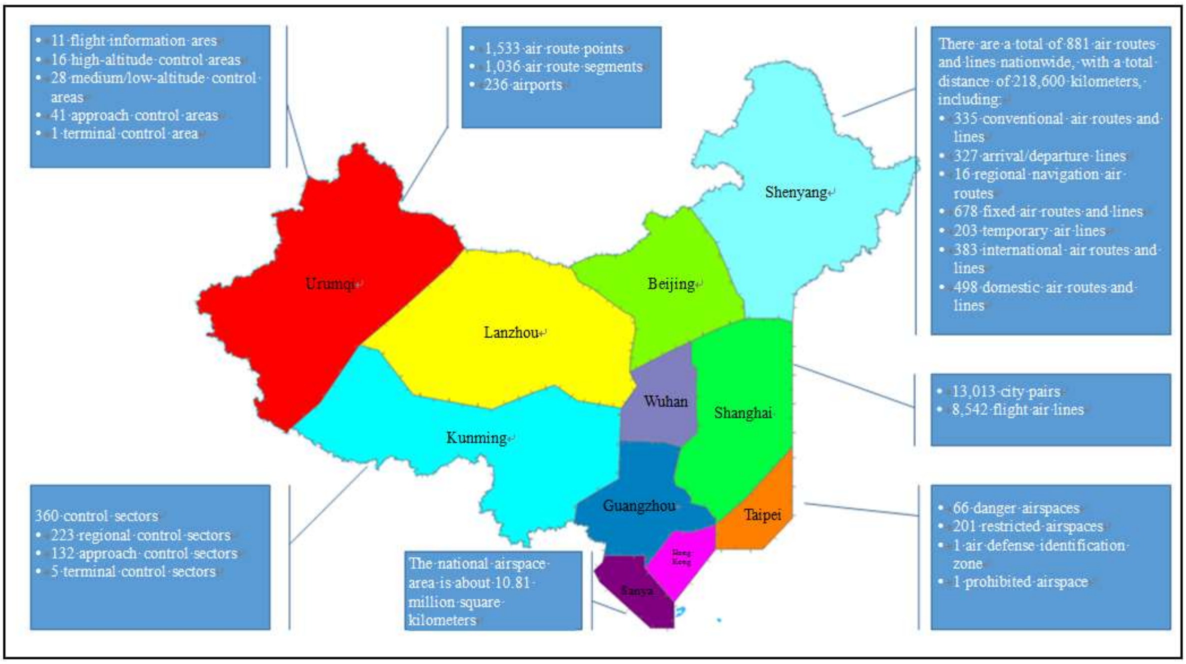


Figure 7: Current Situation of China's Airspace Resources

Flight Information Areas and Special Airspaces

At present, China has 11 flight information regions, namely Beijing, Shanghai, Shenyang, Guangzhou, Wuhan, Lanzhou, Urumqi, Kunming, Sanya, Taipei and Hong Kong flight information area. Except Taipei and Hong Kong, the other nine flight information areas have a total area of about 10.26 million square kilometers, the details are as shown in Figure 8.

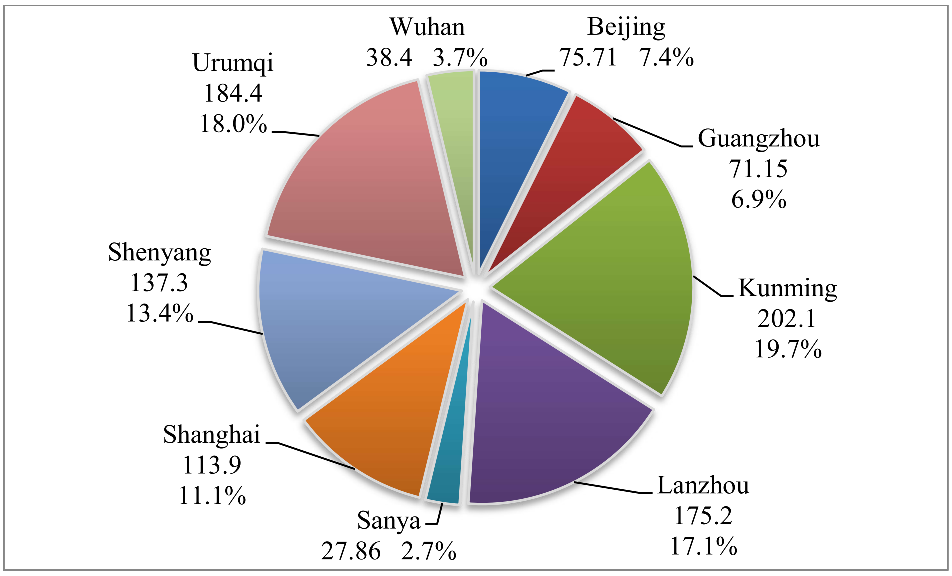


Figure 8: Area and proportion of each Flight Information Area (in 10,000 square kilometers)

At present, China has set 269 various types of special airspaces, including 1 prohibited airspace, 66 danger airspaces, 201 restricted airspaces, and 1 air defense identification zone. Figure 9 and Figure 10 show the number and distribution proportion of special airspaces in each information area.

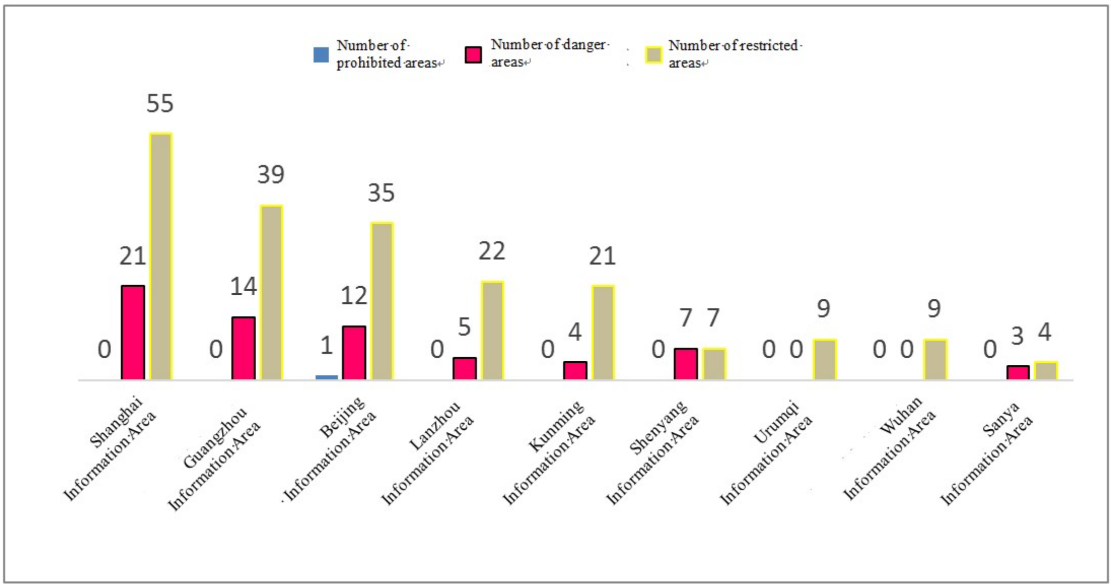


Figure 9: Number of special Airspaces in each Flight Information Area

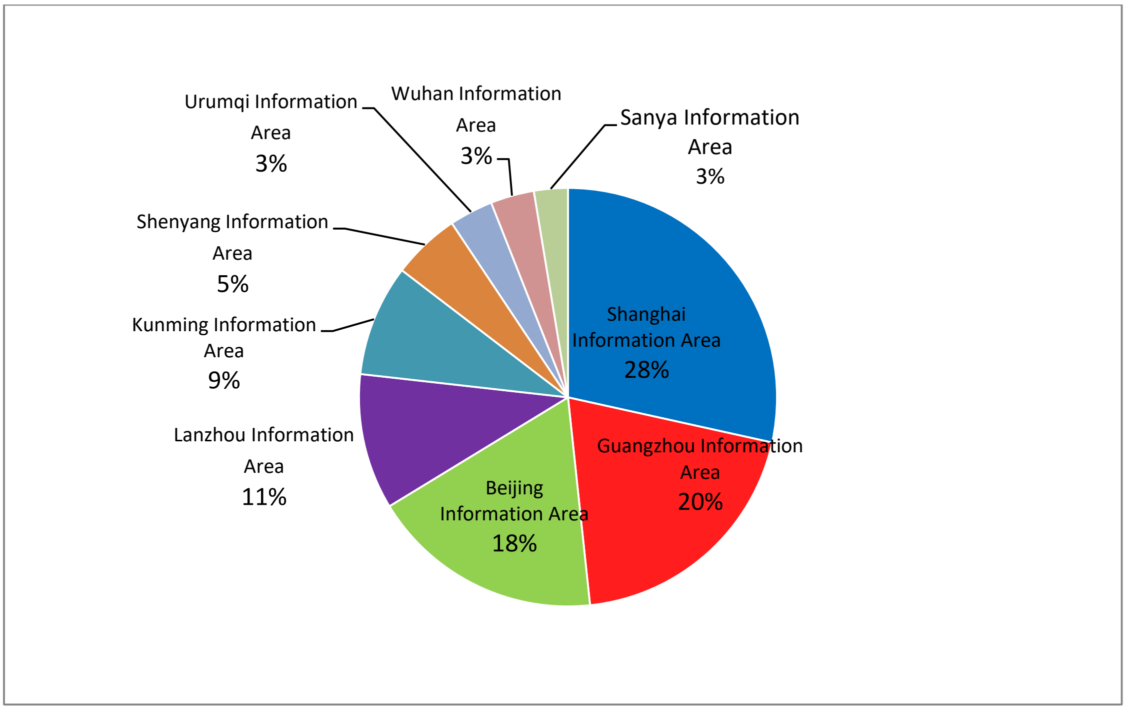
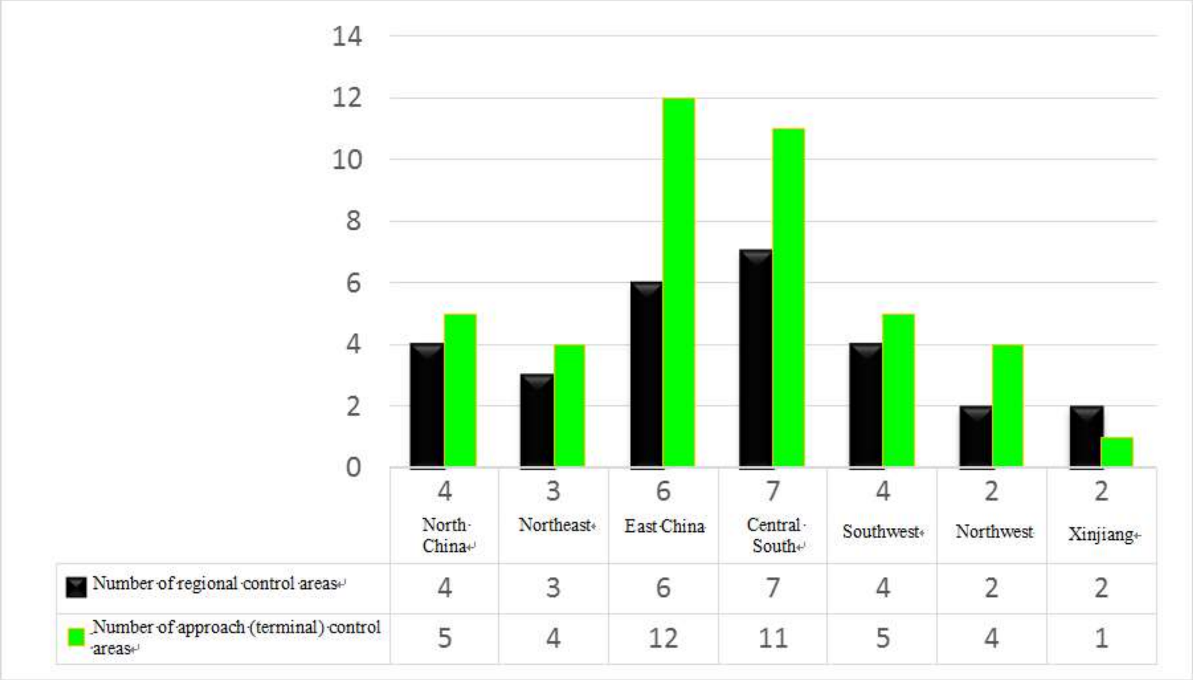


Figure 10: Proportional distribution of the number of special airspaces

Control Areas and Control Sectors

In total, there are 28 regional control areas and 42 approach (terminal) control areas in China, and their specific distribution is shown in Figure 11.



	North China	Northeast	East China	Central South	Southwest	Northwest	Xinjiang
	4	3	6	7	4	2	2
■ Number of regional control areas	4	3	6	7	4	2	2
🟩 Number of approach (terminal) control areas	5	4	12	11	5	4	1

Figure 11: Distribution of Regional/Approach (Terminal) Control Areas in different regions

Among the seven regions, the total number of control sectors in East China, Central South and Southwest China ranks the top three, which have 98, 80 and 54 sectors respectively, each accounting for 27%, 22% and 15% of the total number of control sectors in China (see Figure 12).

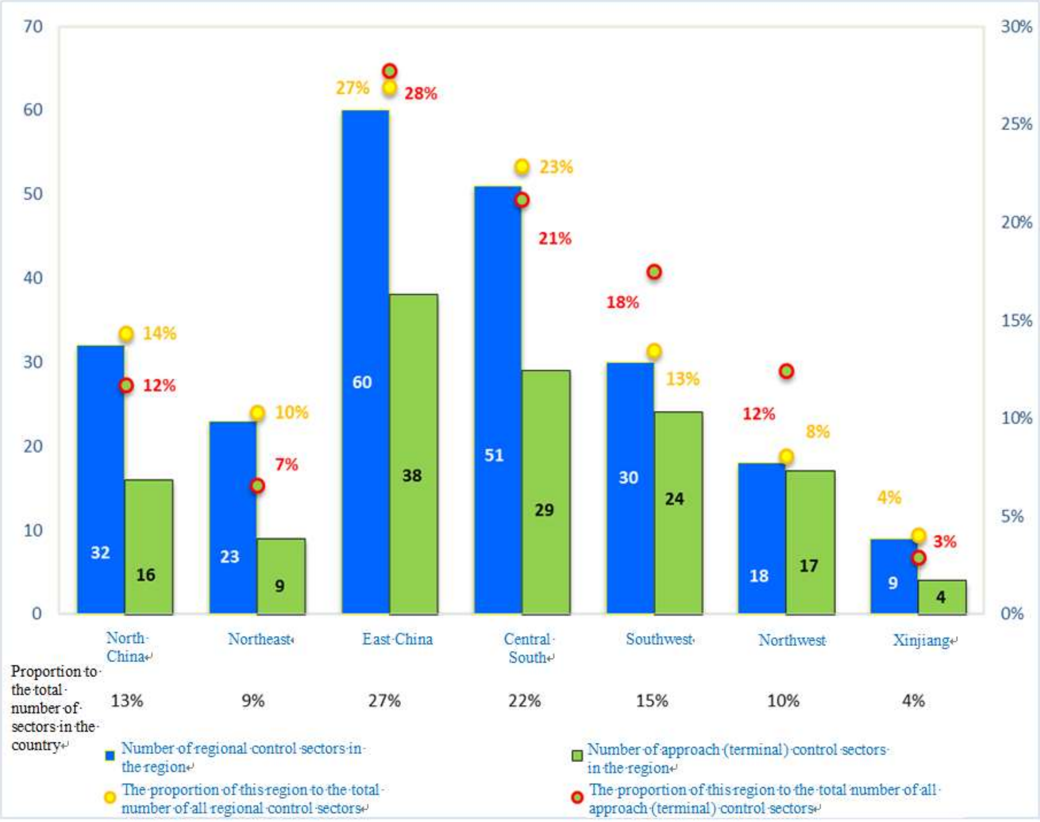


Figure 12: Regional distribution of the number of control sectors in China

Airspace classification

China divides its controlled airspace into four airspace classes (A, B, C and D).

- Class A airspace is high-altitude control airspace. The airspace above 6,600 meters (or more) is divided into several high-altitude control airspaces, in which flights must fly under Instrument Flight Rules (IFR).
- Class B airspace is low- and medium-altitude control airspace. The space above the lowest altitude level and below 6600 meters (not included) is divided into several low- and medium-altitude control airspaces. Within this airspace, flights may fly under Instrument Flight Rules (IFR) or, subject to conditions and approvals, under Visual Flight Rules (VFR).
- Class C airspace is approach control airspace. It is usually defined as the controlled airspace established in the merging area of air routes near one or more airports to control the approach and departure aircraft. It is the connecting part between the low- and medium- altitude control airspace and the tower control airspace. Its vertical range is usually above the lowest altitude level and below 6000 meters (inclusive); its horizontal range is usually the space outside the control range of the airport tower with a radius of 50 km or within the entrance/exit of the corridor. Within this airspace, flights may fly under IFR or, subject to conditions and approvals, under VFR.
- Class D airspace is tower control airspace, normally including landing routes, space above the Earth's surface and below the first holding altitude level (inclusive), and airport maneuvering areas. Within this airspace, flights may fly under IFR or, subject to conditions and approvals, under VFR.

The different airspace classes used in China are different from the ICAO defined classes despite the similar nomenclature.

Air Ways and Air Routes

In total, China has 881 air ways and air routes, with a total distance of 218,591 kilometers calculated by non-repeated distance (see Figure 13). Among them, there are:

- 678 fixed air ways and air routes, with a total distance of 175,078 kilometers, accounting for 80.1% of the total mileage of air routes
- 203 temporary air routes (`temporary´ means that they can be opened upon request in advance) with a total distance of 43,514 kilometers, accounting for 19.9% of the total mileage of air routes.

Among the fixed air routes there are:

- 335 conventional air ways and air routes with a total distance of 129,352 kilometers
- 327 arrival/departure air routes, with a total distance of 35,669 kilometers
- 16 regional navigation air routes, with a total distance of 10,056 kilometers

According to statistics based on their opening-up attributes, in total, there are 383 international air ways and air routes, with a total distance of 113,983 kilometers and 498 domestic air ways and air routes, with a total distance of 104,608 kilometers.

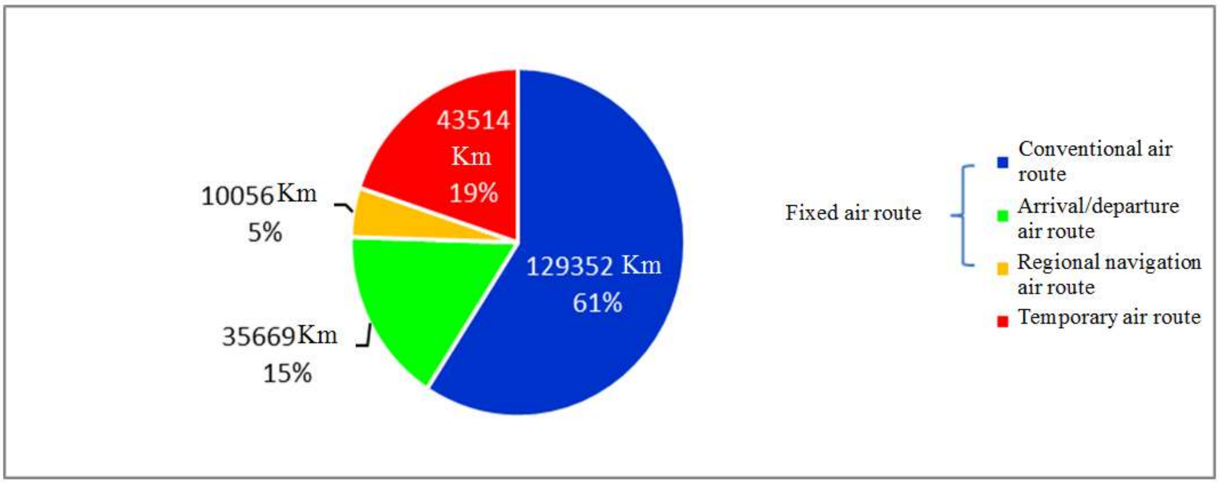
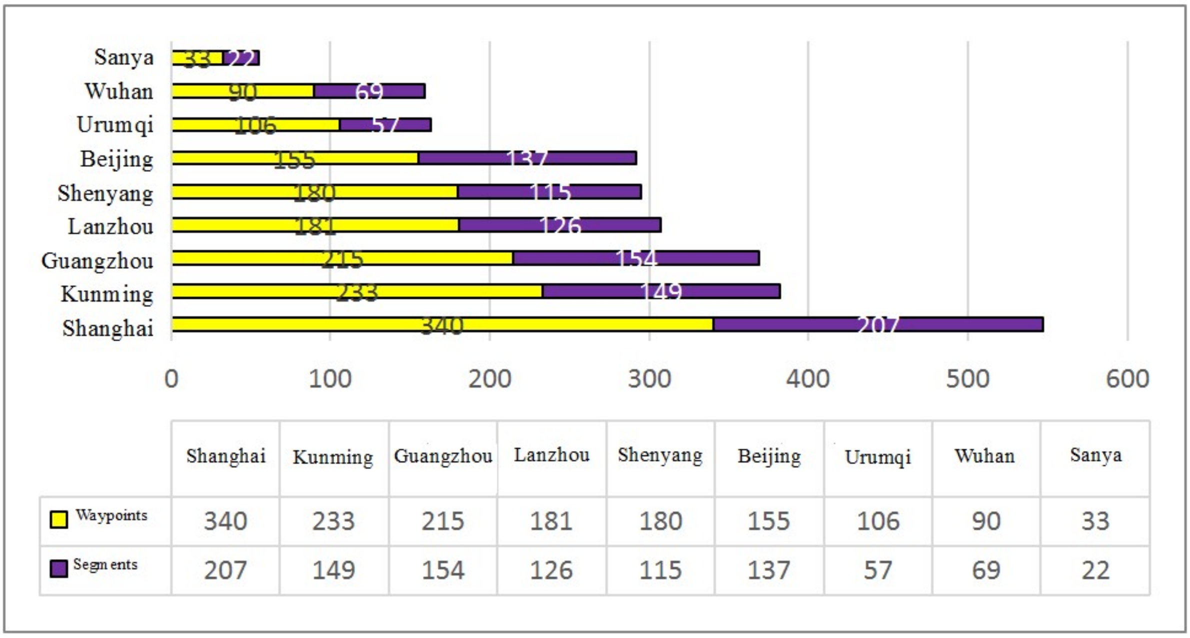


Figure 13: Composition of air ways and air routes in China

Basic Airspace Elements

Figure 14 shows the basic situation of existing waypoints and segments in various information areas in China, among which Shanghai, Kunming and Guangzhou information areas have the most basic airspace elements.

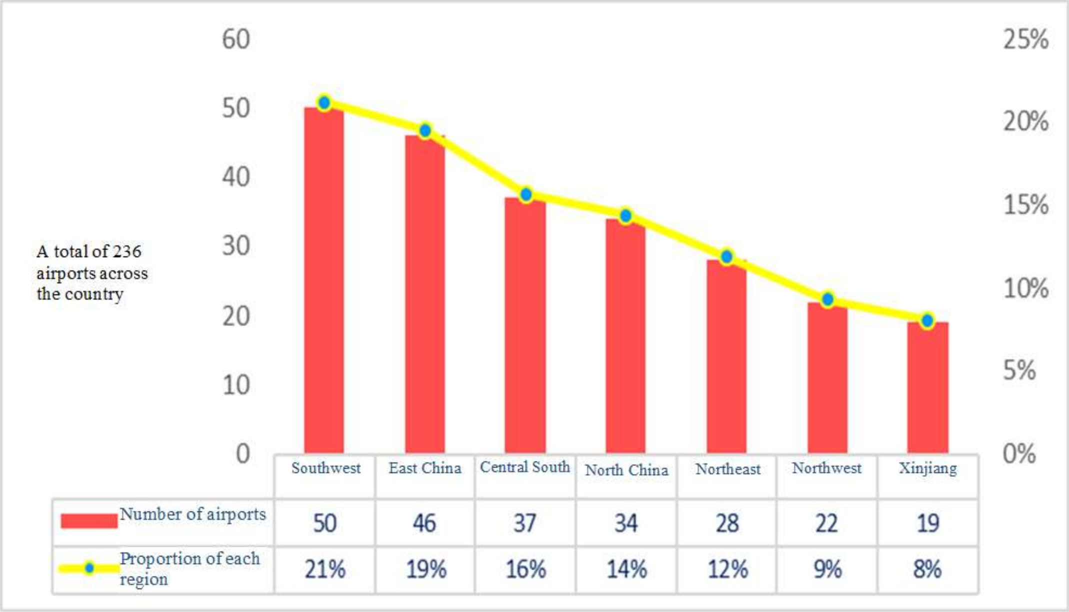


	Shanghai	Kunming	Guangzhou	Lanzhou	Shenyang	Beijing	Urumqi	Wuhan	Sanya
🟨 Waypoints	340	233	215	181	180	155	106	90	33
🟪 Segments	207	149	154	126	115	137	57	69	22

Figure 14: Current situation of basic airspace elements in each Flight Information Region

Airports

Figure 15 and Figure 16 respectively show the distribution of 236 airports published in China in seven regions, and the classification according to airport attributes. Among them, there are 66 international airports and 170 domestic airports. At present, the performance Based navigation (PBN) program design has been completed in all 44 airports where the air traffic control system provides control services, 42 airports have implemented the PBN program, and 29 airports have realized partial or complete separation of arrival/departure lines.



	Southwest	East China	Central South	North China	Northeast	Northwest	Xinjiang
🟥 Number of airports	50	46	37	34	28	22	19
● Proportion of each region	21%	19%	16%	14%	12%	9%	8%

Figure 15: Regional distribution of Chinese Airports

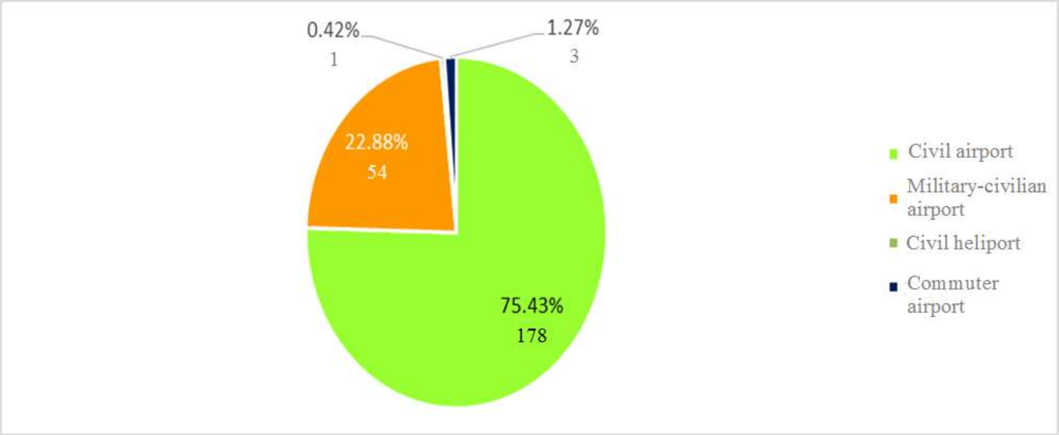


Figure 16: Classification of Chinese Airports

2.2.1.2 MAIN TRAFFIC FLOWS

Airports

In 2017, the number of takeoffs and landings in major airports was 7.515 million, accounting for 81% of the total number of takeoffs and landings of China airports. Among them, the top five airports in terms of annual number of takeoffs and landings are:

- Beijing Capital Airport
- Shanghai Pudong Airport
- Guangzhou Baiyun Airport
- Kunming Changshui Airport
- Shenzhen Baoan Airport

Except for Beijing Capital Airport, which fell slightly back compared with last year, the daily peak takeoff and landing flow of other airports are increasing year by year in general (see Figure 17). The five airports with the largest year-on-year increase in takeoffs and landings are Nanchang Changbei Airport, Zhuhai Jinwan Airport, Zhanjiang Airport, Yinchuan Hedong Airport and Taiyuan Wusu Airport, which increase by 36.34%, 30.47%, 28.71%, 24.67%, 22.21%, and 14.51% respectively compared with last year. Measuring the takeoffs and landings in terms of airport peak hour, Beijing Capital Airport (106), Shanghai Pudong Airport (98) and Guangzhou Baiyun Airport (86) rank the top three, reflecting the busyness of the above airports. At the same time, the annual number of takeoffs and landings of the three major airports accounted for 6.44%, 5.35% and 5.01% of the total number in China, respectively (Figure 18 and Figure 19).

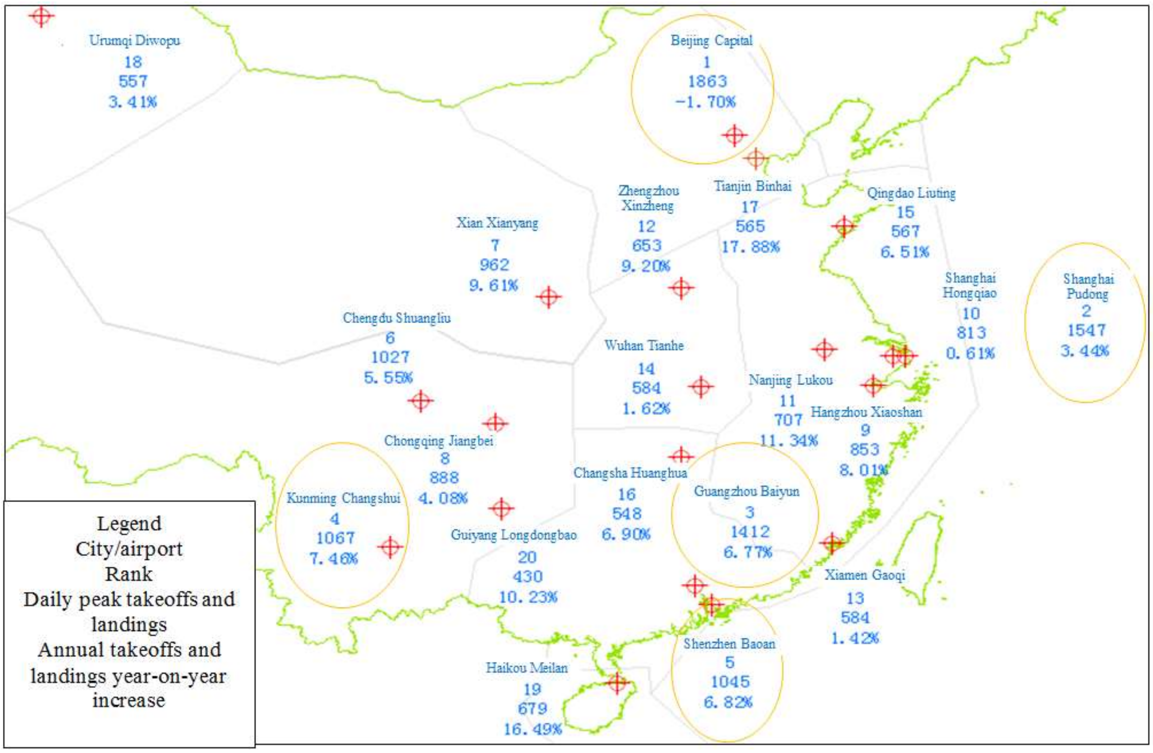
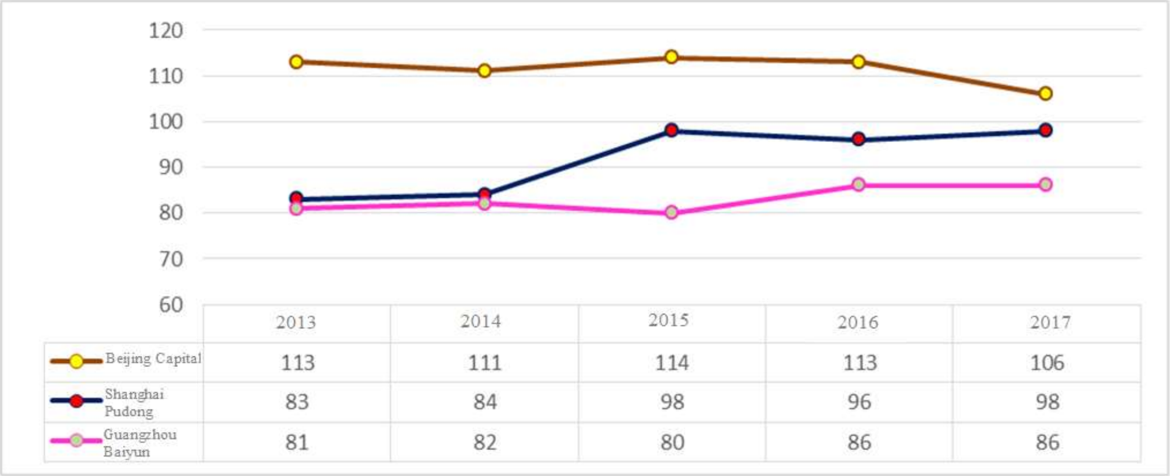
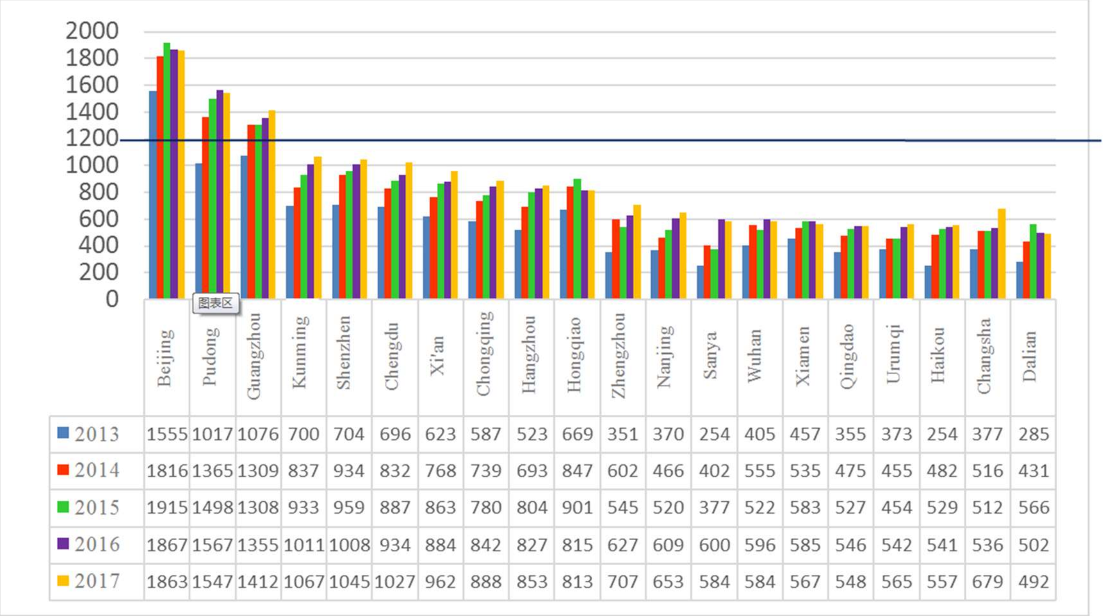


Figure 17: The Top-20 Busiest airports in China regarding daily peak number of takeoffs and landings



	2013	2014	2015	2016	2017
Beijing Capital	113	111	114	113	106
Shanghai Pudong	83	84	98	96	98
Guangzhou Baiyun	81	82	80	86	86

Figure 18: Comparison of the hour peak takeoffs and landings of the three airports in Beijing, Shanghai, Guangzhou in the recent five years

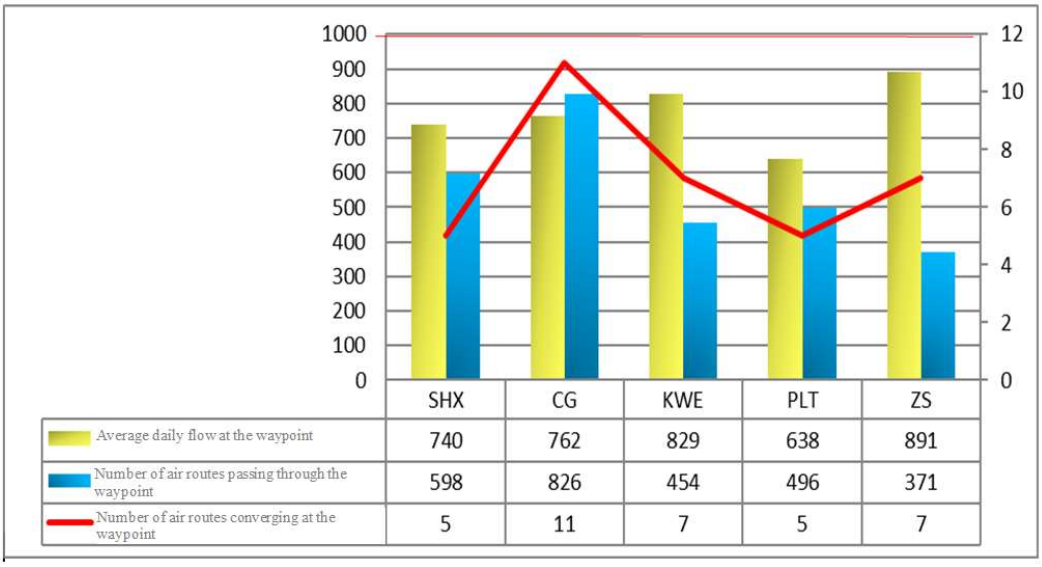


	Beijing	Pudong	Guangzhou	Kunming	Shenzhen	Chengdu	Xi'an	Chongqing	Hangzhou	Hongqiao	Zhengzhou	Nanjing	Sanya	Wuhan	Xiamen	Qingdao	Urumqi	Haikou	Changsha	Dalian
🟦 2013	1555	1017	1076	700	704	696	623	587	523	669	351	370	254	405	457	355	373	254	377	285
🟥 2014	1816	1365	1309	837	934	832	768	739	693	847	602	466	402	555	535	475	455	482	516	431
🟩 2015	1915	1498	1308	933	959	887	863	780	804	901	545	520	377	522	583	527	454	529	512	566
🟪 2016	1867	1567	1355	1011	1008	934	884	842	827	815	627	609	600	596	585	546	542	541	536	502
🟨 2017	1863	1547	1412	1067	1045	1027	962	888	853	813	707	653	584	584	567	548	565	557	679	492

Figure 19: The comparison of traffic flow of the top-20 busiest airports in China regarding daily peak number of takeoffs and landings in the recent five years

Waypoints

Figure 20 and Figure 21 provides the relevant information of the top 20 regional waypoints regarding daily average flow in 2017. Among them, HFE (Hefei VOR), ZHO (Zhoukou VOR), TOL (Tonglu VOR), HOK (Hekou VOR) and LKO (Longkou VOR) rank the top 5, with average daily flow of more than 970 takeoffs and landings, which are converged intersection nodes of multiple air routes. The flight flow of the above waypoints is large and the airspace structure is relatively complex, therefore the structure of relevant air routes can be considered to be appropriately optimized so as to realize flow diversion (Figure 20). The five air route points with the highest increasing rate in daily average flow are SHX (Shangxian VOR), CG (Tianjin VOR), KWE (Guiyang VOR), PLT (Panlong VOR) and ZS (Yanzhuang VOR), with year-on-year increases of 66.29%, 19.25%, 13.25%, 9.81% and 8.92% respectively. Overall, the flow of the main busy waypoints in China still maintains the trend of rapid growth.



	SHX	CG	KWE	PLT	ZS
Average daily flow at the waypoint	740	762	829	638	891
Number of air routes passing through the waypoint	598	826	454	496	371
Number of air routes converging at the waypoint	5	11	7	5	7

Figure 20: Airspace indicators of the top-5 busiest waypoints in China regarding daily average flow increase

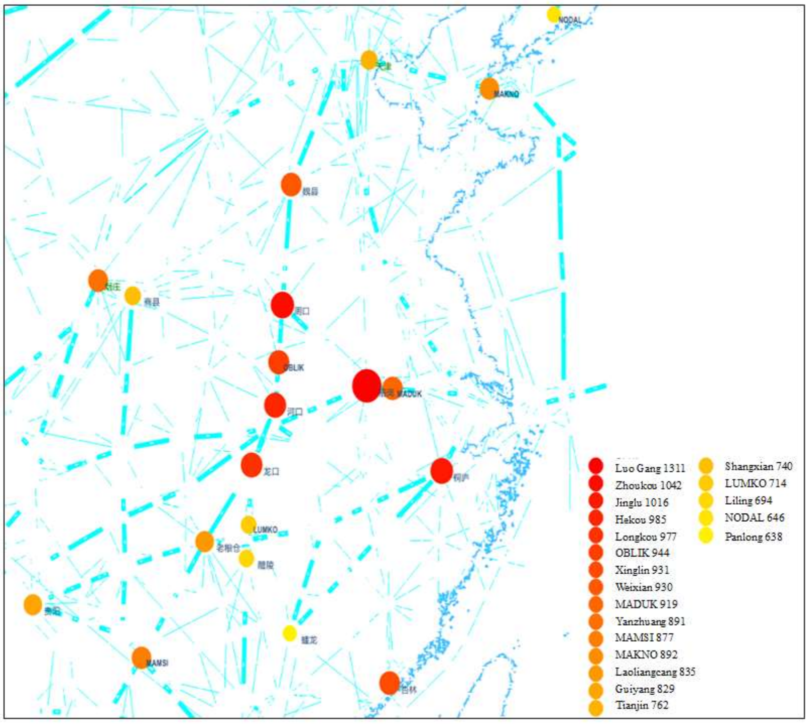


Figure 21: Top-20 busiest waypoints in China regarding regional daily average flow

Entry/exit points

In 2017, there were 1,471,635 inbound and outbound flights in China in total. Figure 22 shows the flow comparison of the top-20 busiest entry/exit points regarding flight flow in the recent three years. It can be seen from the figure that in the past three years, the flow of TAMOT (Hong Kong), SARIN (China-Kazakhstan) and ARGUK (China-Russia) has been increasing year by year; on the contrary, BUNTA (China-Vietnam), DOTMI (Hong Kong), OLDID (Taipei), INTIK (China-Mongolia), and SULEM (Taipei) have shown a downward trend. Some entry/exit points, such as SIKOU (Hong Kong), SAGAG (China-Laos), KAMUD (China-Kyrgyzstan), and MORIT (China-Mongolia) have basically maintained a flat trend in the past three years, with a relatively stable growth rate.

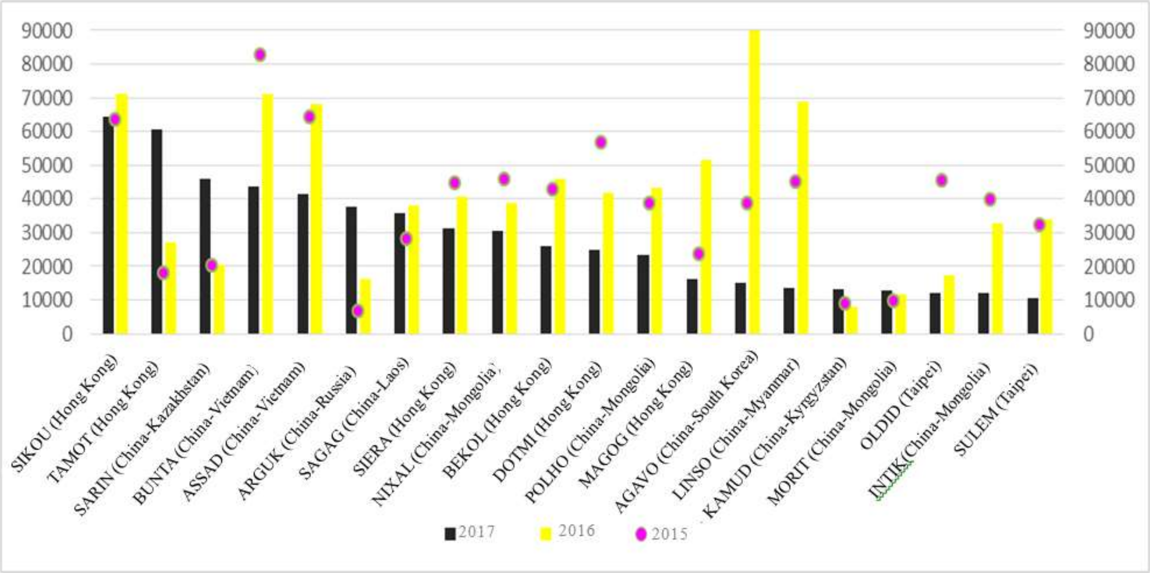


Figure 22: Comparison of the top-20 busiest Entry/Exit Points in China regarding light Flow in the recent three years

Air route segments

In 2017, the top-20 regional air route segments regarding average daily flow mainly concentrates on traditional main air routes such as A461, A470, R343, A593 and G212 (Figure 23). Among them, the congestion of A461 on Beijing-Guangzhou air route is the most prominent. The section from WXI (Weixian VOR) to LIG (Liling VOR) in central and southern China accounts for 51.5% of the total length of air route A461, and keeps a large flow state (over 600 flights) throughout the year.

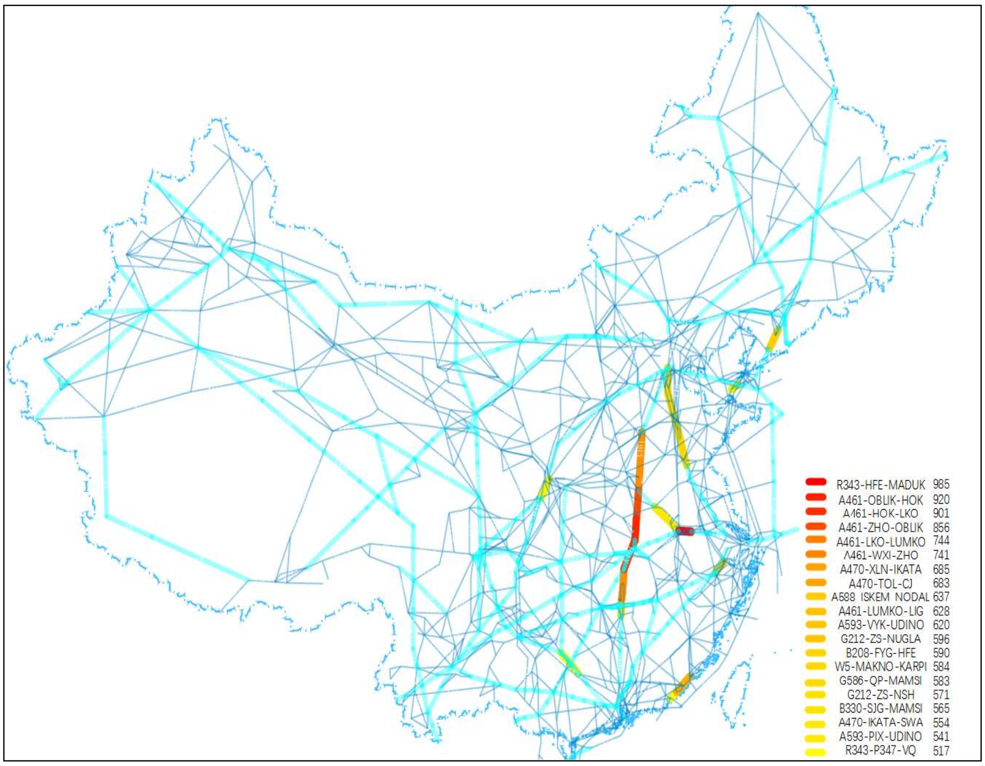


Figure 23: Distribution of top-20 busiest segments in China regarding regional daily average flow

Sectors

In 2017, 95% of the top-20 sectors regarding average daily flow concentrate in Central South, East China and North China. Compared with 2016, about 95% of them show the trend of positive growth. Among them, Guiyang 02, Nanchang 01 and Beijing 08 sectors have a large increase in flow (Figure 24). The flight increment of feeder-line airports such as Liupanshui, Bijie, Zunyi Maotai and Zunyi Xinzhou in Guiyang 02 sector is rapid, which makes obvious year-on-year growth (+28.66%); for Nanchang 01 sector, it is mainly due to the increase of more than 30% in Nanchang airport, which brings the sector a year-on-year increase of 21.92%; for Beijing 08 sector, due to the opening of B208 separate route, the flow of the sector increases rapidly (+13.15%).

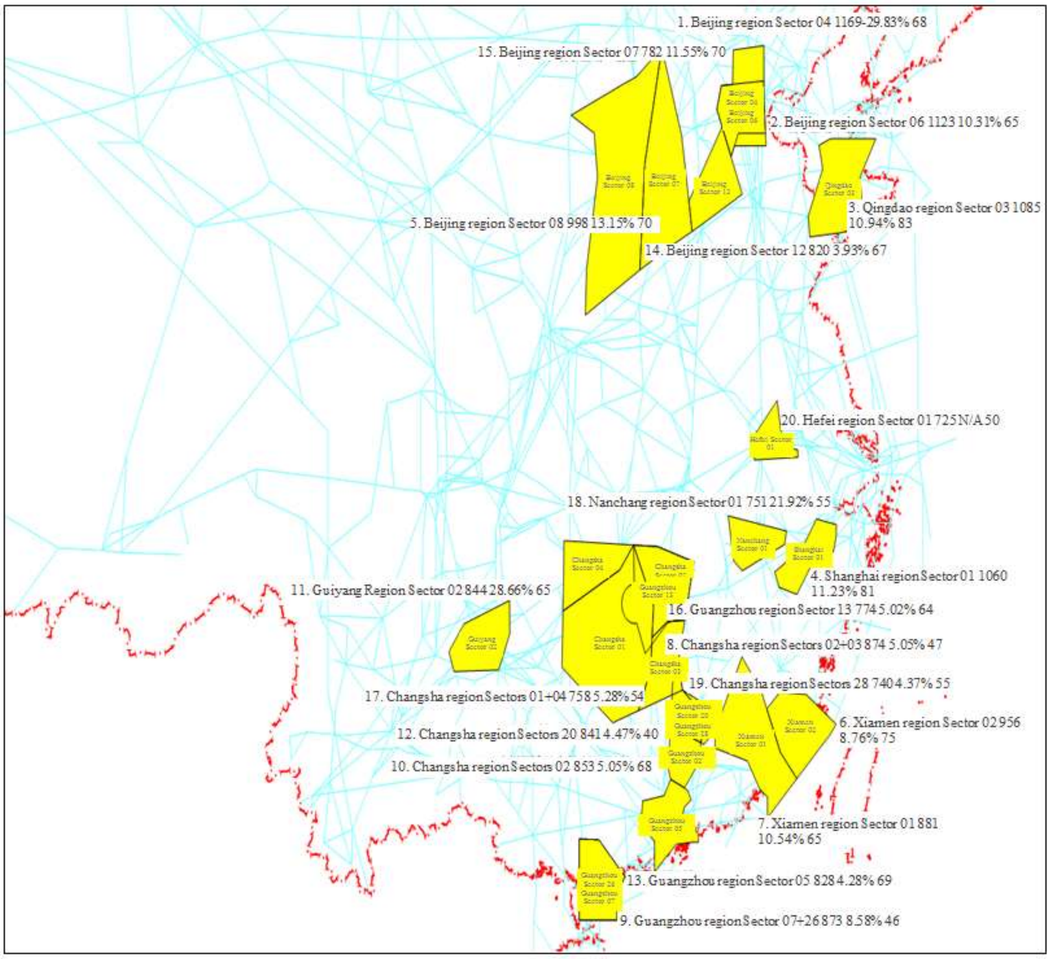


Figure 24: Top-20 busiest sectors in China regarding regional daily average flow

Temporary air routes

In 2017, the top-20 temporary air routes regarding daily average flow are mainly distributed in North China, Central South China and East China, which are also the regions with the highest flight activities. On the whole, the average daily flow of the above temporary air routes reaches 133 flights, and the average daily use time is about 16 hours, with the year-on-year increase of 19.82% and 25.98% respectively (see Figure 25 and Figure 26).

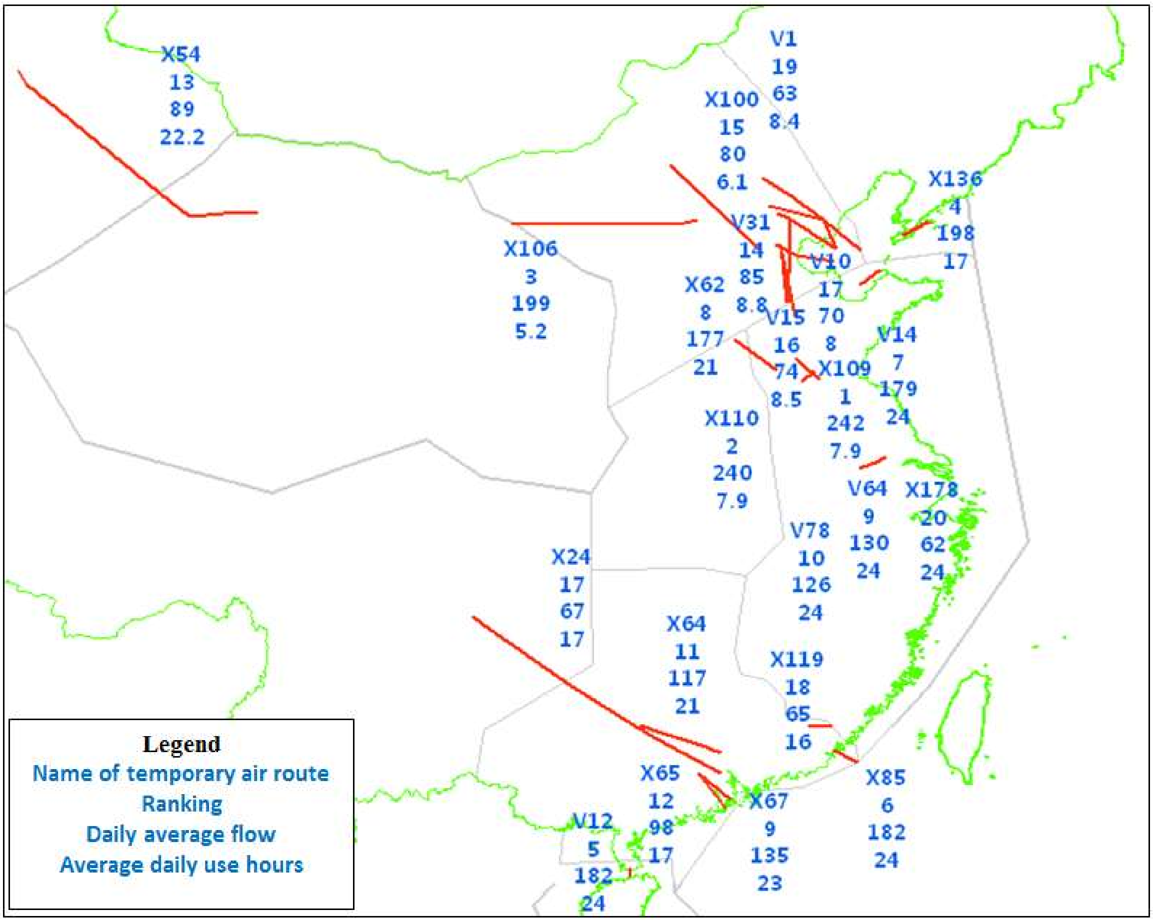


Figure 25: Average daily flow of the top-20 busiest temporary air lines in China (2017)

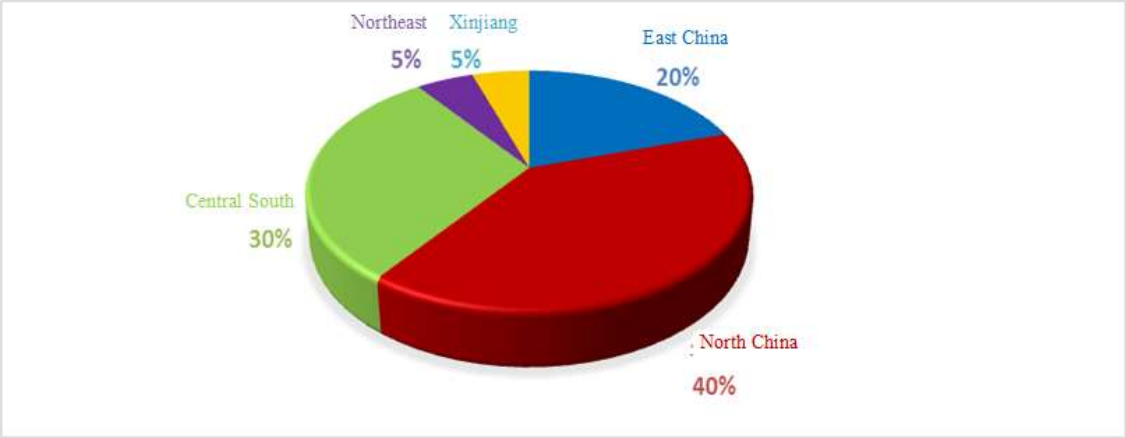


Figure 26: The Proportions of the top-20 temporary air routes regarding daily average flow in each region

The above figures list the average daily flow and average daily use hours of the top 20 temporary air routes respectively. Some temporary air routes in busy regions, such as X109 and X110, have an average daily flight quantity of more than 200 flights, which has become a useful supplement to the fixed air route network in this region, and played an important role in improving the regional airspace operation environment.

2.2.1.3 FLIGHT RULES

In China, VFR and IFR are also important components of ATM rules and are basically in compliance with ICAO standards [GOMT-PRC 2017].

For VFR flights, the Visual Meteorological Conditions (VMC) in China are nearly the same with that of ICAO except for an additional requirement that the indicated air speed (IAS) should be no higher than 250 km/h (otherwise VFR flights must be approved by ATC). In addition, CAAC has formulated more regulations which VFR flights shall comply with, including the requirements for clearance from ATC units and report of time and altitude when flying over each position reporting waypoint. CAAC has also defined the special VFR which is the rule for VFR flight cleared by air traffic control to operate within a control zone in meteorological conditions below VMC. For special VFR flight, the pilot usually applies to the controller and always follows the ATC instructions. The Controller is responsible for the safety separation provision between special VFR flights and other IFR flights.

For IFR flights, apart from related ICAO standards, there are some specific rules in China such as reporting requirements. Besides, the rules for changing from IFR to VFR flight in China are also stricter than ICAO's. For example, a change from IFR to VFR can only be made after the pilot sends application to the controller and obtains the approval with the timing when this change shall be made.

2.2.1.4 ATM ORGANIZATION

The Air Traffic Management Bureau of Civil Aviation Administration of China (referred to as CAAC ATMB) is the functional organization of CAAC to manage national air traffic service, civil aviation communication, navigation, surveillance, aviation meteorology and navigation information. The current governance structure of China's civil aviation ATM system is a three-level structure by CAAC ATMB, regional air traffic control bureau and air traffic control bureau branch (station). The operation organization pattern is basically a three-level air traffic service system with regional control, approach control and airport control as the main lines. The main responsibilities of Chinese ATM system are:

- to implement China's air traffic management policies, its laws and regulations, and to implement the rules, systems, decisions and instructions of CAAC
- to formulate the operation management regulations, standards and procedures of civil aviation ATM
- to implement the airspace use and ATM development and construction planning formulated by CAAC
- to organize and coordinate the construction of national civil aviation ATM system
- to provide national civil aviation air traffic control and communication navigation monitoring, navigation information and aviation meteorological services, monitor the operation status of the national civil aviation ATM system, research and develop new technologies of civil aviation ATM, and organize the application
- to lead and manage the air traffic control bureaus in various civil aviation regions, and be responsible for personnel, wages, finance, construction projects, asset management and information statistics of directly-affiliated units according to relevant regulations

To improve the safety level of China's air traffic management, the operational function and supervisory function of ATM are separated, the operation is managed vertically by the Air Traffic Management Bureau of CAAC, and the administrative functions such as supervision are still in the charge of the government. Specifically, the regional air traffic control bureau is the affiliated institution of CAAC, and enterprise management is implemented in the bureau; air traffic control bureau branch (station) is the affiliated institution of the air traffic control bureau in the civil aviation region where it is located, and enterprise management is implemented in the branch (station). The organizational structure of ATM system is shown in Figure 27.

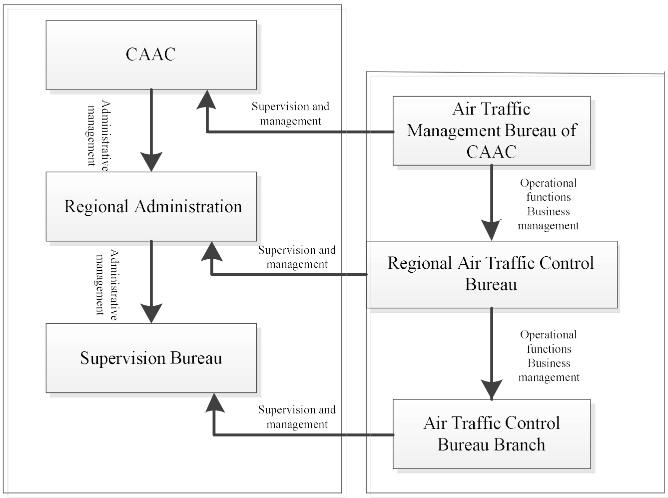


Figure 27: Organizational structure of Chinese ATM system

The Air Traffic Management Bureau of CAAC leads and manages seven major regional air traffic control bureaus and their subordinate air traffic control units. The seven major regional air traffic control bureaus are North China, Northeast China, East China, Central South China, Southwest China, Northwest China and Xinjiang air traffic control bureaus. Each regional air traffic control bureau is also in charge of several air traffic control bureau branches (stations), such as:

- North China Air Traffic Control Bureau is in charge of Hebei, Shanxi, Tianjin and Inner Mongolia air traffic control bureau branches and Hulun Buir air traffic control station
- Northeast China Air Traffic Control Bureau is in charge of Heilongjiang, Jilin air traffic control bureau branches and Dalian air traffic control station
- East China Air Traffic Control Bureau is in charge of Shandong, Anhui, Jiangsu, Zhejiang, Jiangxi and Fujian air traffic control bureau branches and Xiamen, Qingdao, Ningbo and Wenzhou air traffic control stations
- Central South China Air Traffic Control Bureau is in charge of Hainan, Henan, Hubei, Hunan, Guangxi and Guangdong air traffic control bureau branches and Guilin, Zhanjiang, Shenzhen, Sanya, Shantou and Zhuhai air traffic control stations, and Zhuhai approach control center
- Southwest China Air Traffic Control Bureau is in charge of Yunnan, Guizhou and Chongqing air traffic control bureau branches
- Northwest China Air Traffic Control Bureau is in charge of Gansu, Qinghai and Ningxia air traffic control bureau branches

Table 2 and Table 3 below provide an organizational breakdown, together with a list of tasks and responsibilities for the different parts of ATMB is provided.

The main internal business organization as well as the main subsidiary business organizations of the ATM Bureau of CAAC are summarized respectively in Table 2 and Table 3.

Table 2. The main internal business organizations of ATM Bureau of CAAC

	Roles and responsibilities
Strategic Development Department	• guide and coordinate the planning and development of subordinate units • implement the development and construction planning of ATM system • prepare the annual investment plan of ATM projects

	• organize and coordinate the research, development and verification of new technologies for civil aviation air traffic control • undertake the audit, establishment and acceptance check of scientific research projects • responsible for ATM business statistics
Regulations and Standards Department	• draw up the construction plan and implementation plan of ATM system operation quality • coordinate the drafting of normative documents such as ATM operation standards and procedures • organize the establishment of ATM system operation quality monitoring system • organize and coordinate the standardized management of ATM operation • supervise the quality of ATM operation, and study and formulate measures to improve the quality of ATM operation • organize and implement the training of ATM system quality auditors
Safety Management Department	• manage the ATM operation safety of subordinate units, supervise and inspect the implementation of ATM laws, regulations and standards of subordinate units • collect and sort out ATM safety information data and establish an ATM operation safety management system • investigate ATC incidents and accident proneness of subordinate units, and put forward treatment suggestions
ATC Department	• formulate normative documents for air traffic control and navigation information operation management • formulate technical grade standards for air traffic administers • guide and inspect air traffic control and navigation information business • study and formulate measures to improve the safety of control operation and guide and coordinate the implementation of the measures • be responsible for organizing the implementation of professional and technical training for the air traffic administers and navigation intelligence personnel of subordinate units • be responsible for coordinating international ATC and signing transfer agreements
CNS Department	• Formulate normative documents for operational management of communication, navigation and surveillance • guide and inspect the CNS business • study and formulate safety improvement measures for CNS operation, and guide and coordinate the implementation • handle the opening and closing of communication and navigation facilities and equipment, as well as the examination and approval of the station site of CNS systems • be responsible for organizing and implementing professional and technical training for CNS and radio personnel of subordinate units • organize and coordinate civil aviation radio jamming monitoring according to permissions

Meteorological Service Department	• formulate normative documents for civil aviation meteorological operation management • guide and inspect civil aviation meteorological work • study and formulate civil aviation meteorological operation safety improvement measures, and guide and coordinate the implementation of the measures • handle the opening and closing of civil aviation meteorological facilities and equipment, and the work related with site examination and approval • organize and implement professional technical training for civil aviation meteorological personnel of affiliated units
Planning and Infrastructure Department	• be responsible for the construction and management of ATM projects of subordinate units • organize the preliminary design, construction drawing design and completion acceptance of ATM projects • be responsible for overall coordination, supervision and management of the projects • be responsible for design change review and approval, project budget control • be responsible for implementing the construction planning of ATM system projects • formulate management measures for bidding of ATM projects, and supervise and manage the bidding work.

Table 3. The main subsidiary business organizations of ATM Bureau of CAAC

	Roles and responsibilities
Operation Management Center of CAAC ATMB	• be responsible for the national civil aviation flight flow management, and examine and approve the domestic flights and irregular flight times of Chinese and foreign airlines • undertake examination and approval of the applications of Chinese and foreign airlines in the current flight routes and flight altitude layers and the applications for increasing flight altitude layers, and examine and approve the use of flight routes and lines and the open use of the flight altitude layers and airport airspaces • unify and coordinate the national civil aviation ATM work, monitor the daily operation of the national civil aviation air traffic management system, collect, sort out and publish the operation information of the national civil aviation ATM system • understand and master the operation of civil aircrafts and airports, and coordinate flight conflicts and contradictions • organize and coordinate the ATM support for important flights such as Chinese and foreign special planes, emergency rescue and disaster relief, participate in the handling of emergencies such as hijacking and flight accidents, and coordinate with civil aircraft search and rescue work
Airspace Management Center of CAAC ATMB	• organize and coordinate the management and use of national civil aviation airspaces • undertake the design and adjustment of civil aviation Flight Information Areas, various control regions, air routes and lines

	• undertake matters related to the opening-up of airports, air routes and lines • be responsible for the management of national civil aviation flights and air lines • be responsible for the management of temporary air routes • organize and implement professional and technical training for airspace management personnel. Study and put forward the air route planning schemes of all kinds of airspace and air routes in China • study and design various airspace, air route and line setting schemes • study and put forward suggestions for national airspace use policies, technical standards and operational specifications of various airspace and air routes • study and carry out various types of airspace operation environment monitoring and evaluation and aircraft operation deviation monitoring • study and evaluate the operational capacity and operational safety performance of various airspaces • be responsible for the statistics and analysis of airspace operation information, and put forward suggestions for operation improvement • be responsible for organizing national civil aviation airspace experiment, simulation and verification • Be responsible for the coordination, management and technical support of flight program design of civil aviation (including the civil part of civil and military airport) airports • be responsible for studying flight program planning, technical scheme and demonstration • organize and implement professional and technical training for flight program designers
Technical Center of CAAC ATMB	• monitor and evaluate the operation status of national civil aviation CNS facilities and equipment, and coordinate the operation and emergency response of national ATM communication, navigation and monitoring equipment • undertake the tests and evaluation of civil aviation ATM facilities and equipment and the certification and testing of ATM equipment models, and organize the metrological work of ATM system • implement research, development and verification of new ATM technologies, organize technical research and public relation of major ATM equipment, and provide technical support and consulting services for ATM operation and development.
Aeronautical Meteorology Center of CAAC ATMB	• be responsible for the operation and management of national civil aviation meteorological services • publish national aviation weather forecast guidance products • provide national aviation meteorological services for users such as ATM units and airlines • establish a meteorological resource sharing platform, and be responsible for the exchange of domestic and foreign aviation meteorological information • be responsible for monitoring and evaluating the operation of aviation meteorological equipment, and provide technical

	support and guidance for meteorological equipment maintenance and repair • carry out aviation meteorological science and technology R&D, aviation meteorological user demand research, and new technology research • undertake the technical training and user training of civil aviation meteorological system.
Aeronautical Information Service Center of CAAC ATMB	• coordinate the national civil aviation aeronautical information service work • edit and publish aeronautical information data and charts • provide consulting services on aviation data and information • be responsible for issuing and handling NOTAMs • be responsible for reviewing and demonstrating the flight procedures of civil airports
Engineering Construction Headquarters	• be responsible for the project establishment of civil aviation ATM projects, feasibility study, and the technical work in initial stage • organize the implementation of civil aviation ATM engineering construction projects with Air Traffic Management Bureau of CAAC as the project legal person • be responsible for the financial management of the projects implemented by the headquarters • guide the construction of regional ATM bureau projects

2.2.2. TECHNICAL BASELINE

2.2.2.1 GROUND SIDE

At present, there are 4,616 sets of communication, navigation and surveillance equipment in the whole air traffic control system, with 5,570 support personnel for all kinds of equipment in China. In 2019, The accumulated running time of all kinds of equipment was 44,996,284 hours in the whole year. The average monthly normal running rate was 99.993%, the intact rate was 99.975%, and the communication, navigation and monitoring equipment (secondary and above impact events) event rate/10,000 sorties was 0.0019.

Three-level organizational institutions of equipment operation

The operation support system of civil aviation air traffic control equipment consists of three levels of institutions: Air Traffic Management Bureau of CAAC and its directly-subsidiary operation units, regional air traffic control bureau and its directly-subsidiary operation unit, air traffic control sub-bureau (station) and technical support department (see Figure 28). In addition, regional air traffic control bureaus also have air traffic control equipment installation companies, trunking[41] communication companies and other institutions to provide equipment support services.

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[41] Refer to definition in https://www.techopedia.com/definition/9775/trunking

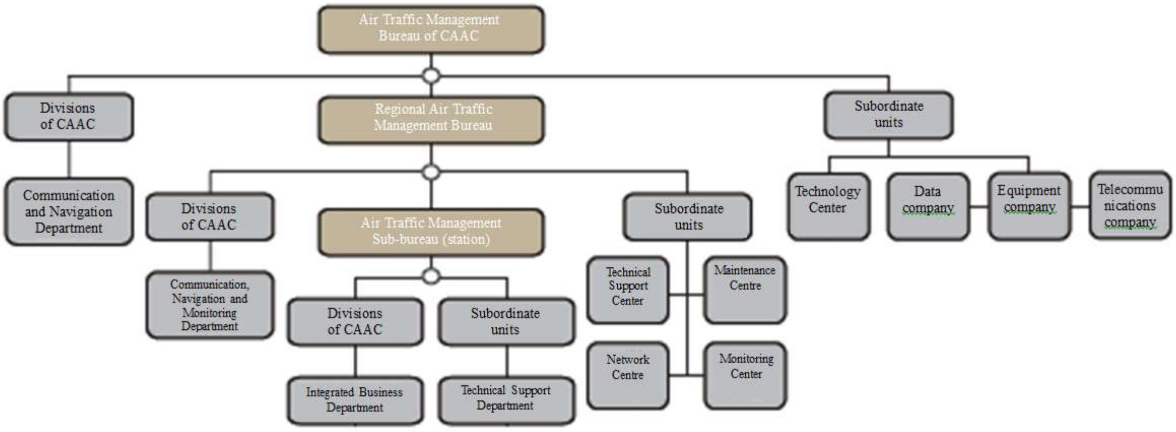

Figure 28: Three-level Organization Chart of Equipment Operation

Equipment configuration

In 2019, there were 621 sets of equipment newly-opened for use in the ATM system and 41 sets of scrapped equipment in total.

By the end of 2019, there were 4,616 sets of various types of communication, navigation and surveillance equipment in the ATM system, including 1,995 sets of communication equipment, 521 sets of navigation equipment, 663 sets of surveillance equipment, and 1,437 sets of other equipment (Figure 29 and Figure 30).

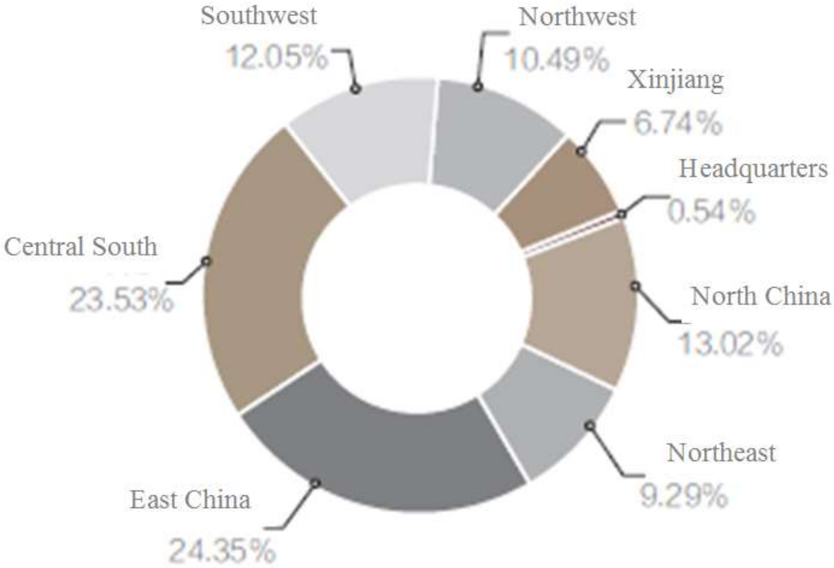

Figure 29: Proportion of equipment units (Sets) in each Region

By the end of 2019, for the use situation of professional equipment of ATM system, 1,734 sets have been used for 1-5 years, 1,369 sets 6-10 years, 860 sets 11-15 years, 422 sets 16-20 years, and 231 sets more than 20 years.

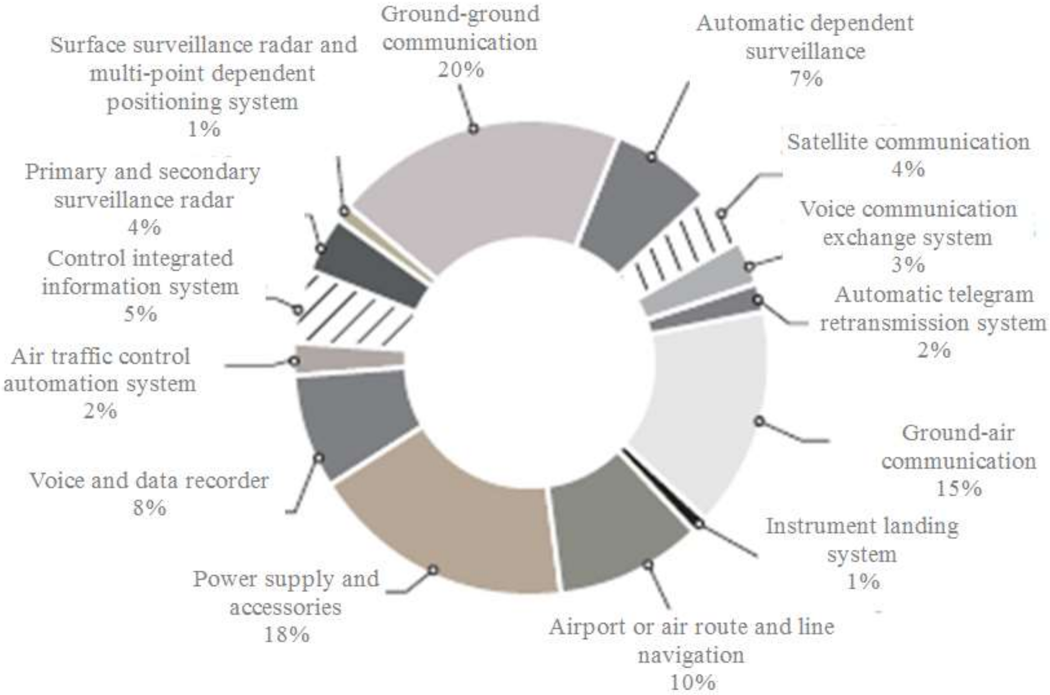

Figure 30: Proportion of the equipment in specialty

2.2.2.2 ON-BOARD SIDE

Avionics technology supporting the operational baseline

There are several advanced avionics systems and devices that are already equipped in China’s newly developed large civil aircraft C919 (refer to Figure 31), such as integrated modular avionics (IMA) system, high-speed data bus, etc., which have improved the safety, efficiency and economy of flight operation.

Figure 31: C919 Cockpit

Integrated Modular Avionics (IMA) System: IMA system is based on modular and open design, which can be extended and upgraded in functions and performance according to demands. It consists of several general information processing modules, data acquisition modules, storage modules, etc. Each information processing module has the same hardware and system software, and different applications can be loaded to accomplish different tasks. High-speed ARINC664 bus is equipped to support the transmission of large amounts of data, thus supporting IMA's real-time information processing and control of on-board system equipment. As a result of increased system integration, system equipment decreases in the presence of increased functionality, which helps to reduce structural weight and improve maintenance performance.

Flight Management System (FMS): The flight management system can interact with and control the navigation system, communication system, automatic flight system, automatic throttle system, radio navigation system, global satellite navigation receiver, etc. It has the core functions of flight planning, flight guidance, comprehensive navigation, performance calculation and trajectory prediction, etc. It can establish a complete flight trajectory according to the flight plan and related information, and then automatically derive the airplane course error according to the data provided by the navigation system, and give automatic correction, which greatly reduces the burden on the pilot by achieving the optimized trajectory to reduce aircraft fuel consumption and to improve the economic efficiency.

Integrated Cockpit Display System: The cockpit display system is the core system of human-machine interaction between pilot and aircraft. It provides the pilot with the main flight status such as speed, altitude, position and other onboard systems, and is a direct way for the pilot to understand the flight status. The integrated cockpit display system realizes highly integration of different types of display information through software processing, and is able to display simultaneously multiple kinds of data on the screens such as primary flight data (speed, altitude, attitude, etc.), navigation, communications, surveillance, electronic checklists, meteorological and terrain and other system operating status, providing better ergonomic performance.

Other avionics systems include for example new generation communication and datalink systems, high-precision inertial navigation and global satellite navigation receiver, weather radar, ATM transponder and aircraft health management system.

2.3. COMPARISON OF BASELINES IN EUROPE AND CHINA (T2.1.4)

This section compares the commonalities and differences between the current ATM System in Europe and China, described respectively in the chapters 2.1 and 2.2. This analysis aims to establish a common awareness about the current ATM systems from both sides and to identify the factors that could have an impact on the future implementation of the greener ATM concepts. It also serves to build a collaborative environment as the prerequisites of new concept development for greener air traffic. It is essential to assess and understand the strengths, weaknesses and challenges of each ATM system, and to exchange experiences and feedbacks about practices and the procedures already in place. This is the only way to ensure that greener ATM concepts being developed within the framework of this project will be suitable, relevant and tailored to the situation in both world regions.

The following analysis is very much based on chapters 2.1 and 2.2, and has been worked out in several online workshops that were attended by European and Chinese partners of GreAT.

2.3.1.1 AIRSPACE STRUCTURE AND MANAGEMENT

The way airspace is organized and managed has an extremely important role within each ATM system. It is a key enabler for achieving a higher flight efficiency and for maximizing fuel and emissions savings. The differences between the current airspace structures in Europe and China are assessed in relation to the air traffic services to be provided. In the following subchapters, the results of the comparison between the different airspaces and ATS practices are presented.

En-route operations

The global airspace is divided into nine air navigation regions by ICAO. Europe and China belong respectively to EUR and ASIA air navigation regions. These regions are further divided into Flight Information Regions (FIRs). There is no standard size for FIRs – it is subject to administrative convenience of the country concerned. In only few cases, in Europe, there is a vertical division of the FIR, in which case the lower portion remains named as FIR, whereas the airspace above is termed as upper information region (UIR). Likewise, FIRs in China are divided in Upper control area and mid/low-altitude flight control area. The exact definitions of these areas are provided in Table 4.

Table 4. The definitions of FIR in Europe and China

	Europe	China
Upper portion of the FIR	The UIR is the part of airspace above a variable vertical limit. It is generally set, in most cases, between FL660 and the division level defined by each country.	Upper controlled airspace can be set up for the airspace above standard barometric altitude of 6,000 meters (excluding) within the territory of PRC [GOMT-PRC 2017].
Lower portion of the FIR	The lower airspace is part of the airspace below the variable vertical limit. It is controlled airspace below the division level and outside the terminal or airport airspace and includes airways linking the airport with upper airspace.	The mid and low-altitude controlled airspace can be set up for the airspace with standard barometric altitude from 6,000 meters (inclusive) to a specified lower altitude [GOMT-PRC 2017].

Table 4 shows that both airspaces in Europe and China are structured in a similar way, although the use of different nomenclature and offsets (Flight Level versus barometric altitude).

As stated in ICAO Annex 11, the different portions of the controlled airspace shall be designated in relation to the air traffic services that are to be provided, if any [ICAO 2018]. In each FIR or across FIRs, one or several ACCs (Area Control Centers) and/or UACs (Upper Area Control Centers) provide En-route air traffic services in Europe. In China, aircraft flying in upper, mid and low-altitude controlled airspaces receive air traffic control services provided by regional control centers.

Table 5 illustrates some relevant facts about the sectorization of both airspaces. It allows to compare between the number of ACC and En-routes sectors providing En-route control services in Europe and China. The fragmentation topology of the European airspace is striking. There are roughly three to four times more FIR, ACC and Sectors in Europe than in China for quite the same total airspace area.

Table 5. Quantitative comparison between the airspace organization in Europe and China

Europe	China
Total airspace area =10.8 million km²	Total airspace area = 10.81 million km²
Number of FIR/UIR[42] = approx. 60[43]	Number of High-altitude control areas = 16
	Number of FIR= 11
Number of ACC = approx. 70[44] (EUROCONTROL: 68 ACC)	Number of medium/low-altitude control areas (called also regional control areas) = 28
Number of sectors: approx. 700 ATC En-route sectors managed by NM[44]	Number of regional control sectors= 223
Number of ANSPs = 40 in Europe (41 in the EUROCONTROL area). The 5 biggest ANSPs are DFS for Germany, DSNA for France, ENAIRE for Spain, ENAV for Italy and NATS for the UK. They bear 60 % of total European gate-to-gate service provision costs and operate 54 % of EU traffic[45].	Number of regional ATM bureau = 7 They are North China, Northeast China, East China, Central South China, Southwest China, Northwest China, and Xinjiang air traffic control bureaus.

Altogether, the figures indicate that the European airspace is obviously much more fragmented than the Chinese one. This is a significant difference between both ATM systems. The airspace fragmentation has become for some time an urgent matter in Europe as it considerably impacts the efficiency of European ATM system, which explains the deployment of numerous European projects and initiatives aiming to harmonize the European airspace design and network management. Great achievements are already done, and more are ongoing to cope with the future traffic growth.

Airspace classification

Airspace in Europe is classified and designated in accordance with ICAO in the different airspace classes (A, B, C, D, E, F and G). Nevertheless, each country has the freedom to structure its airspace with the different airspace classes according to its own specific demands. This led to lack of harmonization in the current application of ICAO ATS Airspace Classes by the ECAC States. Further, this makes it necessary to simplify and harmonize the airspace classification to facilitate cross-border sectorization, and thereby avoid complexities involved with applying different rules and procedures.

On the other hand, there are mainly four classes named A, B, C and D in China. Class A covers the upper airspace above 6600 meters, class B the lower airspace below 6600 meters in En-route area, class C is approach airspace that is connecting the lower airspace

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[42] In most European countries there are only FIRs.

[43] https://www.eurocontrol.int/publication/flight-information-region-firuir-charts-2019

[44] https://www.icao.int/MID/Documents/2019/ACAO-ICAO%20ATFM%20Workshop/1.3.1-%20EUROCONTROL%20Experience.pdf

[45] https://ec.europa.eu/transport/modes/air/ses_el

and tower control area, class D contains the tower control area. In China, airspace A is used only by IFR and airspaces B, C and D can be used by IFR or, subject to conditions and approvals, VFR.

All things considered, it is important to highlight that the airspace classes in China differ from the airspace classes in Europe although the similar nomenclatures. They are not defined as per ICAO, but rather in accordance only with the native law and regulations. CAAC is planning to reform the airspace classification in accordance with ICAO in the near future.

This is a major difference on both sides. It is also worth noting that, within the Chinese airspace, the classification of airspace is harmonized since it is related to only one country unlike Europe (27 states).

Airspace restrictions

Historically, many European Danger Areas and Restricted Areas have been inactive or unused for most of the time for which they have been notified as being active. To overcome this inefficient use of the airspace, the Flexible Use of Airspace (FUA) concept was introduced within Europe. With the application of the FUA concept, airspace is no longer designated as pure "civil" or "military" airspace, but considered as one continuum in which all users requirements have to be accommodated to the greatest possible extend. The FUA concept allows the maximum shared use of airspace through enhanced civil/military co-ordination. The application of FUA ensures that any airspace segregation is temporary and based on real use for a specified period. FUA regulates the availability of airspace for military purposes, which is temporarily segregated for safety reasons, and flexible ATS routes (conditional routes) for general air traffic. These routes supplement the existing ATS route network and lead through temporary segregated airspace (TSA). In Europe, this concept is widely used, whereas in China a similar concept is not yet implemented. In fact, 269 special airspaces are identified in China (refer to chapter 2.2.1.1). Any optimization of the use of these airspaces, through for instance the implementation of concepts like FUA, should bring a significant benefit for civil airspace user.

More generally, the rules related to civil and military flights in both regions are completely different. In Europe, the same rules apply to both. Civil controllers may control military flights and vice versa. Equally, both sorts of flights may basically use the same airspace. Only very special situations are covered by extra military rules. Military training is done in temporary reserved airspaces, which may be crossed by civil flights under special circumstances. In China, civil and military airspace users cannot use the same airspace. Hence, different ATM rules are applicable to military air traffic with a much stricter separation of civil and military aviation. This explains the reason why a dedicate Military Coordination Controller is prescribed in China. In contrast, liaison controllers may, but not necessarily have to, be employed in Europe where military aircraft are controlled by civil controllers and vice versa.

ATS routes

The way ATS routes are designed and used is a key factor to influence the performance of ATM network. More direct and shorter routes will reduce the aviation environmental footprint though more efficient flight trajectories. The flight efficiency could be improved by enhancing both route availability and utilization. For that reason, every European state is migrating or plans to migrate from the conventional ATS routes to Free Route Airspace (FRA). Several FRA initiatives are already implemented within Europe in different forms (i.e. FRA and route network mix, published direct route network, temporary FRAs, etc.). 55 of 70 European ACCs have either fully or partially implemented free route airspace operations. There is an increasing trend for ACCs to conduct cross border operations and to lower the base level of FRA to the maximum extent possible. Full operations European wide are expected by 2023/2024[46]. For the time being, both the fixed ATS route network and the Free Route concept are coexisting in Europe, while in China only fixed ATS route network is used. The air routes in the Chinese airspace are classified according to either the airspace users (international or domestic users) or to the duration of the use (temporary or permanent use). Nevertheless, most of ATS routes including domestic ones are usable for all airspace users. In other words, most of domestic air routes can be used for international flights by application in advance. All available ATS routes in Europe and China are gathered respectively in the RADs and/or national AIPs. Shortcuts and direct routes are also possible in both ATM systems in principle, when granted by the ATCO. Besides, a set of entry and exit points for the airspace are set up. Their use is strictly prescribed in China, whereas in Europe they are more meant for the planning purposes, and other positions along the airspace border might be used on short notice, when coordinated between related ATC centers.

To sum up, no FRA is yet defined and only conventional fixed ATS network is used in China. This is assessed as a significant difference between the ATS routes network from both sides.

Terminal Maneuvering Area (TMA)

An efficient TMA design and utilization is an important factor impacting the flight efficiency and TMA capacity, and could be reached though the implementation of advanced navigation capabilities, the use of optimized procedures (such as continuous descent approaches (CDAs)) and the development of advanced ATC support tools (such as AMAN). Table 6 compares the TMA structures, its related procedures and control services in Europe and China.

Table 6. TMA structure and its related procedures in Europe and China

	Europe	China
Definition	The structure of the terminal airspace is laid by the principles defined in chapter 2.1.1.1. Almost all the European countries are following these principles to a certain extent.	The approach controlled airspace is the connecting area between the upper controlled airspace or the mid and low-altitude controlled airspace and the aerodrome control zone, or the mid-altitude and low-altitude controlled airspace and the aerodrome control zone, and its vertical range is usually below 6,000 meters (inclusive) and above the lowest flight level; The horizontal range is usually within a radius of 50 km or within the corridor entrance and exit, except for the control area of the aerodrome control tower [GOMT-PRC 2017].
Used procedures	• SID and STAR (as per ICAO) • RNAV / GPS Transitions exist at many airports (used in very high traffic TMA structures and very busy aerodromes) in Europe.	• SID and STAR (as per ICAO) • RNAV / GPS Transitions

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[46] https://www.eurocontrol.int/publication/free-route-airspace-fra-implementation-projection-charts

	• At some places in Europe, Point Merge system developed by EUROCONTROL is also used. • More and more European airports have T- or Y-bar based instrument approach procedures (IAP), where the final waypoint of the STAR is the IAF of the IAP.	
Air Traffic Service provided	The Approach control services may be performed by ACC centers or delegated to the ATC tower. The required CWPs is defined according to local needs and on a discussion basis.	The APP may take over ACC tasks, ACC may take over APP tasks, Tower may take over ACC and APP tasks. In addition, the required Controller Working Positions are defined based on the number of flight movements.

It shows that the structure of the TMA is relatively similar on both sides although the use of different nomenclature and offsets. However, some additional procedures and techniques, for instance Point Merge and T- or Y-bar based instrument approach procedures, are being experimented and used in European TMA aiming to achieve more optimized TMA operations. Additionally, different methods are employed to evaluate the number of the required APP CWPs.

Control Zone (CTR)

As per Table 7, the CTR is defined in the same way and there are similar CWPs (AD, GND, SUP and CD) in the ATC tower for both Europe and China.

Table 7. CTR structure and the provision of aerodrome control services in Europe and China

	Europe	China
CTR definition	Aerodrome Control Zones afford protection to aircraft within the immediate vicinity of aerodromes.	The aerodrome control zone usually includes the traffic pattern and the track leg after the final approach locating point, as well as the space below the first holding altitude level (inclusive) to the earth surface and the aerodrome maneuvering area [GOMT-PRC 2017].
Air Traffic Service provided	The most conventional ATC Tower layout is: • aerodrome controller • ground controller • clearance delivery controller • tower planning controller • tower supervisor At some European airports with more traffic, aerodrome controllers might be assigned for dedicated runways.	The Work Seats of Aerodrome Control Tower are: • Aerodrome Control Seats • Ground Control Seats [more than 40,000 Take-off/ landing MVT per year or ILS CAT II] • Clearance Issuing Seats [more than 40,000 Take-off/ landing MVT per year or ILS CAT II] • Notification Coordination Seats • Director Seats • Military Coordination Seats

		Additional aerodrome controller and ground controller seats when needed according to the number of runways and complexity of taxiways [GOMT-PRC 2017].

2.3.1.2 MAIN TRAFFIC FLOWS

Traffic volume & Forecast

In 2017, the air traffic handled by Europe was approximatively twice the traffic managed by China (refer to Table 8). In 2019, the rate of the flight on-time in China (81.65%) is higher than in Europe (77.8%) and the average flight delay in China (15 min) is higher than in Europe (13.1 min). In addition, the main cause for delays in China is the weather conditions. Yet, the main cause for the delay in Europe is the airspace capacity. At the airport, the main reasons for delays are quite similar namely the weather and the airport capacity. Clearly, both Europe and China share the same worries and concerns about the flight punctuality as there are several similarities between both situations, despite the discrepancies between the main causes reported from both sides.

It should be also noted that the Military cause is an important reason for the delay in China which is not the case in Europe. That is also an indicator of the efficiency of the solutions already implemented in Europe in this regard (such as FUA and FRA).

Table 8. Traffic volume in Europe and China

	Europe	China
Traffic volume	In 2017, Europe recorded strong and broad-based traffic growth taking flight totals to a record 10.6 million.	In 2017, China recorded flight totals of 5.32 million.
Delays	Airline punctuality improved in 2019 with 77.8% of flights arriving within the 15-minute threshold, or earlier than their scheduled arrival time (STA). Based on airline data, the average delay per flight from 'All-Causes' was 13.1 minutes per flight [EUROCONTROL 2019d].	Flight on-time rate (2019) = 81.65% Average flight delay (2019) = 15 min
Traffic forecast	For Europe as a whole, the Regulation and Growth scenario (most-likely) has 16.2 million flights in 2040, 53% more than 2017 [EUROCONTROL 2018b].	The annual growth rate of air transportation is estimated at approximately 12,2% in the past 5 years and it is expected to continue growing in the future.
Causes of delays	The main reasons for en-route ATFM delay in 2019 were: • en-route ATC capacity (32%) • en-route ATC staffing (17%) • en-route weather (15%) Airport weather (12%) and airport capacity (8%) were the main delay causes attributed to airports [EUROCONTROL 2019d].	The main reasons for delay in 2019 were: • Weather cause = 47% • Airlines cause = 21% • Military cause = 26% • ATC cause = 2.3%

Airports

To achieve a higher level of sustainability, the traffic congestion and capacity crunch on airports, often being bottlenecks of the air transport system, should be addressed. Table 9 demonstrates that from both sides there are very busy airports facing similar or same kind of challenges. Thus, common ideas and solutions are beneficial for both. All these airports are part of the 30 busiest airports worldwide. The situation for both sides is comparable.

Table 9. Most congested airports in Europe and China

	Europe	China
Total number of airports	• Small airports: 2107 • Medium airports: 867 • Large airports: 159	236 airports: • 66 international airports • 170 domestic airports • 13,013 city pairs • 8,542 flight air routes
The busiest airports	Frankfurt (FRA), Amsterdam (AMS), Paris (CDG), London-Heathrow (LHR), Istanbul (IST), Munich (MUC), Madrid (MAD), Barcelona (BCN), Rome (FCO) and London-Gatwick (LGW).	Beijing Capital Airport, Shanghai Pudong Airport, Guangzhou Baiyun Airport, Kunming Changshui Airport and Shenzhen Baoan Airport
Airport CDM	all the above listed airports have implemented A-CDM.	all the above listed airports have implemented A-CDM.
Equipment	Major European airports must be capable of CAT I-II-III precision approach and landing. Special systems, e.g. A-SMGCS[47] are also widespread in Europe, and enable handling air traffic under bad weather conditions as well. An A-SMGCS level 2 is the most used in European airports, except major Airports where a higher level is generally deployed (3 or 4).	Major Chinese airports must be capable of CAT I-II-III precision approach and landing (including ILS) operations. All the top 30 airports in China already have A-SMGCS Level 2 capability. Beijing Daxing International Airport has completed the construction of A-SMGCS Level 4.

2.3.1.3 FLIGHT RULES

Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) are the two sets of rules for operating any aircraft in Europe and China.

Both, European countries' and China's regulations, are based on ICAO recommendations and restrictions on flight rules. The main difference between European and Chinese approach is how they handle the deviations from ICAO rules. In Europe, the principle of subsidiarity can be seen, however Chinese regulation is more prescriptive.

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[47] NOTE: EUROCONTROL Specification for A-SMGCS Services Edition 2.0 supersedes prior EUROCONTROL A-SMGCS documentation that referred to Level 1 and 2. The new documentation uses the following service types instead of levels: Surveillance Service, Airport Safety Support Service, Routing Service, Guidance Service**.**

Flight plan management

The whole process is starting at the FPL handling and management. The theorem, as described in chapter 2.2.1.3, is similar in both places with some little differences (e.g. type of airplanes which must submit FPLs, the deadline of FPL submission, the handling of changes in the FPL, deleting process of FPLs, etc.).

2.3.1.4 ATM ORGANIZATION

The governance structure of the European ATM system is structed in a two-level system; the first level is the national or state level (ANSPs) and the second one is the supranational level which includes the European institutions such as EU, EUROCONTROL and EASA (refer to Table 10). On another hand, the current governance structure of China's civil aviation ATM system comprises a three-level structure by CAAC ATMB, regional air traffic control bureau and air traffic control bureau branch (refer to Figure 27).

Table 10. Institutional setup in Europe

Actor	Service provision	Regulation	Supervision
ANSPs	✓	Initiation, consultation, implementation	✗
National Institution (authorities, ministries, parliaments etc.)	✗	Initiation, consultation, codification	Supervision, regular (e.g. annual) and irregular checks (e.g. awarding of certificates)
ECAC	✗	✗	✗
Eurocontrol	✓	✓	✗
European Union	✗	By European Council, European Commission, European Parliament	✗
EASA	✗	✓	✓

Table 11. Institutional setup in China

Actor	Service provision	Regulation	Supervision
CAAC ATMB	✓	✗	✗
Regional ATMB	✓	✗	✗
ATM Branch office	✓	✗	✗

CAA of China	✗	✓	✓ (supervises the CAAC ATMB)
Regional CAA	✗	✓	✓ (supervises the regional ATMB)
Local Regulatory Authority	✗	✓	✓ (ATM Branch office)

As shown in Table 10 and Table 11, ANSPs and NM are responsible for the ATS provision in Europe, while CAAC ATMB, regional ATMB and ATM branch offices are responsible in China. In terms of regulation, China and Europe follow the guidance of ICAO. As expected there are some major and minor differences to ICAO, but the given countries describe these precisely in their national AIPs. For Europe, there are additional regulation and legislation organization and institutions. In China, the supervision is made at each level by a dedicated entity. In Europe, it is also the case: On the national level by national institutions (via regular audits) and on the European level by EASA. From both sides, there are regular inspections but in China, they are stricter than European ones.

More generally, the Air Navigation Service structure in China is slightly different from Europe. For instance, the provision of AIS and MET are part of ATS. The Air Traffic Service Reporting Office is local, while in Europe it might be local or centralized depending on national law.

It could be concluded that, despite the difference in the global ANS structure, the ATM structure is the same from both sides. In terms of services provided, the ATM covers ASM, ATFM and ATS.

Air traffic Flow management

The aim of air traffic flow management is the same in Europe and China. The primary role of the ATFM is to manage the traffic in dependence of demands, routes and capacity with the collection of input data, demand-capacity-balancing and creating new solutions. Another goal is the increase of economic and ecologic efficiency for ANSPs, airliners, passengers, third parties and environment and protecting controllers from sector overload, which can occur in case of high traffic, in certain sectors and certain time periods.

The Network Manager (NM) is the organization responsible for flow management in Europe. It performs the flow management tasks at the Network Manager Operations Centre (NMOC). It optimizes traffic flow by constantly balancing capacity supply and demand while ensuring the safe and efficient operation of flights going to and over Europe. In China, the Operation Management Center of Air Traffic Management Bureau of CAAC provides the tasks in relation to flow management.

In terms of organization of flow management, there is a very important deviation between Chinese and European network management. In Europe, there are 3+2 different time-based phases of the network management which are the following:

- Preliminary planning and forecasting
- Strategic level
- Pre-tactical level
- Tactical level
- Post Operation Analyses

Similarly, there is a continuous air traffic flow management system in China as well, however the flow management process is not separated into time-based subtasks like in Europe. Due to this fact, the planning phase is not so varied and detailed as in Europe.

Flow management measures: The flow regulator measures that aims to prevent the overload of air traffic network in China are as follows:

- Ground delay program (GDP)
- Airspace Flow Program (AFP)
- Miles-in-trail (MIT)
- Coordinative rerouting
- Fix Balancing
- Altitude restriction
- Airborne Holding program
- Ground Stop program
- Interaction between "ground delay" flow management programs.

The flow management measures used in China exist in a very similar way in European ATFM as well, but there are differences in the process of each procedure. Besides, European flow management have some other opportunities for a more efficient air traffic management (e.g. FRA, FUA). In short, it can be stated that the purposes of flow management are the same in both China and Europe, but the available procedures, skills, tools and processes can be different.

In addition, the declared sector capacity for flow management in China shall be scientifically evaluated. The maximum number of aircraft that can be provided with radar services at the same time shall be determined according to the actual conditions of the control area, such as environment, equipment, personnel skills, sector size or route density [GOMT-PRC 2017]. In Europe, the sector capacity is determined on a daily basis by experience.

Airspace Management (ASM)

The ASM has quite the same definitions and functions on both sides, except for the rules applicable to the military users. On the European side, military and civil users are equally defending their interests, whereas on the Chinese side, the military are imposing constraints to the civil air traffic.

Table 12 shows slight differences in VFR and SVFR weather minima and differences in separation minima, but they remain basically comparable. It underlines that in China more precise rules for the separation between VFR flights are prescribed than in Europe.

Table 12. VFR & IFR Separation minima

Europe	China
The safety distance between VFR flights is based on the pilot’s judgement.	The safety distance between VFR flights is explicitly prescribed.
How the VFR flights are controlled depends on airspace classification (ICAO airspace classes)	The VFR flights are controlled depending on altitude and speed, flight plan/routing and release clearance.
The en-route coordination procedures are described in LoAs / OOs and often involve silent (automatic) exchange of information.	The en-route coordination procedures are detailed standard coordination procedures which seems to be more conventional.

The VFR pattern dimensions are published for every aerodrome.	The VFR pattern dimensions are prescribed and standardized.
The traffic volume in VFR pattern does not have limit.	The traffic volume is explicitly limited in VFR pattern.
Several levels are available so it is possible to fly the optimum level.	The Chinese FL definition is almost the same with European one after CAAC implemented RVSM standard in 2009, except for very small difference in altitude (~30m) at some FLs above 8400 meters due to different metric. Nevertheless, it might be observed that the FL allocation for separation is more flexible in Europe than in China.
IFR separation minima: 5 NM in en-route, 3 NM within 30NM radius in TMA where ASR is available	For IFR flights, apart from related ICAO standards, there are some specific rules in China.

2.3.2. TECHNICAL BASELINE

2.3.2.1 GROUND SIDE

The CNS infrastructure and equipment supporting the provision of ATS service in Europe and China are highly similar. However, there is more diversity in terms of system suppliers and technologies from European side, which implies less efficiency and higher costs. For China, this is not really the case.

2.3.2.2 ON-BOARD SIDE

Same aircraft types are flying in both European and Chinese airspaces. Therefore, it could be concluded that the on-board equipment is quite similar. Moreover, there are some similarities in the CNS architecture and equipment between the China's newly developed large civil aircraft C919 and Airbus or Boeing aircrafts. Nevertheless, some of the equipment are developed by domestic manufacturers.

In Both Europe and China, the RNAV5 and RNAV1 are used respectively in ACC and TMA.

2.3.3. SUMMARY OF THE ATM BASELINE COMPARISON

The commonalities and differences between Europe and China are summarized in Table 13. Both ATM systems are similar in several aspects. The global airspace structure and the ATS provided seem to be the same, although the use of different terminologies and metrics. However, when it is examined in depth, the European airspace is considerably more fragmented and rigid, compared to Chinese one, probably due to the multiple involved states, actors and institutions that have to find an agreement to change something. At the same time, and for the same reason, Europe has since a while now intensified its efforts to defragment and harmonize the airspace, by implementing several advanced and efficient solutions (such as FRA, FUA, etc.) which are not yet implemented in China. The GreAT project will be one opportunity to discuss some of these new concepts in West of China, and to assess the resulting benefits from it. Another major difference between both regions is the definition of the airspace restrictions. In Europe, these restrictions are managed in a very flexible way in contrast to China, where they are rather permanent. In particular, this concerns the airspaces used by military aviation. Civil and military aviation are equally handled by the European ATM system, implying the use of the same rules and airspaces, and are controlled most of the time by the same air traffic controllers. In China, more strict rules and different airspaces are used, and additional dedicated controller position are needed for civil-military coordination. This is consistent with an overall finding of this comparison study: in China, rules and procedures are stricter and more prescribed than in Europe. In addition, and although that Europe is currently handling / will handle more traffic than China, the situation in both countries is highly similar. Both are dealing with the same challenges and issues and are operating the busiest airspaces and airports worldwide. They are also using and developing similar technical ground and airborne solutions. The cooperation between the two will be very fruitful and beneficial, since great achievements have been already made in the past and very ambitious goals are targeted by both in the future.

Table 13. Summary of the ATM Baseline comparison

Topic	Assessment				Comments
	Commonalities	Difference			
		Low	Medium	High	
Airspace structure			X		The airspace structure is basically the same from both sides despite the difference in nomenclatures. On European side, ICAO terms and wording are almost fully used. On Chinese side, sometimes different terms are used for the same thing. It is also notable that the most widely used measurement units in Europe, America and Australia are feet and NM, while in China, ATC is using a meter and kilometer metric.
Airspace organization				X	The quantitative comparison between the airspace organization in Europe and China reveals that the European airspace is much more fragmentated than the Chinese airspace. Europe is dealing with about 3 to 4 times more FIR, ACC and Sectors than China, even if they have the same total airspace area. It is also to be noted that, in contrast to China, the European ATM structure is rigid and thus very hard to change, considering the numerous involved parties and countries.
Airspace classification				X	The airspace classification in China does not quite follow the standards of ICAO, as is the case in Europe, but based on native laws and regulations.
Airspace restrictions				X	The restrictions imposed to the use of airspace in Europe are being more and more temporary set. This was made possible through the implementation of FUA concept. In contrast, all airspace restrictions in China are permanent which explains the high number of special dedicated airspaces.

Civil-Military Cooperation			X	The rules applicable to civil and military flights in both locations are completely different. In Europe, the same ATM rules apply to both, whereas in China different rules are applicable to military with a much stricter separation of civil and military aviation. This explains also the need and use of additional dedicated military coordination controller positions to specifically handle this coordination.
TMA		X		Globally same structure and principles are used for the design of the TMA. Additional procedures and techniques are being explored in Europe.
CTR		X		From both sides, there are similar CWPs (AD, GND, SUP and CD) in the tower.
ATS routes			X	Both the fixed ATS route network and the Free Route concept are coexisting in Europe, while the implementation and use of FRA is increasing. Unlike Europe, China is using only fixed ATS route network and no FRA airspace is yet defined. Most of routes are usable for every airspace user in Europe in China.
Airways		X		Controlled airspace in China is established along airways, air route zones and civil aerodrome areas; in Europe it depends on national laws.
Air Traffic situation	X			The air traffic handled by Europe for instance in 2017 was approximatively twice the air traffic managed in China but the delay matter is equally significant for Europe and China despite the different main causes.
Airports	X			Obviously, there are more airports in Europe but the situation is still quite similar from both sides. Europe and China are dealing with hub airports ranking within the 30 busiest airports worldwide and facing the same kind of challenges and issues.
Flight rules	X			With few minor differences, there are similar flight rules as they are based on ICAO,
ATM Governance		X		The governance structures in Europe and China are different. This could be explained by the numerous European parties and states involved in comparison to only one country in case of China. It explains also the urgent need of harmonization of ATS service provision in Europe. Additional regulation and legislation organization and institutions exist in Europe. It should be also noted that the rules and supervision are stricter in China.
ATM X				The global structure of ATM is the same from both sides
ASM			X	The rules applicable to military aviation are quite different.
ATFM		X		In Europe, there are 3+2 different time-based phases of the network management. The flow management

					process in China is not separated into time-based subtasks. To sum up, the purposes of flow management are the same in both China and Europe, but the available procedures, skills, tools and processes can be different.
ATC Licensing			X		ICAO's requirements apply to all ATCOs across the globe. Additional specific rules from both sides (EASA for Europe, and Rules of License Management for China). In addition, new ratings have been introduced in Europe namely Rating Endorsements, Unit Endorsements and License endorsements.
Liability and rewards			X		In Europe, there is no rewards, only liability, but they are not as detailed as on Chinese side. In China, units and persons are rewarded for good performance and liable for bad performance. In addition, Europe and China are dealing with mistakes in different ways ("just culture" versus "rewards and punishment").
Ground and On-board equipment	X				Quite similar equipment and technologies are used from both sides.

3. FUTURE ATM PROGRAMS AND CONCEPTS

This section describes current research activities and relevant initiatives before and outside of the GreAT project, and summarizes ICAO requirements for ATM concepts, especially towards trajectory-based operations. Again, a comparison between Europe and China is included.

At first, relevant ICAO references are summarized in this chapter. Current concepts and requirements for future ATM concepts, aiming at TBO, are extracted. Secondly, an overview of the SESAR program is provided, highlighting all activities that play a major role and/or that are to be considered for developing greener ATM concepts. Thirdly, the same is described for CAAMS in China. Both section structures are synchronized again to ease the comparison, which can be found at the end of this section.

3.1. CURRENT TBO CONCEPTS AND CONCEPT REQUIREMENTS OF ICAO

This section is a summary of ICAO Docs 9854 ("Global Air Traffic Management Operational Concept") and 9882 ("Manual on Air Traffic Management System Requirements"). Aspects that are relevant for the developing the GreAT concepts and for cross-checking them with ICAO expectations and requirements are extracted.

3.1.1. GLOBAL AIR TRAFFIC MANAGEMENT OPERATIONAL CONCEPT (ICAO DOC 9854)

In 2005, the International Civil Aviation Organization (ICAO) published the "Global Air Traffic Management Operational Concept", describing the way the ATM world should go the next years to handle the predicted growth in air traffic around the world [ICAO 2005]. Being more a vision and a roadmap than a concept, the document describes the view of the airlines regarding the requirements and constraints, which have to be fulfilled to guide the whole air traffic sector with airlines, airports, air navigation service providers, and all other involved stakeholders, into an efficient, profitable, and safe future. From the viewpoint of ICAO and analogues the airlines, the air traffic is essential for the health of the economy of regions and countries, and therefore has to be endorsed by all parties of politics, economy, and science. Starting in 2005, the concept covers a period of 20 years and proclaims the realization of all requests until 2025, despite the appreciate fact, that not all technologies and procedures could be implemented in this time. The baseline scenario for the concept was the air traffic environment of the year 2000.

The main statement of the document is that the air traffic sector will rely on the explicit and unambiguous information exchange for an integrated, harmonized, and globally interoperable ATM. The vision of the ICAO covers the consistency or raise of the safety level, an optimum economic, the environmental sustainability, and the meeting of all national security requirements.

For the conceptual view of the document, the ATM-system covers all needed and available resources and services to fulfill the airlines' requirements and expectations. The guidance principle covers safety, humans, technology, information, collaboration, and continuity with the possibility of measuring the mentioned criteria. Instead of the direct implementation of collaborative decision making (CDM), the ICAO counts on a dynamic and flexible decision making, which rest on the unlimited availability of information as well. For optimum use of the system's performance, the user expectations have to be balanced in some cases. Summarized, the main postulation of the ICAO's concept document is a new dealing with ATM information, whereas the underlying processes should be changed only evolutionary, never revolutionary to reach a global harmonization and cooperation in the air traffic system.

For the ICAO, the ATM-community consist of the aerodrome community, airspace providers (contracting states), airspace users (the largest segment in the ATM-community), ATM service providers, ATM service industry, ICAO, regulatory authorities (responsible for certain aspects, e.g. performance), and the states.

The ICAO concept identifies seven future main components of the ATM-system, relevant for the shaping of the future ATM organization. The components are:

A. Airspace Organization and Management
B. Aerodrome Operations
C. Demand and Capacity Balancing
D. Traffic Synchronization
E. Airspace User Operations
F. Conflict Management
G. ATM Service Delivery Management

In sections 3.1.1.1 to 3.1.1.7 below, these components proposed by ICAO are explained in more detail.

3.1.1.1 AIRSPACE ORGANIZATION AND MANAGEMENT

The airspace should be accessible for everyone under the same conditions. It should be managed dynamically, flexibly, and on demanded services by adapting boundaries, divisions, and categories to the traffic patterns under the same globally valid regulations. The strategic organization is subordinated by the ATM community, the tactical management by the ANSPs. The airspace design should be simple and straight forward, allowing the flexible planning of dynamic trajectories without delay and restrictions. Airspace restrictions should not be permanent and allowing the possibility of mixed usage. If airspace restrictions have to be launched at certain time periods, this should be done with a distinct temporal forerun.

Airspace management is defined as a process to organize the airspace in a way that meets the needs of airspace users. The interference for traffic separation should be minimized by service providers. The airspace management should favor individual flight routes and requests structured routings only in cases of over-demand. The introduction of new rules should start in the areas, where the expectations of the ATM community are not being met today.

3.1.1.2 AERODROME OPERATIONS

The ICAO Doc 9854 states that the demands on aerodromes are the supporting of the ATM and the air navigation service providers (ANSP), so that airlines can use the full capacity of airspace and airports. Airports must consider the impact on the ATM-system in all their activities. Every flight should be treated and scheduled as an en-route to en-route cycle to determine their role in the ATM-system. Specific requirements on aerodromes are the reduction of the runway occupancy time (ROT), full operational availability of the airport capacity also under adverse meteorological conditions, extended (high speed) exits at the runways, and precise and safe guidance on taxiways and apron under all weather conditions.

In addition, information about all aviation-related activities as well as all departures and arrivals have to be provided to all stakeholders on the airport at every time. This includes also the position of every aircraft and every vehicle on the ground. Environmental aspects have to be considered for all activities by design.

3.1.1.3 DEMAND AND CAPACITY BALANCING

The ICAO perceives demand and capacity balancing as a main factor to minimize the effects of ATM-system constraints and the effects of aerodromes and airspaces capacity restrictions. It is the tool for the optimized use of all kinds of resources for all stakeholders, and should be integral part of the ATM-system and the dynamic and flexible collaborative decision-making process. To achieve an optimal balancing, the process has to use all available data and forecasts, which have to be accessible for all involved stakeholders.

The operational concept distinguishes between a strategic, a pre-tactical, and a tactical stage. The strategic stage is the basis for the predictable scheduling and responds to fluctuations in schedules and demands as well as seasonal changes of weather and weather phenomena. The strategic schedules require a tactical flexibility. The pre-tactical stage covers the current allocation of ANSPs, airspace users and the aerodromes. Adjustments should be done by CDM processes for resource allocation, trajectory and airspace optimization, and scheduling target times. The tactical stage does not allow a demand management in the sense of demand and capacity balancing, instead it reacts on dynamic changes in weather, infrastructure status, resources, and all kind of disruptions.

The demand and capacity balancing encompasses processes for the identification of deviations and the optimization of possibilities to ensure the utilization of aerodrome and airspace capacities. Because the balancing bases on forecasts, meeting of the planned trajectories is a prerequisite, but adapting on situations is essential. It can be used to compensate local deficits. In contrast to aerodrome operations (Subsection 3.1.1.2), the balancing process treats flights with a gate-to-gate view.

The demand and capacity balancing process depends on some intrinsic factors. As available information may change in short-term, decisions may change with the same rapidity. If the timespan for decisions is limited, the balancing process demands for fast reactions of the stakeholders. The resulting balancing can only be as good as the quality of the forecasts allows; and mistakes may happen, caused by unforeseen events.

3.1.1.4 TRAFFIC SYNCHRONIZATION

Traffic synchronization is the interaction of the demand and capacity balancing process and air traffic separation, and supports the efficient traffic flow. Applied in the tactical stage of scheduling, it serves for safe flows in air and on ground and enables the equalization of traffic volumes. With the help of Arrival, Departure, Surface, and other Manager tools (XMAN-approach), the optimized traffic flow and sequencing avoid bottlenecks. The XMAN-approach coordinates and supports the negotiation of 4D-Trajectories and the reduction of path stretching areas in the Terminal Maneuvering Area (TMA). Traffic synchronization should be applicable at all airspaces and aerodromes where the optimum sequencing is crucial to accommodate the air traffic demand.

The optimization tools and processes of traffic synchronization are arrival and departure sequence adjustments, the strict use of 4D-Trajectories, delegating of separation adherence to the cockpit, and the dynamic adaption to the local wake vortex situation.

3.1.1.5 AIRSPACE USER OPERATIONS

Airspace user operations refer to the ATM-related flight operations, and include safety and efficiently enhancement as well as a raised tactical and strategic situational awareness and conflict management. These operations cover the areas of air transport, military, business, aerial work, and recreation. All areas have different possibilities and capabilities, and are using disparate scheduling time horizons. For this reason, the airspace user operations should consider the characteristics of all vehicles, whereby the aircraft design and the operational possibilities should be taken into account every time. In addition, all ATM-systems should be based on global standards and ensure a global interoperability.

As in other areas of flight management, all relevant information should be provided by the ATM-system and be available for the airspace users. The mission planning should be conducted by the airspace user in cooperation with the ANSPs and aerodromes, by applying demand and capacity balancing.

In connection with the aircraft performance data, flight conditions, and the actual ATM resources, airspace user operations allow the optimal service of 4D-trajectory management and as a result flying along user-preferred trajectories.

3.1.1.6 CONFLICT MANAGEMENT

The aim of conflict management is limiting the risk of collisions. The hazards cover collisions with other aircraft, terrain, obstacles, and obstructions on ground, weather, wake turbulences, and surface vehicles. Also planning flaws may lead to incompatible airspace activities and thus to dangerous situations. Because of different separation minima, all mentioned hazards require differing avoiding strategies. For the future, the ICAO sees the conflict management responsibility clearly on the side of the airspace user.

The ICAO operational concept proposes the introduction of a three-layer conflict management with a strategic level, a separation provision level, and the collision avoidance level. The strategic conflict management starts before departure and bases on the conflict-free 4D-Trajectory. The separation provision represents the tactical level and is used whenever the measures on strategic level are not efficient. This may be in effect during the approach phase in the TMA. The third level is the direct collision avoidance and thus no part of the separation provision.

The separation provision is an iterative process, differentiated in the four phases: detection, formulating solution, implementation, and monitoring. New trajectories should be checked regarding conflicts beforehand as far as available information allow it to reduce the number of trajectory renegotiations and recalculations. To ensure the separation minima, ICAO defined the separation mode, a rule-set of procedures and conditions. The separation mode incorporates the required safety level, activity, hazard, qualification and role of the involved actors, weather conditions, and traffic density.

The separator may be an agent, the airspace user themselves, or the responsible air traffic service provider. The predetermined separator depends on the type of the hazard and should segregate the traffic prior any need of separation provision. Self-separation has to be done if the airspace-user is responsible for the prevention of hazards. A distributed separation exists, if different separators for different hazards for one airspace user are defined. The cooperative separation responsibility defines the roles if the separation from hazards is temporary delegated and the termination of the delegation has to be known by all affected airspace users. If more than one separator is in charge, it does not mean a cooperative separation is conducted. A separation provision service has to be available when the safety or the ATM design requires that. In the development of separation modes, separation provision intervention capability must be considered.

3.1.1.7 ATM SERVICE DELIVERY MANAGEMENT

The ATM service delivery management specifies the rules for the distribution of responsibilities. As a component of this management, the ANSPs have to change their support to an on-request basis. The ATM service delivery management by trajectories includes the trajectory, profile, the aircraft’s and the flight’s intend, and the clearances. As a basis for the other components, the information service is responsible for the exchange and the management of aeronautical information and provides accredited, quality assured, and timely delivered data for the ATM community as soon as they are available. Also, meteorological information is an integrated function of the ATM-system as they are needed for the calculation of optimal trajectories. Shared weather data have to be available in the cockpit as they raise the safety during flight, and enable the reduction of the environmental impact of the air traffic. The meteorological information helps aerodromes to use their optimal capacity.

The ATM service delivery management encompasses other essential services, too. This includes the air defense systems, search and rescue with specialty sub-fields, the aviation accident and incident investigation services, law enforcement, and regulatory authorities.

3.1.1.8 ACTUAL LIMITATIONS OF THE ATM-SYSTEM

The ICAO identified some limitations in the concept for the provision of the traffic services. Incompatible systems and tools exist in the different states, which may not be replaced in the next years. It may need a long time for developing and deploying improved systems, and the introduction of these new technologies into the air fleets. Voice radio will stay the most used communication technic for the next years due to its coverage and the lack of a reliable digital data exchange over huge distances, so the availability of real-time information is confined. The airspace divisions suffer up today under political discussions, and CDM works satisfying only at some major airports around the world. At some places, resources are available but not optimally usable. At the end, the limitations include the limited ability to maximize the benefits for aircraft with advanced avionics. The mentioned limitations lead to excessive system-related ground and en-route delays.

Subsequent challenges are circuitous arrival and departure routes and procedures, and due to restricted areas, indirect fixed routes between the destinations. Restricted areas include airspace reserved for defense purposes, which is excluded for civil air traffic, at least at certain periods. Airspace restrictions and capacity limitations result in aircraft operations at inefficient altitudes, speeds, and in unfavorable wind fields as well as insufficient flexible reactions during weather-related disruptions.

3.1.1.9 PLANNING

The ICAO Operational Concept describes in the appendix the relationship between the concept and the planning process for the stepwise introduction of the proposed improvements for the ATM-system. The planning process should be a well-understandable, manageable, and cost-effective sequence of improvements on global, national, and regional levels. The suggested improvement-steps cover a forecasting of civil aviation activities, creating a planning structure, distinguishing in global, national, and regional planning, planning for implementation in selected areas, operational analysis for the identification of the operational requirements, the technical planning process with operational analysis, development of a implementation strategy, and the system architecture. At the end, the planning process will be finalized with the general transition issues, the migration from the present system to the more advanced ATM-system [ICAO 2005].

3.1.2. MANUAL ON AIR TRAFFIC MANAGEMENT SYSTEM REQUIREMENTS (ICAO DOC 9882)

Three years after ICAO Doc 9854, the Manual on ATM System Requirements (ICAO Doc 9882) was published, which is very much based on the ATM system components described in section 3.1.1. Doc 9882 follows the spirit of Doc 9854 and provides more detail on requirements and expectations for future ATM systems. These expectations and requirements, especially those that are relevant for the work performed in the GreAT project, are extracted below.

3.1.2.1 OVERALL ATM SYSTEM REQUIREMENTS

The following requirements are described for the whole ATM system as such:

Performance Based Operations

The ATM system should set up performance requirements and performance targets instead of focusing on / prescribing a specific technical or operational design. Performance assessment mechanisms should be in place to verify if performance targets are met. These performance targets should respond to and fulfil aviation community’s expectations. When considering this basic principle, the ATM system also supports (but is not necessarily restricted to) trajectory-based operations (TBO). Table 1 summarizes the KPA performance requirements according to ICAO.

Table 14. KPA performance requirements as per ICAO

KPA	Performance requirements
Safety performance	Safety performance measurement should be evidence-based and should be standardized (same indicators, models, assumptions). The same high level of safety shall always be maintained, including during any transition phases from one system design to another one; involving prepared contingency plans. Collision avoidance systems shall serve as a backup

	safety net. Safety risks shall be communicated in the ATM community.
Security	The sovereignty of the states shall not be compromised, and the security level shall comply with a coordinated minimum. Security management principles shall involve collaborative decision making.
Access and Equity	The ATM system shall support all aircraft types and all missions, including manned and unmanned flights; and it shall enable even highly diverse traffic with lowest possible restrictions.
Cost Efficiency	The implementation of improvements shall be assessed in a cost-benefit-analysis for ensuring Cost Efficiency.
Capacity	The ATM Capacity shall always be sufficient, according to agreed levels, and shall be provided in a cost-efficient and resilient way. As far as possible, provided capacity shall be fully used as much as possible.
Environmental	The ATM system shall in any case consider environmental issues, shall set up and monitor the achievement of environmental performance targets, and shall use a collaborative decision-making process to find the best balance between environmental and economic interests.
Predictability	Predictability shall be ensured by a comprehensive information exchange between ATM community members.
Flexibility	The ATM system shall provide maximum Flexibility to all airspace users, allowing them to operate wherever, whenever and whatever they desire on short notice to exploit operational opportunities.
Single-flight efficiency	The so-called single-flight efficiency shall be maximized by the ATM system for all flights at the same time.
Global Interoperability	Global Interoperability shall be achieved by international standardization.

Community Participation

The ATM Community shall participate in relevant collaborative decision-making processes and shall have easy access to information needed for that.

System-Wide Information Management (SWIM)

SWIM shall be implemented according to global standards. Measures shall be in place to guarantee a high quality, validity, accuracy, resolution and availability of relevant information, whenever and wherever it is needed. This includes for example status information about ATM resources, flight parameters, aircraft performance characteristics and weather information as well as information integrated from different sources. This shall also be used to create ATM system optimum initial trajectories and dynamically optimize them according to possibly new circumstances. When used in TBO, the calculation of environmentally optimum trajectories shall be enabled, allowing the establishment of pragmatic environmental performance targets and the measurement of the degree of achievement. Again, the spirit of collaboration plays an important role here.

System Design

Systems used in ATM and in aviation in general shall follow global standards to guarantee interoperability. A standard ATM system vocabulary shall be used around the world. Human factors shall be carefully considered especially in the HMI design; and a safety assessment shall be conducted to exclude safety risks when brought into operation. Automation shall be used collaboratively where deemed appropriate to achieve ATM system performance targets. A frequency allocation management shall be in place and considered to exclude interferences. Aircraft and ATM system designs shall consider each other's constraints, capabilities and requirements.

3.1.2.2 ATM SYSTEM REQUIREMENTS RELATED TO ATM SYSTEM COMPONENTS

The following requirements are described for the individual ATM system components introduced in section 3.1.1:

Airspace Organization and Management

The airspace organization and management shall flexibly accommodate all types of air activities across borders, and shall react dynamically and flexibly to airspace demands, with minimum restrictions. The user preferred routing shall be approved as much as possible. All activities within the airspace should be known to the ATM system.

Aerodrome Operations

Aerodrome Operations shall enable an efficient use of collaboratively agreed aerodrome capacity under all weather conditions, with a minimum airborne holding time for arrivals. Surface movements and the use of aerodrome equipment and services shall be coordinated through a collaborative decision-making process, reducing the ground holding time with running engines for departures to a minimum as well; and providing all relevant information to the aerodrome community. This includes also information about the position and the intent of all aircraft and vehicles, together with performance characteristics. Environmental and security issues are to be considered.

Demand and Capacity Balancing (DCB)

DCB shall consider system-wide traffic flows, shall increase predictability and maximize capacity utilization. This shall be based on accurate predicted capacity demand and availability, accurate weather information and infrastructure status information. Current and predicted airspace conditions shall be considered. Again, a collaborative and system-wide process shall be used to resolve local demand-capacity balancing problems. The effectiveness of taken measures shall be evaluated in a post-event analysis.

Traffic Synchronization

Traffic Synchronization shall ensure an orderly flow of traffic from gate to gate, and maximize traffic throughput and efficiency at the same time. The desired trend towards TBO is explicitly described here, including dynamic trajectory re-negotiation / management and may include aircraft self-separation techniques.

Airspace User Operations

Here the airspace user needs shall be in the foreground. The ATM system shall consider user-preferred trajectories during all flight phases. Trajectory negotiation by ATM shall be done with the goal to reduce the changes to the user-preferred trajectory to an absolute minimum. The ATM system shall also enable dynamic user-preferred trajectories (i.e. capability to easily handle new trajectories on short notice). One enabler for this shall be a continuous air-ground information exchange, including information about actual aircraft performance characteristics.

Conflict Management

Conflict management shall be done on three levels: strategic, separation provision and collision avoidance; and shall prevent conflicts between two aircraft, between an aircraft and terrain, obstructions, wake vortexes, weather, surface vehicles and incompatible airspace activities. The responsibility for doing the conflict management shall be clearly allocated (‘separator' role). This can be done by the airspace user or a separation provision service. In case strategic conflict management mechanisms are considered to be insufficient, additional tactical conflict mechanisms shall be implemented to limit the risk of collisions.

ATM Service Delivery Management

ATM service delivery management shall cover all flight phases from gate to gate. One pre-requisite for that is that the airspace user shares flight intentions with the ATM system, and all operations within the airspace are known to the ATM system. It shall monitor compliance with negotiated / approved trajectories. Again, aircraft performance characteristics shall be considered when approving trajectories for execution. ATM services shall consider the navigational performance of airspace users.

3.1.3. SUMMARY AND REVIEW

As the concepts developed in GreAT can be seen as fundamental research, which will be driven to concrete greener ATM concepts up to TRL 4, the principles and requirements laid down in these two ICAO documents are applicable but might not be fully developed. The GreAT concepts or concept elements should more be considered as steps towards the vision outlined in these ICAO documents, and the concepts / concept elements can be assessed for that (see section 4.5.4).

The ICAO documents on hand contain no final and complete TBO concept. Only parts of it are mentioned, e.g. the user-preferred trajectory shall be used as input, and the modifications to it, that are done by a negotiation process, shall be as small as possible. These modifications shall not only be done for the reason of traffic de-conflicting, but also for the purpose of making them more efficient. Further, the negotiation process shall be done continuously to allow dynamic user-preferred trajectories. The majority of all other described principles and requirements are not specific to TBO and are already partly applicable to today's ATM system.

However, it should be mentioned that various principles and requirements are related to, and competing against each other, leading to the conclusion that only trade-off situations can be achieved. A few examples are described below:

Capacity Availability against Capacity Utilization

The desired situation here is that on one hand there is always enough capacity available to respond to the demand. This can be achieved by keeping spare capacity in readiness, to be able to react to sudden and unforeseen increases in demand. The disadvantage is that capacity produces costs, and economists recognize unused capacity as unnecessary costs.

Therefore, on the other hand, the desired situation is that available capacity never stays unused, and its utilization is always 100% to have a solid justification for capacity costs. This can only be achieved when the demand exactly matches with available capacity, or when the demand is even higher than that to have some “spare” demand on hold in case of a sudden decrease. The problem is that the demand is very variable, difficult to predict and it is hardly feasible to always achieve an exact match. In addition, keeping “spare” demand on hold produces large delays for airspace users.

The solution can only be a trade-off between keeping spare capacity in readiness and intentionally accepting additional delay in case of an unforeseen situation where even this spare capacity is not sufficient. More accurate demand predictions might help here but will always have some degree of uncertainty. Further, costs of unused capacity are necessary and crucial to a certain extent, and should be recognized as such.

Safety against Single Flight Efficiency

Here, the desired situation is that all airspace users can follow the trajectory that allows them to fly with maximum flight efficiency. However, those optimum trajectories of all flights are more often conflicting with increasing traffic density, and solving these conflicts will make the trajectory less efficient. The degree of deviation depends on the desired remaining risk of collision, and consequently, on CNS performance and separation minima. Again, a trade-off situation occurs: higher safety levels, which means a lower remaining risk of collision, leads to increased CNS performance requirements and/or increased separation minima, and will lead to a larger deviation from the most efficient trajectory; and vice versa.

TBO against dynamic user preferred trajectories

As described in these ICAO documents, TBO shall involve a trajectory negotiation process to make desired trajectories conflict-free. But planned trajectories are exposed to uncertainties when being executed, which increase with increasing time in the future. Dynamic user-preferred trajectories, that involve changes on short notice, can be considered as additional disturbances that are further increasing these uncertainties of all other trajectories. An additional tactical level for separation provision will even further increase these uncertainties. And continuous re-negotiation of all trajectories, especially when done at once for all flight phases and over hours of flight time, might lead to the situation that those uncertainties are propagated through the whole air traffic system and amplified during propagation, leading to various inefficiencies and maybe even safety risks. As a conclusion, the application of TBO leads to the requirement to reliably and precisely execute negotiated trajectories, and to keep any changes to an unavoidable minimum. Continuous re-negotiation can only be successful on a very local level, without affecting the area outside of this local focus.

Flexibility against Predictability

The most prominent example is surely the contrast of flexibility against predictability. On one hand the desired situation is maximum flexibility, which allows any airspace user to do any air operation at any time without any pre-notification. This directly leads to a zero-predictability situation. On the other hand, the desired situation is maximum predictability, which can only be achieved when the flight intend is accurately announced in advance, and precisely executed then, allowing no deviation or dynamic change at all. This directly leads to a zero-flexibility situation. As a conclusion, there can only be a trade-off between both, but they can never be both maximized to 100% at the same time.

Environmental aspects are already mentioned as important aspect in both ICAO documents, even if those documents have already been published more than 10 years ago. Nevertheless, also economic interests are competing against environmental interests. The basic problem in this competition is that economic interests are followed, planned and concrete actions are taken just for the next few years. In contrast to that, environmental consequences are rather small for the same time frame, and they have to be considered for a much larger time horizon to be fully realized. This is why environmental aspects have often been considered subordinate to economic interests. This is about to change, and environmental aspects will become more important in the future. Also, the effectivity of measures to reduce the impact of aviation on climate change has to be considered on the same long-term basis. It cannot be expected that the climate change can be stopped with a big-bang approach; and even small savings of CO_2 emissions are important as they have an effect over decades and centuries.

3.2. SINGLE EUROPEAN SKY ATM RESEARCH (T2.1.3)

The Single European Sky ATM Research (SESAR) is the technological pillar of the Single European Sky Initiative. The SESAR program was set up in 2004 to promote technological modernization and harmonization of the ATM systems. The new ATM systems shall be able to cope with growth and diversity of air traffic in a safe, efficient and green way. To that end, SESAR had created a pipeline enabling the definition, development, validation and deployment of innovative technological and operational ATM solutions.

Figure 32: SESAR Lifecycle

This pipeline is composed of 3 phases [EUROCONTROL 2019a]:

- The definition phase (2005-2008) identified the expected performance requirements of the new ATM systems and the most suitable solutions to achieve them. During this phase, a high-level roadmap was also defined. One of the most important deliverables of this phase was the European ATM Master Plan.
- The development phase (2008-2024) puts in place all necessary research and development activities to produce required technologies identified during the definition phase. In this phase, the European Operational Concept Validation Methodology (E-OCVM) is deployed. This methodology implements a progressive de-risking and validation approach. SESAR covers only 3 phases of the E-OCVM lifecycle: V1, V2 and V3. These 3 validation phases correspond to 3 development iterations of the development process, ending to increasing level of maturity. The results of this phase are collected in one document called the SESAR solutions catalogue [EUROCONTROL 2019c], which gathers all the technical and operational solutions being explored across Europe during the two phases SESAR 1 and SESAR 2020.
- The deployment phase (2015-2040) aims to deploy across Europe the validated ATM solutions in accordance with the SESAR Deployment Program developed by the SESAR Deployment Manager. This program organizes local, regional and European-wide implementation activities. It details how the implementation shall be carried out, based on a coherent planning to timely deliver the solutions.

The ATM development strategy, defined during the definition phase and summarized in the ATM Master plan, is presented in Chapter 3.2.1. Some of the most prominent ATM solutions are outlined in chapter 3.2.2. In addition, some projects dealing with TBO will be listed in Chapter 3.2.3.

3.2.1. THE OVERALL ATM DEVELOPMENT STRATEGY

The SESAR overall ATM development strategy is defined and described in the European ATM Master Plan [EUROCONTROL 2019a]. The document covers the visions and objectives of the Single European Sky Air Traffic Management Research (SESAR) project. It represents the planning framework for a comprehensive ATM modernization across Europe over the envisaged target time-period until 2040. The SESAR research and development program identifies, assesses, and validates technical and operational concepts in simulated and real operational environments.

The report starts with the SESAR vision and comprises a performance view, an operational view, a deployment view, and the business view. When started in 2004, the SESAR vision was to deliver an ATM system for Europe that can handle the predicted growth and the diversity of traffic in a safe and efficient manner. Innovations are identified by the European Commission (EC) as the key enabler of the restructuring and the core of the transformation are Trajectory-based Operations (TBO). As the biggest challenges identified in the European ATM are the capacity crunch of aerodromes and airspace, the increasing delay of 1.83 minutes per flight[48], and the CO_2 emissions[49]. Some of the envisaged yearly capacity performance targets have not been met since 2014 [EUROCONTROL 2019b]. The solutions to meet this goal are digitalization and a digital transformation of the underlying ATM and ATC infrastructure, which allows capacity on demand through scalable systems. The yearly updated Master Plan document represents an actual snapshot of the development and scheduling. It is provided with yearly minor adjustments and bigger updates every three or four years.

3.2.1.1 THE COVERAGE OF THE ATM MASTER PLAN

The main aim of the ATM Master Plan is the description of an ATM system, which is resilient and fully scalable, and can handle the worldwide growing air traffic of manned unmanned air vehicles in all classes of airspaces in a safe, secure, and sustainable manner with zero systematic inefficiency. This shall be achieved through a combination of modern airspace design, new technologies already available or to be developed, with a new level of stakeholder collaboration and automation support for the strategic, pre-tactical, and tactical air traffic movement coordination, based on new Artificial Intelligence (AI) software solutions for predictions in all systems and procedures. To reach these goals, four cornerstones are identified in the Master Plan:

- Optimized ATM network services,
- High-performing airport operations,
- Advanced air traffic services,
- Enabling aviation infrastructure.

Additionally, the Master Plan gives a first glimpse on the U-space, a framework designed to fast-track the development and deployment of fully automated drone management systems [SJU 2017a].

The SESAR project differentiates four main phases of the European ATM modernization process, which all need the cooperation with industrial partners [SJU 2017b]:

A. Implementing a system-wide information management across borders and aircraft to address known critical network performance deficiencies.

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[48] Average in 2018, the intension was 0.5 Minutes.

[49] The overall European ATM CO_2 emission grew by 5.2% from 2017 to 2018.

B. Launch first ATM data services and cross-border free-route operations and initiate U-space for drones.
C. Defragmentation of European skies through dynamic airspace and management of routine drone operations.
D. Digital European Sky with a full scalable system. This includes the air-ground system integration and data services.

The perception of SESAR is, during the traversing of the four phases, the boundaries between air traffic control and air traffic flow management will blur. The state of the work estimation to date is that one third of the SESAR solutions have been delivered, one third is in development, and one third must be undertaken in future research and development programs. To meet the goal of the digital sky until the year 2040, it might be necessary to shortening the innovation cycles of technical and procedure development. With the European Digital Sky, resources on ground and in air will be connected optimally for the collaboration and operation if they were a single organization including drones and super-high-altitude operation. EUROCONTROL expects improved air navigation services productivity through the move from voice to the (digital) data communications.

To meet these targets, it is crucial that the military aviation is fully associated with the whole SESAR life cycle, including dual-use of airspace, developments, and systems.

3.2.1.2 THE TRANSITION TO THE EUROPEAN DIGITAL SKY

SESAR sees for the next years four transitional phases to achieve the European Digital Sky:

A. Address known critical network performance deficiencies to increase information sharing between ATM shareholders.
B. Efficient services and infrastructure delivery for the transition from the physical to a digital infrastructure.
C. Defragmentation of the European skies through virtualization. The transition is gradual into a highly connected, service-oriented, and network-driven context. The infrastructure system must be de-coupled from the ATC operations.
D. The last phase is the target vision of a fully digital sky with a high degree of automation in air and on ground. Systems with trained AI will offer significant support to pilots and controllers and many actions can be initiated by automation. The machine-to-machine communication is automated.

In connection with the envisaged innovations, the automatic level of the support systems will rise from the first "Decision Support Level" to the fifth and highest "Full Automation Level". Automation may offer a safety opportunity on the way towards a zero-accident performance. Today, many systems accomplish the second level "Task Execution Support". To reach the third "Conditional Automation" and the fourth "High Automation Level", some innovations in the areas of augmented approaches, self-separation, complex digital clearances, intelligent queue management, dynamic capacity management, broadband ground and air communication, and cloud-based drone information management must be established. Using more and advanced automated systems, air traffic controllers may be more deployed for complex work.

The European ATM modernization must be conducted as a whole and not in segmented portions to meet the goal of a high level of automation with dynamic sectors based on demand and airspace availability and across Flight Information Regions (FIR) cooperation.

3.2.1.3 ESSENTIAL OPERATIONAL CHANGES IN THE EUROPEAN ATM

SESAR defined nine essential operational changes (EOC) as main focus areas for the future ATM system:

1. CNS: CNS infrastructure and services
2. iN: ATM interconnected network
3. dS: Digital AIM and MET services
4. U-s: U-space services
5. vS: Virtualization of service provision
6. ATp: Airport and TMA performance
7. dA: Fully dynamic and optimized airspace
8. TBO: Trajectory-based Operations
9. M3: Multimodal mobility and integration of all airspace users

The EOCs are not independent of each other, and the precondition is an interconnection through a high-bandwidth low-latency network infrastructure. Building up an ATM service delivery infrastructure, TBOs with complex trajectory synchronization mechanism will be possible.

3.2.1.4 CNS: CNS INFRASTRUCTURE AND SERVICES

The goal of the first essential operational change in ATM will optimize the infrastructure on ground and air towards a service oriented architecture. As a result, the separation of CNS service provider and ANSPs will happen. Based on a CNS backbone, comprising the multi-link Pan-European Network Service, Global Navigation Satellite System (GNSS), and ADS-B, the transformation from voice to digital with broadband connectivity expands the possibilities and safety of communication.

3.2.1.5 IN: ATM INTERCONNECTED NETWORK

Today, the ATM environment is characterized by many local and custom designed solutions with a low overall performance. The ATM interconnected network has to be established for the integration of the Air Traffic Flow and Capacity Management (ATFCM) and ATC planning functions. The network enables all relevant stakeholders in collaborative decision-making processes in everyday and in non-nominal situations to find the best possible solutions. In addition, the network operation plan (NOP) will be available for all stakeholders simultaneously and with real-time visualization of the evolving network environment. In this way, the network increases the available flexibility to airspace users for addressing daily or unexpected business needs.

3.2.1.6 DS: DIGITAL AIM AND MET SERVICES

The digital Aeronautical Information Management (AIM) and the digital meteorological services will provide static and dynamic aeronautical and meteorological information in digital form and independent of the used media systems. With the appropriate interfaces, the data will be accessible for human operators and ATM systems with the same level of quality. Additionally, they will be processed for individual requests, specific geographic areas, or functional features for ground and on-board systems. Inversely, the data acquisition will take place on ground as well as on-board.

3.2.1.7 U-S: U-SPACE SERVICES

The U-space services are the future framework for the European drone traffic management system. It will define new airspace types and its availability for Unmanned Aircraft System (UAS) operations. As the EUROCONTROL expect a steep ascent of the UAS numbers in the near future, the airspace will be designed for high drone traffic volumes. Additionally, U-space will be scalable by design for a high level of autonomy and connectivity between the drones, the manned flight traffic, and the ground systems. It will support a safe, efficient, and secure access to airspace and the digital UAS management system [SJU 2018].

Through RPAS and drones, EUROCONTROL expects more automation innovations for manned aviation, like a single crew cockpit, single pilot operations (SPO), and, at the end, fully automated and autonomous flights.

Aviation companies are keen to keep the infrastructure clean, so manned and unmanned vehicles have to use the same infrastructure and services. The existing ground infrastructure does not meet the postulated requirements and needs new safe, secure, clear, and effective interfaces for humans and automatic systems.

3.2.1.8 VS: VIRTUALIZATION OF SERVICE PROVISION

Today, the worldwide Air Navigation Service (ANS) bases on local implementations. With the virtualization of this service, the separation of positions of systems and the point of use lead to virtual ATC centers. The virtualization will serve scalability and resilience for all-weather operations. To achieve this objective, a smarter and more fail-safe interoperability between functional systems has to be enabled. The using of standardized operating methods, procedures, technical equipment, and services throughout Europe are the key preconditions. The first applications of the virtualization of the service provision are remote tower operations (RTO) and remote tower centers (RTC) for a flexible use of resources.

3.2.1.9 ATP: AIRPORT AND TMA PERFORMANCE

Since a few years, airport operations and airspace user operations are significant contributors to network-wide flight delays. Additionally, bad weather conditions are a capacity factor for sectors and aerodromes worldwide. Many international airports work to a large extend at their capacity limit and are vulnerable to any kind of disturbances. At the same time, airports and TMAs are critical factors for whole air traffic network. Future airside actions to raise airport capacity are a more sophisticated traffic sequencing, reduced separation between arriving aircraft, and a more predictable runway occupancy time. On the landside, an enhanced taxi management and a smooth navigation in low-visibility conditions are the next envisaged fields of work.

3.2.1.10 DA: FULLY DYNAMIC AND OPTIMIZED AIRSPACE

Today, the worldwide airspaces are partitioned into sectors, organized and managed on state level by national Air Navigation Service Providers (ANSP). Through the fully dynamic and optimized airspace, free-route airspace (FRA) processes and system support will be introduced. The dynamic airspace will quit the fragmented airspace structures and introduce the network-centric optimized airspace for the full trajectories of flights and major flows. Obviously, it supports a vertical and horizontal interconnectivity and covers large-scale cross-border free-route airspaces. The airspace organization and the guidance and monitoring through air traffic controllers will be supported by automated tools. The new airspace works on local, sub-regional, and regional level.

3.2.1.11 TBO: TRAJECTORY-BASED OPERATIONS

Trajectory-based Operations (TBO) are the overarching SESAR and EUROCONTROL concept. Controllers, pilots, military, and advanced systems need all the same trajectory information, starting with the agreed Reference Business Trajectory (RBT), progressing during flight with the authorized and the executed RBT. Trajectories are used to detect, analyze, and resolve potential conflicts and to monitor agreed aircraft- and traffic-optimized trajectories. The TBO will be deployed through extended flight plans (eFPL) and updated continuously by ATC during flight. The TBO will be achieved through 4D-trajectory optimization and enabled by a System Wide Information Management (SWIM). SWIM allows the real-time exchange of 4D-trajectory data, weather, and general aeronautical information with standardized interfaces. The detailed 4D scheduling optimizes airport capacities, even under bad weather conditions. Improvements as enhanced runway throughput, amended safety nets, and more accurate navigation and routing tools increase the flight phase predictability and reduce buffers as well as fuel consumption.

3.2.1.12 M^3: MULTIMODAL MOBILITY AND INTEGRATION OF ALL AIRSPACE USERS

The multimodal mobility and integration of all airspace users describes the mobility as a service, connecting numerous modes of transport for people and goods in a seamless door-to-door service. The expectation is that over the next years, the diversity and the number of aircraft will rise continuously. Different modes of transport as car, train, airplane, helicopter, and drones will be combined seamlessly for personal trips. The integration of remotely piloted aircraft systems (RPAS), rotorcraft, business, and general aviation through IFR procedures using performance-based CNS infrastructure is one of the SESAR's priorities.

3.2.1.13 THE CHALLENGES OF THE DIGITAL SKY IMPLEMENTATION

The Master Plan and its implementation must deal with some uncertainties and challenges. On the one hand, the air traffic is growing in volume and diversity with a significant uncertainty in the growth rate. During the last years, the capacity growth has become increasingly complex, and the research activities had to be heightening for ample capacity expansions [EUROCONTROL 2018a]. On the other hand, the society has to deal with growing environmental challenges. Furthermore, the reliance on digital shared information (open data) requires the willingness, to make the own data available to all other stakeholders.

On the technical side, the move towards automation in other sectors will also shape the future of flight. Additionally, there are further uncertainties in the time frame concerning the research and development activities, their implementation, and their full operational capability. The digital sky will have to deal with simultaneous implementations in the ATM network services, air traffic services, airport operations, and aviation infrastructure. This also includes the air-ground integration and autonomy to enable urban mobility, single pilot operations, autonomous cargo and large passenger aircraft as well as the ATM U-space convergence. The new services require hyper-connectivity and machine-to-machine applications, which need the development of next generation links, networks, and applications.

SESAR identified the key performance areas capacity, cost efficiency, operational efficiency, environment, safety, and security for the decision of the European Digital Sky progression. Its year 2035 performance ambitions for the controlled airspace are orientating on the SES high-level goals from 2005.

Capacity is a higher challenge for bigger airports, a lesser for smaller ones and airspaces. Starting with the baseline of 2012, the departure delay on airports should be reduced by 10% to 30%. Simultaneously, the network throughput of IFR flights should grow by around 60%. To increase the time efficiency, the difference between actual gate-to-gate trajectory and the corresponding unimpeded gate-to-gate trajectory has to be reduced. This might be achieved by optimizing the taxi-in, taxi-out, arrival, and the en-route phases. Comparing the time-efficiency of the last years, the flight delay has increased from 9.5 minutes departure delay in 2012 to 14.7 minutes in 2018.

To increase the cost efficiency, the direct gate-to-gate ANS cost per flight should be reduced by up to 40% and the accordance additional flight time should be reduced from 8.2 minutes to around 4 minutes. The increase of arrival predictability is one of the desired key-outcomes of SESAR. It should be accomplished with the help of the business trajectory, which starts already before push-back. The increase in predictability would allow airlines to reduce buffer-times, typically used for softening sudden disturbances.

With the reduction in flight time and the gate-to-gate fuel consumption, the directly connected CO_2 emissions should be decreased by up to 10% per flight. For the KPIs cost efficiency and the environment, the long-life cycles of technology are the biggest challenge for introduction new systems. The improvement in fuel efficiency might be increased through a reduction of ATM-trajectory constraints, but may be leveled through fleet composition, traffic patterns, local airport rules, geography, and noise restrictions near airports. Some strategic actions of airlines may result in a rising fuel consumption per flight, but reduced fuel flow per passenger or kilogram of cargo [EASA 2019]. Under unfavorable conditions, airport constraints may restrict further air traffic growth. The SESAR solutions for noise reduction are continuous climb operations (CCO), continuous descent operations (CDO), curved, steep and segmented approaches, and noise preferential routes.

The most ambitioned goals concern flight safety. Up to the year 2035, the accidents with direct ATM and ANS contribution should drop to zero and therefore an improvement by 100%. For the ATM related security incidents resulting in any kind of traffic disruption, the goal is no significant disruptions due to cyber-security vulnerabilities. Consequently, all solutions and systems must be protected against security threats and will remain subject to safety assessments [EASA 2018]. The new standards for safety and security may be achieved by provisions for highly automated and autonomous air-ground systems with integrated safety and cybersecurity features embedded in a trust framework of hyper-connected and virtual networks.

3.2.2. DESIRED SOLUTIONS FOR FUTURE ATM

The current nation and sector-based ATM system is rapidly reaching its limits [PRR 2020]. It becomes urgent to improve the current ATM system qualitatively by applying new modern and "revolutionary" technologies. However, it is recognized that technological change in ATM is usually very slow, considering the required standardization activities and safety requirements. SESAR is helping to merge new technologies in ATM by boosting productivity and innovation speed. More generally, the new ATM system shall evolve to meet increased demand and adapt to the changing environment. The ultimate goal is to move from segregated airspace operation to integrated airspace where operations are coordinated seamlessly. Sharing of information and interoperability are the key to ensure that all stakeholders have access to the correct, same and accurate information at the right time. The interoperability of systems and the data exchange between all actors shall clearly be secured.

Figure 33: ATM current challenges

The ATM is facing many challenges, among others (Figure 33):

- New players: the new ATM system shall be adapted to accommodate new players such as drones and the emerging Unmanned Aerial Vehicle (UAV). The main challenge in the drone sector is to develop technologies and procedures that allow their operation in regular airspace;
- New technologies: substantive technological progress in satellites, communication and digitalization should be applied in ATM. That will lead to significant progress in innovation and facilitate the implementation of new concepts and ideas namely virtual centers and corresponding centralization of some ATM services, remote towers for ATC, flight-centric operations, sector-less ATM, etc. The use of artificial intelligence in ATM is also being further explored;
- More demand: the air traffic in Europe is constantly growing. This growth is predicted to increase. The EU airspace and airports are reaching saturation. Capacity increases and enhanced efficiency are becoming an urgent need. SESAR is providing solutions to first make a better use of the present capacity, and second to improve the performance of the ATS provision by introducing new technologies, procedures and processes. The ATM system is being adapted with the vision to have fully integrated operations in the future and then to overcome the current fragmented system.

To face these challenges, SESAR is exploring an extensive number of possible solutions. A SESAR Solution is a program output of R&I activities, that relates either to an operational or a technological improvement, which have been designed, developed and validated in response to performance needs identified in the European ATM Plan.

Because SESAR program is performance-driven [EUROCONTROL 2019c], every SESAR Solution is assessed and documented according to a set of key performance areas (KPA) Which are:

- Improved predictability: measured by the variability in the duration of the flight;
- Reduced costs: refers to the costs associated with air navigation service provision;
- Increased airport capacity: refers to runway throughput at 'best-in-class' airports;

- Increased en-route airspace capacity: refers to en-route airspace;
- Increased TMA airspace capacity: refers to airspace in the surrounding area of one or more airports (terminal maneuvering area);
- Reduced fuel consumption and emissions: refers to the average reduction in fuel consumption per flight in Europe.

Some solutions bring specific local value, for example the introduction of remote tower. Others are organized to deliver benefits in a synchronized way across Europe.

In the following subchapters, one example of the solution related to each challenge will be presented.

3.2.2.1 REMOTELY-PILOTED AIRCRAFT SYSTEMS (RPAS) INTEGRATION

The unmanned air vehicles or UAV are rapidly filling the airspace. The emergence of civil drones as new player is of major concern for ATM. Drones have been used for years in military; their access to airspace was restricted to segregated airspace. The current main challenge is to develop technologies and procedures that allow their operations in regular airspace alongside with commercial traffic. SESAR addresses also the impact of such traffic mix on the controller tasks / workload, regulations, standards and working methods. A particular focus is also placed on integrating RPAS in the airport surface. Only some solutions dealing with RPAS are included in the SESAR catalogue. More exhaustive solutions, services and technologies are explored within the framework of U-space, an initiative of the European Commission. They are targeting primarily the safety, and secondarily the capacity. They are still in the pipeline and will be deployed only when they reach the required maturity level. Nevertheless, both the supply and the demand for drones are accelerating, which is why there is high pressure to create a system that allows the use of drones for both private and business purposes.

3.2.2.2 REMOTE TOWER

One of the most prominent examples of the desired solution for future ATM is the remote tower, a technology where Europe is leading. It is also one of the success stories in SESAR. This example could be seen as one step towards the virtualization of the ATM system. As matter of fact, the physical presence of the ATCO at the airport will be not indispensable anymore. The solution is being implemented in Europe during SESAR 1 and SESAR 2020 by taking a progressive approach. This is consistent with the stepped approach adopted by SESAR. Initially conceived as a smart, safe and sustainable solution for airports with very low traffic density, the technology is now being researched for provision of air traffic services to more than one airport simultaneously from a centralized location called Remote Tower Centers (RTC), known as multiple remote tower. As part of this solution, it is also expected to improve the HMI design to reduce ATC Controllers’ head downtime and workload, as well as to increase situation awareness and controllers' productivity. The solutions related to remote tower are targeting primarily the cost-effectiveness. The construction costs for new ATC Tower being considerably high, remote tower will allow cost saving by providing ATS from centralized locations. Furthermore, combining ATS services from various aerodromes in a centralized control room independent of airport location will enable to share valuable ATS provider resources and infrastructures more efficiently.

One of the major projects related to remote towers is the project PJ05, conducted from 2016 to 2019. Its results were very promising. Therefore, a new project called PJ05-W2 DDT was started on December 2019, and it is expected to be completed on December 2020. These two projects are coordinated by DLR and each involves 30 participants.

3.2.2.3 SOLUTIONS ACTING AS CAPACITY ENABLERS

A huge number of SESAR solutions are categorized as capacity enabler. This proves the urgency to overcome the airspace congestion and the complexity of this matter. This challenge is addressed from different perspectives. Each element in the ATM system has the potential to be a constraint point to the airspace capacity, from landside to runways and from en-route waypoints to the flight paths themselves.

To achieve an efficient use of the airspace, it is first important to:

- Improve sequencing for arrivals and departures;
- Improve the ATCO coordination tools;
- Use better routing (Free routes, more direct routes, Continuous Climb Operation CCO, Continuous Descent Operation CDO, etc.)
- Use a Network Operation Plan to show in a single window information in real time about the air traffic situation across Europe;
- Improve and automatize the detection and resolution of airspace congestion and enable efficient dynamic sectorization;
- Improve the predictability of the traffic, considering all pertinent data such as downlinked data from the aircraft;
- Seamlessly integrate the meteorological data generated by European meteorological agencies into aeronautical information service provision;
- Better share the information though SWIM;
- Enable flight centric ATC and better collaborative control;
- Implement virtual centers and related services;
- Improve the ATCO productivity by introducing more modern support tools and technologies.

3.2.3. CURRENT RESEARCH PROJECTS ASSOCIATED TO TBO

Current ATM is based on a filed flight plan and tactical interventions by ATC as the flight progresses[50]. The idea behind trajectory-based operations (TBO) is to enable the ATM system to know and, where appropriate, modify the flight's planned and actual trajectory, before or during flight, based on accurate information that has been shared by all stakeholders. This will lead to efficiency gains for both individual aircraft and for the network as a whole. TBO calls for full integration of flight information to create a synchronized view of flight data by all actors involved. This shared information also includes any constraints imposed by the various ATM stakeholders. The benefits of TBO are the enhanced safety, security, predictability and reduced fuel consumption and corresponding emissions. TBO is one of the identified SESAR EOCs and could be considered as the heart of the SESAR program. All essential operational changes (EOC) are interfacing with each other. Some EOC are a precondition/ enabler for TBOs such as dS, CNS and iN (explanations for abbreviations are contained in Figure 34). Some others like dA and ATp allow creating a maximum benefit from TBO. In fact, an advanced MET service and a modern CNS infrastructure and service are prerequisites for more accurate trajectory prediction. The ATM interconnected network is the mean to share this trajectory between all concerned stakeholders. Conclusively, the airport and TMA performance will be improved by integrating more advanced sequencing tools and by enabling a dynamic airspace configuration, thanks to new accurate and shared trajectories.

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[50] https://www.sesarju.eu/sesar-solutions/trajectory-based-operations

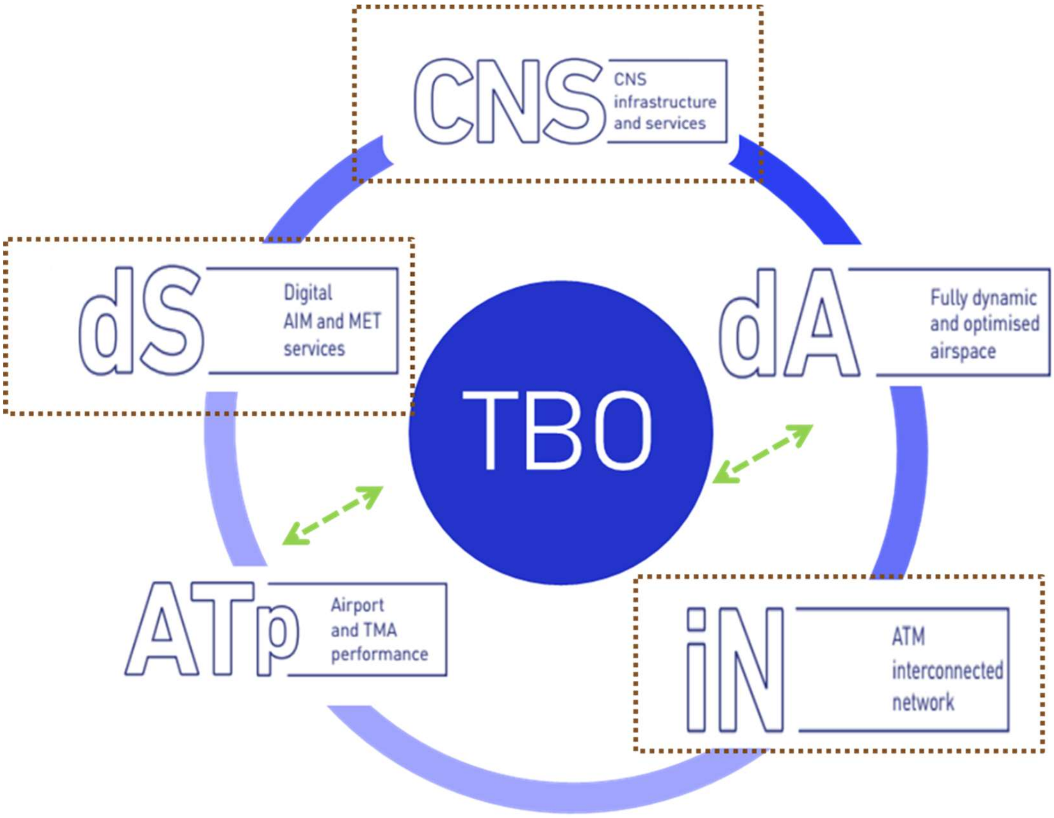

Figure 34: the interdependencies between TBO and other EOCs

All the solutions related to TBO and listed in SESAR catalogue [EUROCONTROL 2019c] are mainly dealing with three questions:

- How to improve the trajectory prediction itself, considering more accurate inputs from all actors and during all flight phases;
- How to improve ground based and airborne safety nets using this updated shared trajectory as well as all the data downlinked from the aircraft to the ground system;
- How to adjust uncertainty margin enabling future automation tools to provide better separation and sequencing of the aircraft.

The most of the SESAR solutions related to TBO within SESAR program are aiming to increase the safety level as a priority. However, in GreAT project, the main focus is laid on the reduction of the environment footprint.

The solutions proposed by SESAR are achieved by more than 300 projects, themselves involving several partners working at their own site throughout Europe. In the following subparagraph, three projects related to TBO will be presented.

3.2.3.1 PILOT COMMON PROJECT (PCP)

The Pilot Common Project (PCP) was established though Regulation 716/2014 issued by EC to support the implementation of the European ATM Master Plan [SDM 2017]. It identifies and makes mandatory the deployment of ATM functionalities that:

- contribute to achieving the ATM Master plan EOC;
- are mature enough for implementation;
- require a synchronized deployment.

It mandates the implementation of these functionalities by the member states of the European Union and their operational stakeholders to ensure a synchronized, coordinated and timely deployment.

The PCP includes 6 ATM functionalities and 20 sub-functionalities required to be implemented across Europe in the timeframe 2014-2027. These functions are:

- AF1 – Extended AMAN and Performance Based Navigation in the High-Density TMAs
- AF2 – Airport Integration and Throughput
- AF3 – Flexible Airspace Management and Free Route
- AF4 – Network Collaborative Management
- AF5 – Initial System Wide Information Management
- AF6 – Initial Trajectory Information Sharing

A new project called Common Project CP1 was recently defined as an update of PCP.

3.2.3.2 INITIAL TRAJECTORY INFORMATION SHARING (PJ31 DIGITS)

The project Initial Trajectory Information Sharing (PJ31 DIGITS) was launched 2016 for a duration of 4 years with a 6-month extension to cover the delay. It aims to demonstrate the ATM benefits that can be achieved by using downlinked 4D trajectory data in ground systems. This project focus on the development, validation and certification of an airborne processing unit capable of sending ADS-C data, including Extended Projected Profile (EPP) to the ground system according to Aeronautical Telecommunication Network (ATN) Baseline 2 standard. The project coordinates development actions and performs demonstration activities in a very representative environment and close to the real operational conditions. These demonstrations will pave the way for the implementation of the AF6 of the PCP. The synchronization of the air and ground trajectories is expected to bring benefits in terms of flight efficiency, mainly by enabling better descent profiles and improved arrival sequencing. The better quality of the ground trajectory prediction will also allow the enhancement of the tools that support ATCOs, and then increasing productivity. Results of the demonstration should quantify performance improvements resulting from the demonstration activities, using relevant KPAs from the performance framework defined in the ATM Master Plan [SJU 2012].

DIGITS bridges the gap between the early validation of the Trajectory Based Operations concept achieved in SESAR 1, with successful flight trials in 2012 and 2014, and the deployment of PCP AF6.

3.2.3.3 4D TRAJECTORY MANAGEMENT (PJ18 4DTM)

The 4D trajectory of an aircraft consists of the three spatial dimensions plus time as a fourth dimension[51]. This means that any delay is in fact a distortion / disturbance of the trajectory as much as a level change or a change of the horizontal position. Tactical interventions by air traffic controllers rarely consider the effect on the trajectory as a whole due to the relatively short look-ahead time (in the order of 20 minutes). The 4D trajectory concept aims to ensure flight on an optimal and practically unrestricted trajectory for as long as possible in exchange for the aircraft being obliged to meet very accurately an arrival time over a designated point. SESAR is supporting the implementation of 4D trajectory aiming to improve the trajectory accuracy. Currently, the flight plan is “barely” updated after takeoff. The few updates are mostly manually performed by the different operators within different systems, which are often not interconnected. The lack of complete, updated, coherent, precise and unique aeronautical information implies the

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[51] https://www.skybrary.aero/index.php/4D_Trajectory_Concept

deterioration in the accuracy of predicted trajectories, and limits the benefit from and development of new modern and efficient solutions, tools and concepts. Uncertainties make it difficult to plan without including wide margins in traffic planning, which clearly worsen the ATM system performances. It is therefore becoming urgent and of extreme importance to have an integrated, accurate and unique picture of the traffic at European level. It is the only way to increase efficiency and safety and to meet the ATM performances requirements in the years ahead.

The SESAR 4D trajectory management (PJ18 4DTM) [52]. project was launched on 2016 for the duration of 4 years. This project is pioneered by Indra. It involves 27 Stakeholders including ANSPs, ATM system suppliers, avionic system suppliers, etc. It is considered as one of the key projects identified in SESAR2020.

The project seeks to contribute to harmonized, global collaborative trajectory information definition and sharing (ground – ground, air – ground) to ensure a unique and integrated view of all flight trajectories (including military ones) for ATM stakeholders. The published progress reports for this project show the progress of the works as planned, and prove the potential of these solutions to enable the aircraft to choose the most direct route and plan flights with an unprecedented accuracy. This project plans and performs trials involving different countries, control centers and aircrafts, so that the new technologies and concepts will be tested in an environment similar to the reality.

To sum up, the main benefits of 4D Trajectory Operations are:

- Improvement of air traffic operations by increasing the overall predictability of traffic,
- Optimal operations for airlines (aircraft using preferred routes and levels),
- Better service provided (due to ground-ground and air-ground interoperability) – fewer trajectory distortions,
- Reduced costs (e.g. fuel and/or time),
- Reduced emissions,
- Increased capacities (en-route and airport) – controllers would be able to handle safely more traffic,
- Easier to handle traffic for the controllers (fewer conflicts, information comes well in advance) and
- Provide a single/shared, updated and complete view of the ATM environment (flight trajectory, airspace, meteorological and network data).

3.3. CIVIL AVIATION ATM MODERNIZATION STRATEGY (T2.1.3)

3.3.1. THE OVERALL ATM DEVELOPMENT STRATEGY

3.3.1.1 THE ROLE OF CAAMS

As another important ATM system development planning after NextGen and SESAR in a global context, the Civil Aviation ATM Modernization Strategy (CAAMS) provides important

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[52] The project information is extracted from the website: https://cordis.europa.eu/project/id/734161

guidance for promoting the development and construction of China's civil aviation ATM system [ICAO 2019].

3.3.1.2 THE PURPOSES OF CAAMS

At present, the Civil Aviation Administration of China (CAAC) is moving towards the strategic goal of "one acceleration and two realizations", while the civil aviation ATM system is also in the crucial stage of accelerating the construction of "Four-excellent ATM (excellent safety, excellent efficiency, excellent intelligence, and excellent collaboration)" and promoting the high-quality development of ATM. Therefore, the purposes of CAAMS are to seize the favorable opportunity of technical changes in the international ATM field, deepen the understanding of the basic laws of the ATM industry, strengthen the top-level design and overall layout of ATM development, and speed up the research, verification and application of new navigation technologies.

3.3.1.3 OPERATIONAL CONCEPT OF CAAMS

In CAAMS architecture, operational concept is used to describe what mode will be used by China's civil aviation ATM to provide services for airspace users in the future. In recent years, CAAC have pushed the operational concepts of CAAMS solidly in depth from eight aspects: airspace organization and management, collaborative traffic management, busy airport operation, trajectory-based operation, multi-mode separation management, joint operation of civil and military aviation, performance-based service, and information management. Details are provided in the list below:

(1) Airspace Organization and Management: By improving airspace management mechanisms, optimizing airspace structure and designing and applying specific schemes, the organization and management of airspace are to be more scientific and reasonable.

(2) Collaborative Flow Management: By establishing a multi-level traffic flow management system and a regional collaborative decision-making mechanism, and by carrying out cross-border flow management cooperation, the basic network for national flow management is to be initially established.

(3) Operation of Busy Airports: By strengthening the management of approach, departure, and airport surface operation, the operation of busy airports is to be tending towards refinement.

(4) Trajectory-based Operation: The overall development plan and implementation strategy of civil aviation ATM trajectory-based operations (TBO) is to be formulated, and the technical research of using data link communication to realize digital control in all stages of flight is to be carried out.

(5) Multi-mode Separation Management: Separation guarantee and conflict management means are transiting gradually to distributed autonomous separation operation.

(6) Joint Operation of Civil and Military Aviation: The cooperation between civil and military ATM in the fields of information sharing, airspace optimization, personnel training, military and civil aviation collision prevention and major mission support is being promoted continuously.

(7) Performance-based service: According to the performance requirements on communication, navigation and surveillance of airborne and ground systems, different ATM services are to be provided for different airspace users according to different performance levels.

(8) Information Management: A networked and standardized system-wide information collaborative environment is to be built up, and the information management system is to

be improved constantly. The preliminary research on civil aviation ATM data center is to be carried out, and a catalog of information resources of the whole system is to be compiled.

3.3.1.4 IMPLEMENTATION STAGES OF CAAMS

The following implementation stages can be distinguished in CAAMS:

Stage I (2020-2025): Strengthen the foundation and make up the shortcomings. Focus on strengthening the construction of basic information service capabilities such as system-wide information management, meteorological information service, and digital information management, improve the infrastructure construction supporting the operation of ATM system such as data link communication, integrated navigation, and multiple surveillance, solve the shortcomings of ATM operation safety guarantee and service quality, focus on improving the operation capabilities of busy airports and terminal areas, digital control in all stages, and national flight flow management, and build a safe and efficient ATM system to effectively realize the goal of building China a country with strong civil aviation.

Stage II (2026-2035): Comprehensive promotion. Build a collaborative information service environment supporting future trajectory-based operation, develop space-air-ground integration, networked data communication, precision navigation and comprehensive monitoring technologies, comprehensively promote the applications based on new control service modes such as trajectory operation, autonomous separation assurance and airport ATM fusion operation, and have the ability to lead the development of global ATM in many fields.

3.3.1.5 IMPLEMENTATION PRINCIPLES OF CAAMS

CAAMS follows four implementation principles, which are described below.

Unified planning and step-by-step implementation. The implementation of CAAMS will be a long-term continuous process; standing at the height of overall development, to realize the goal of building China a country of strong civil aviation, CAAMS should carry out unified planning and scientific layout, and formulate phased implementation goals in combination with the five-year planning of the system, and effectively support the action goals of "Four-excellent ATM".

Dock with the world, and consider own features. On the one hand, the formulation of the implementation roadmap should be carried out under the guidance of the overall policies, standards and norms of International Civil Aviation Organization (ICAO) to ensure that the implementation progress is generally matched with the Global Air Navigation Plan (GANP) and the seamless ATM plan in the Asia-Pacific region. On the other hand, it is necessary to consider the actual situation of China's civil aviation to draw up a technical roadmap with Chinese features, appropriately transcend in some fields with relatively mature technologies, and strive to achieve the dominant right of international civil aviation standards.

Comprehensive promotion and focused applications. The implementation and promotion of CAAMS should not only pay attention to the overall layout of China on national ATM and the promotion of the key capacity building items of CAAMS in a global and systematic way, but also consider the unbalanced development of different regions and the demand differences of various business categories, and select the key tasks with urgent application needs, high technology maturity and strong global leading nature to realize advance in key areas.

Independent, controllable and leapfrog development. In the process of implementation and promotion, CAAMS should not only pay attention to the introduction and digestion of international advanced cutting-edge technologies, but also guide domestic industries and scientific research institutions to increase their independent innovation capacities, improve the localized production ability and level of new technologies and equipment in ATM, ensure that core technologies and equipment are independent and controllable, and effectively promote the leap-forward development of China civil aviation from a big country to a leading country in the field of ATM.

3.3.2. DESIRED SOLUTIONS FOR FUTURE ATM

Directed by operational requirements, driven by performance improvement, and focusing on the key areas and weak links in the future technical development of China's civil aviation ATM, it is desired to make efforts to consolidate operation foundation, strengthen the research and application of key technologies, and form a number of key tasks on the basis of sorting out the technical layout and development routes of CAAMS. An overview can be found in Figure 35.

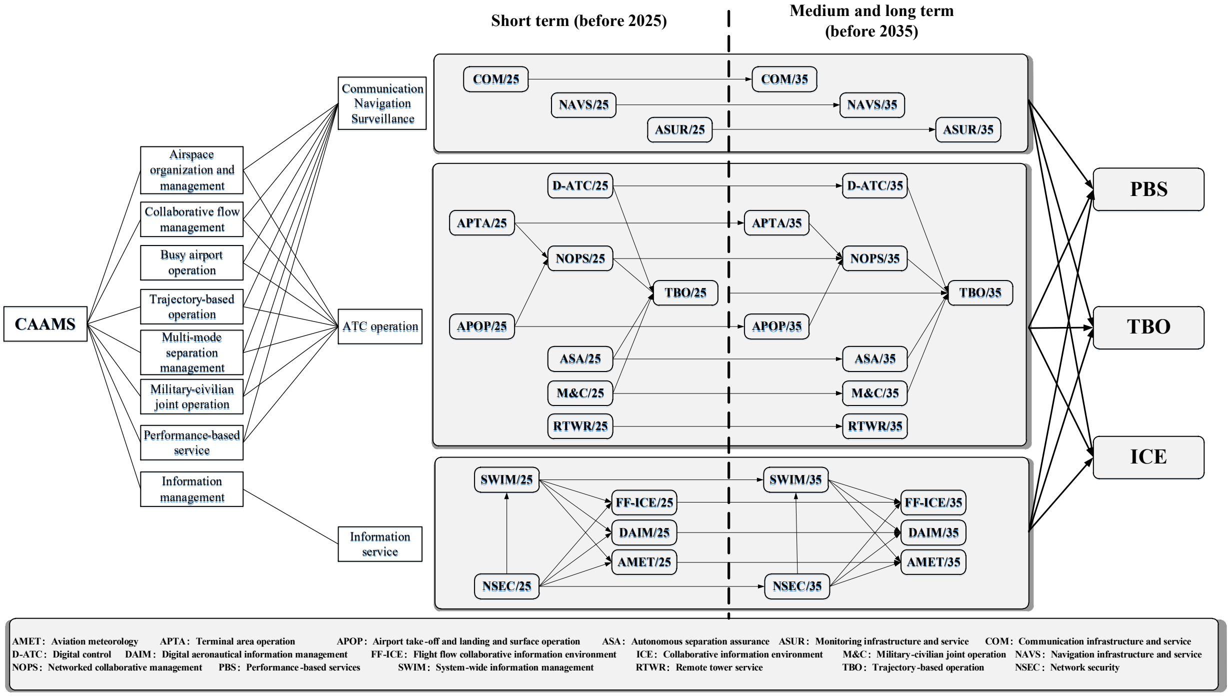

Figure 35 Development Routes of Key Technologies of CAAMS

3.3.2.1 IMPROVING THE COMMUNICATION, NAVIGATION AND SURVEILLANCE INFRASTRUCTURE AND SERVICE CAPABILITIES

In the following text, several key tasks related to CNS improvements are explained by providing a task description and a short-term and medium to long-term implementation path for every task.

Key task 1 (COM): Improve communication infrastructure and communication services

Task description:

Promote the construction of communication infrastructure such as ground-to-air voice/data communication system, satellite voice/data communication system and ground communication network, improve data link communication services, to effectively support the modern air traffic service guarantee system.

Implementation path:

(1) Short term (before 2025): In terms of ground-to-air data link, realize the VHF mode 2 data link coverage in the national airspace, and popularize the Aeronautical Telecommunications Network (ATN) service mode. In some areas, provide the capability of full-stage digital control service, promote the upgrade of VHF mode 2 ground station system, be compatible with ACARS Over AVLC (AOA) and ATN service modes, support Performance Based Communication and Surveillance (PBCS) analysis and reporting capability, provide ADS-C-based extended trajectory data download service in initial four-dimensional trajectory operation to support initial four-dimensional trajectory operation. In the aspect of airport surface communication, promote the application of AeroMACS system in national airports and the work of national networking. In the aspect of satellite communication, based on Inmarsat satellite service SB-S, be compatible with ACARS service and ATN B2 service, have the ability of PBCS analysis and reporting, and support initial four-dimensional trajectory operation.

(2) Medium and long term (before 2035): Improve the construction of VHF data link network and satellite data link network, be compatible with ATN/OSI and ATN/IPS dual protocol stacks, support the capability of dual-protocol information processing and exchange; carry out the test and application of LDACS broadband communication technology on air routes; make ground-to-air communication system support full TBO operation; carry out the application of ATM ground-to-air communication based on China's autonomous communication satellite system, and build a space-air-ground integrated aviation communication technology and application system.

Key task 2 (NAVS): Improve navigation infrastructure and navigation services

Task description:

Improve the network layout of land-based traditional navigation facilities and equipment, popularize the application of various enhanced technologies of satellite navigation, support the international standardization of Beidou navigation, build ATM navigation facilities supporting satellite navigation operation, and form an air-ground integrated aviation navigation service network.

Implementation path:

(1) Short term (before 2025): In the aspect of land-based navigation, supplement and improve the network layout of DVOR/DME stations of the land-based navigation system according to airspace requirements, support the operation of traditional air routes and flight procedures; build DME stations network layout supporting PBN operation route and flight procedure; cut down and gradually phase out non-directional beacon (NDB) equipment in transport aviation operation. In the aspect of satellite navigation, build a satellite-based ground integrity monitoring network, build a satellite-based navigation monitoring system integrity information release platform, continue to develop and improve the RAIM prediction system, and promote the application of satellite navigation ground-based augmentation system (GBAS) and airborne-based augmentation system (ABAS); Promote the application of satellite navigation satellite-based augmentation system (SBAS), carry out technical demonstration and verification of dual-frequency multi-constellation ground-based augmentation system (DFMC GBAS) compatible with Beidou system, and support the promotion of international standard construction of DFMC GBAS.

(2) Medium and long term (before 2035): Promote the aviation navigation application based on Beidou navigation system. The performances of dual-frequency multi-constellation GNSS with Beidou as the core and its enhanced system to meet the performance requirements as the main navigation source for domestic air routes and terminal areas and the main or auxiliary navigation source for airport precision approach operation; realize the multi-mode GNSS with Beidou as the core to be the main navigation source for PBN and ADS-B operation, promote the deployment of DFMC GBAS compatible with Beidou system at transportation airports, and improve the precision approach efficiency and low visibility operation support capability of airports; gradually establish a satellite-ground integrated aviation navigation service network to improve the comprehensive performance of aviation navigation services.

Key task 3 (ASUR): Improve surveillance infrastructure and surveillance services

Task description:

Improve air traffic surveillance capability, improve the application level of new technologies, optimize the layout of surveillance infrastructure, meet the demands of air traffic service for surveillance technology application, improve the guaranteed capability of air traffic safety, increase airspace capacity, improve operational efficiency, and promote the high-quality development of ATM system.

Implementation path:

(1) Short term (before 2025): The terminal (approach) control areas should be deployed with short-range primary surveillance radar in a planned way according to the operation demand, and independent and uncooperative surveillance means shall be provided; short-range/long-range primary surveillance radars can be deployed according to operational requirements in areas with complex airspace structure and dense operation of various types of airspace users, and in the border areas of air routes and lines. Deploy and improve the S-mode secondary surveillance radar in the air route, airline and terminal (approach) control area where radar control is implemented, and promote the networking application of S-mode secondary surveillance radar; further supplement and improve the national ADS-B ground station surveillance network, realize the surveillance coverage of air routes, lines and transportation airports, improve the functions of ADS-B data processing centers at all levels to meet the data access requirements of various demands and applications, and carry out the test and verification of ADS-B IN (air-air surveillance) technology application; make Beidou system and Beidou satellite-based augmentation system become the key navigation sources for ADS-B operation; promote the construction of China's autonomous global low-orbit satellite mobile communication system and satellite-based ADS-B; carry out the test, verification and construction of wide-area multi-point positioning operation.

(2) Medium and long term (before 2035): Realize the integrated application of secondary surveillance radar and ADS-B, introduce Beidou satellite navigation system, and improve GNSS safety and positioning ability; popularize the application of ADS-B IN technology, and realize air-air surveillance; deepen the application mode and scenario of satellite-based ADS-B air traffic management surveillance, and gradually promote its application; supplement the wide-area multi-point positioning system, and provide surveillance service as one of the cooperative surveillance technologies.

3.3.2.2 IMPROVING THE OPERATION EFFICIENCY AND SERVICE QUALITY OF ATM

In the following text, several key tasks related to Operation Efficiency and Service Quality improvements are explained by providing a task description and a short-term and medium to long-term implementation path for every task.

Key task 1 (APOP): Improve the ATM support capability of airport departure, approach and surface operations

Task description:

By strengthening the management of approach, departure and surface operations, enhance the airport operation safety in low visibility and complex environment, and effectively improve the throughput capacity and operation efficiency of busy airports.

Implementation path:

(1) Short term (before 2025): Realize main and standby AMAN systems or functions at the top ten airports in China, realize AMAN functions at airports with passenger throughput exceeding 20 million passengers, explore the application of DMAN system, and promote the application of cross-regional expansion of AMAN technology; expand the application scope of A-SMGCS Class III, deploy A-SMGCS Class IV application at airports with an average daily take-off and landing of more than 1,000 sorties, accelerate the realization of crew full-situation awareness and electronic taxi guidance at airports with required conditions, and provide airport surface taxi guidance service under low visibility conditions to improve runway safety and ATM support capability; realize the popularization and application of surface monitoring and aircraft taxi guidance technology with GNSS (including Beidou) and its enhanced systems as location sources, and realize the application of surface monitoring and aircraft taxi guidance based on GNSS in large airports with annual passenger throughput exceeding 20 million passengers and typical small and medium-sized airports. Based on A-SMGCS, integrate various operation system functions, such as electronic process sheets and digital ATM, to form a unified, efficient and all-in-one integrated tower system. Technical standards and configuration specifications of the integrated tower system will be studied and formulated, and gradually deployed in large busy airports to fully support the tower control operation of large busy airports.

(2) Medium and long term (before 2035): Realize the integration and promotion of approach, departure and surface management systems, and promote the application of multi-airport AMAN/DMAN technology and its collaborative application with traffic management system; gradually promote the application of technologies such as crew augmented visual system; for medium and high density airports, it is necessary not only to strengthen the fusion of approach and departure management system and surface management system to realize the fusion and synchronization of approach and departure management and surface management, but also to strengthen the docking between airport collaborative decision-making system and ATM operation system, so as to gradually realize the operation fusion of airport and ATM. Form complete standards, rules and regulations for integrated tower system technologies, functions, configuration, construction and operation, comprehensively popularize and apply the integrated tower system, and support the integrated and efficient operation of all airport towers control operation work.

Key task 2 (APTA): Improve the ATM support capability in the terminal areas of busy airports

Task description:

By optimizing the flight program design of airport terminal areas, popularize the application of new technologies such as performance-based navigation (PBN), continuous descent operation (CDO), continuous climb operation (CCO), precision approach, dynamic wake separation, etc., to improve the overall operation efficiency of the terminal areas of busy airports.

Implementation path:

(1) Short term (before 2025): Fully promote the application of PBN approach and departure flight procedures, provide GBAS Class I precision approach guidance service at airports with special needs, and promote the application of CDO and CCO; carry out the trial operation of aircraft wake reclassification RECAT.

(2) Medium and long term (before 2035): Provide GBAS Class II/III precision approach guidance service, and promote the applications of parallel runway simultaneous approach, parallel dependent approach, independent parallel approach, etc.; promote the application of RECAT, and provide time-based separation service of dynamic wake and time-based parallel approach.

Key task 3 (D-ATC): Promote the technical application of digital control in the whole stage

Task description:

Use data link technology to realize digital control, covering all flight phases such as flight take-off, departure, cruising, approach and landing, and providing reliable, real-time and efficient control services.

Implementation path:

(1) Short term (before 2025): Provide digital control services such as digital release based on Departure Clearance/ Datalink Automatic Terminal Information Service (DCL/D-ATIS), automatic information notification, CDM key moments, etc. in the operation stage of airport surface; provide digital control services such as PBCS-based CPDLC/ADS-C in remote routes or ocean areas; provide D-ATIS-based digital control service in air routes, and carry out new generation CPDLC/ADS-C digital control test and verification based on VDLM2 and ATN.

(2) Medium and long term (before 2035): Provide CPDLC/ADS-C digital control service based on VDLM2 and ATN for the whole flight stage; carry out digital control test and verification based on satellite communication data link; provide digital control service based on satellite communication data link for global flight.

Key Task 4 (NOPS): Improve the networked collaborative management capability of flight flow

Task description:

Under the concept system of trajectory-based operation, realize the goals of integrated, networked, collaborative and precise flow management, take the lead in Asia-Pacific region, realize docking with the world, and effectively improve the flight flow management ability and air traffic operation efficiency in China.

Implementation path:

(1) Short term (before 2025): On the basis of information sharing, strengthen the collaborative operation of all parties, layers and stages of flow management, including coordination for airspace use, capacity and flow balance, airport operation, emergency handling; strengthen centralized decision-making for a wider range of flow problems, covering all stages of flow management from pre-planning to post-analysis, and realize the integration of flow management and capacity management; construct a national collaborative platform for flow management, and utilize a series of tools such as regional collaborative release, time slot exchange, ground delay program (GDP), airspace flow program (AFP) and ground stop program (GS) to support the formulation and implementation of flow management measures; lead the development of flow management in the Asia-Pacific region by building a collaborative decision-making platform, formulating operation rules, and conducting cross-border flow management experiments, and realize close integration with the international flow management operation system.

(2) Medium and long term (before 2035): Based on the collaborative information environment of flight and flow, realize the data sharing of flow management and aviation meteorology, aviation information, and control information resources, and realize the integration of operation information of ATM, airports and airlines to predict the overall operation performance of flights and networks more accurately in a more real-time way, and further implement more global flow management considering the effect of air traffic network; improve the accuracy, timeliness and reliability of capacity restriction identification and flow prediction to narrow the gap between flow management decision-making and actual operation demand, achieve the goal of precision flow management, and gradually realize flow management based on time and four-dimensional trajectory.

Key task 5 (TBO): Promote the integrated application of trajectory-based operation

Task description:

Formulate the concept of TBO in China's civil aviation, establish the TBO and technical system architecture, increase R&D investment in key technologies and support systems in TBO, and carry out integrated application demonstration of TBO in typical air routes and control areas.

Implementation path:

(1) Short term (before 2025): Select typical test air routes to demonstrate and verify the initial four-dimensional trajectory operation of small-scale flights, access airborne 4DT to the flight flow management system, and carry out integrated application verification such as free air route selection and optimal flight altitude allocation; encourage airlines to upgrade aircraft avionics systems to have four-dimensional trajectory operation capability; select multiple air routes in a region and typical terminal areas to carry out large-scale demonstration and verification of TBO, build the FF-ICE collaborative information environment before take-off, and initially realize the sharing synchronization and collaborative management of air-ground and ground-to-ground four-dimensional trajectory.

(2) Medium and long term (before 2035): Build FF-ICE collaborative information environment, realize four-dimensional trajectory collaborative management in the whole operation cycle, and verify the capabilities of control operation, flow management and traffic sequencing based on four-dimensional trajectory in turn, and demonstrate and verify the practical application in major airports and air routes in China.

Key task 6 (ASA): Promote autonomous aircraft separation assurance

Task description:

Make full use of the capability of airborne avionics system of aircraft, explore a new control mode of air-ground distributed separation maintenance, realize autonomous separation assurance of aircrafts, relieve the pressure of centralized control on the ground, and support more flexible and dynamic flight operation to effectively improve flight operation efficiency.

Implementation path:

(1) Short term (before 2025): For the air routes or regions with required conditions, demonstrate and verify the autonomous separation assurance and terminal area trailing flight of aircrafts with the capability of autonomous separation assurance.

(2) Medium and long term (before 2035): Carry out application verification of the mixed operation of centralized control and distributed control; moderately promote aircraft autonomous separation assurance technology, carry out the planning of special air routes or special airspace to implement the application of new control modes; realize the mixed operation of centralized control and distributed control according to performance requirements.

Key task 7 (RTWR): Promote remote tower control service

Task description:

Improve the integration degree of all kinds of information in the airport tower control system, comprehensively apply advanced monitoring and positioning technologies (such as video surveillance, multi-source surveillance, augmented reality, intelligent identification), communication technology, meteorological monitoring technology, etc., realize remote monitoring and control command on airport aircraft operation, provide remote tower control service for remote small airports, and reduce the operational cost of airports.

Implementation path:

(1) Short term (before 2025): Popularize the application of integrated tower technology in large and medium-sized airports, and improve the operation efficiency of tower control through high information integration; carry out test and verification of remote tower control in remote small airports.

(2) Medium and long term (before 2035): Popularize the application of remote tower control service in remote small airports, and support the control command of different-place remote tower center on the operation of multiple airports; carry out technical verification and application of virtualized and intelligent airport tower in large and medium-sized airports.

Key task 8 (M&C): Joint operation of military and civil ATM

Task description:

Broaden the development scope of military-civil ATM integration, enrich the forms and upgrade the level. Based on the principles of information sharing and system sharing, actively promote military-civil aviation operation coordination mechanisms such as coordination of major activities, coordination of emergency response, flexible use of airspace, and joint operation of military and civil aviation in busy terminal areas to improve the utilization efficiency of airspace resources and improve the cooperative operation level of military-civil ATM.

Implementation path:

(1) Short term (before 2025): Promote the establishment of a national airspace system and national airspace classification standards, and establish a military and civil aviation joint supervision and evaluation mechanism for airspace management; improve the coordination mechanism of military and civil aviation control, and realize the coordination of daily control, coordination of major activities, coordination of emergency response, and joint operation of terminal areas; deepen the construction of low-altitude flight service guarantee system, build a ground-to-air flight service guarantee system consisting of low-altitude flight service national information processing system, regional information processing system and flight service stations, and explore solutions for mixed operation of manned and unmanned aircrafts; build a general ATM talent team, unify the ATM talent training standards, and realize mutual recognition of military and civil aviation control qualifications.

(2) Medium and long term (before 2035): Carry out overall planning for the construction of military and civilian ATM facilities and equipment, unify military and civilian ATM standard procedures, and gradually unify aviation information, aviation meteorology and flight plan information exchange standards for military and civil aviation, so as to realize the interconnection and intercommunication of airspace information, meteorological information, flight plans, etc., and realize the integration of military and civil aviation control & command and the unification of flight method procedures; the low-altitude flight service guarantee system shall fully cover low-altitude reporting, airspace surveillance, and general airports, and the test and application of manned/unmanned aircraft mixed operation shall be carried out.

3.3.2.3 SPEEDING UP THE CONSTRUCTION OF ATM COLLABORATIVE INFORMATION SERVICE CAPABILITY

In the following text, several key tasks related to Collaborative service capability improvements are explained by providing a task description and a short-term and medium to long-term implementation path for every task.

Key task 1 (SWIM): Building a system-wide information sharing architecture

Task description:

Build a unified, flexible and efficient information sharing architecture based on data centers for various business information, realize the safe, effective and timely sharing and exchange of data among different business systems of civil aviation, and lay an information sharing foundation for the construction of a modern air traffic management system.

Implementation path:

(1) Short term (before 2025): Formulate the planning of civil aviation ATM data center and implement it. According to the actual needs of information sharing and exchange of various civil aviation operation entities, formulate a set of SWIM standard specifications, which shall be consistent with international standards while meeting the actual operation needs of China's civil aviation; research and build a SWIM platform system which is based on civil aviation ATM data center, and which supports the whole system information sharing architecture, select pilot areas to carry out the application of SWIM information service, and realize the sharing and exchange of flight, surveillance, intelligence, meteorology and flow information among ATM departments, airlines, airports and industry users; actively participate in global SWIM regional cooperation.

(2) Medium and long term (before 2035): Complete the infrastructure construction of civil aviation ATM data center, comprehensively promote the system deployment and application, and establish a civil aviation business information exchange mechanism with SWIM standards and specifications as the core; establish an industry data exchange architecture and comprehensively promote the information service application of SWIM; carry out the application of ground-to-air data exchange, complete the transformation of relevant ground and airborne equipment, and add relevant contents into airworthiness regulations, so as to realize all-round data exchange of civil aviation.

Key task 2 (AMET): Improve the capability of aeronautical meteorology service

Task description:

Grasp the two main lines of civil aeronautical meteorology service capability modernization and business capability modernization, make full use of modern information technologies such as big data, Internet of Things, cloud computing, artificial intelligence, data simulation, etc. to develop intelligent meteorological business, carry out generally-benefited meteorological service, and explore institutional innovation to make intelligent meteorology become the main driving force and important symbol in the construction of a higher level of meteorological modernization in the modern air traffic management system.

Implementation path:

(1) Short term (before 2025): Establish an aeronautical meteorology numerical forecasting system to improve the important weather forecasting level that affects the normal operation of flights, such as strong convection, low cloud and low visibility, and have the capability of providing continuous and seamless accurate meteorological service for the whole process of aviation operation. The influence and contribution of meteorological service to the normal flight shall be improved significantly; strengthen the weather detection capability of airports and terminal areas, optimize the operating environment of meteorological detection facilities, and significantly improve the early-warning capability of thunderstorm, strong wind, heavy precipitation and heavy fog; fully improve the "capabilities of accurate forecasting, facility support, scientific and technological innovation, and personnel qualification", and basically build a modern civil aeronautical meteorology service system to meet the needs of civil aviation transportation.

(2) Medium and long term (before 2035): Combined with information technologies such as big data, artificial intelligence, and Internet + (a new concept proposed by Chinese government to promote the merging of Internet and traditional industries) to basically build a smart weather service system mainly featured by "deep operational integration, generally-benefited meteorological service, three-dimensional detection and perception, intelligent forecasting and early warning, fine scientific management, and continuous scientific and technological innovation", and fully integrate it into a modern, safe, efficient, smart and collaborative ATM system.

Key Task 3 (DAIM): Realize digital aeronautical information management

Task description:

With the theme of transformation from aeronautical information service (AIS) to aeronautical information management (AIM), improve the aeronautical information operation management system, establish a perfect digital aeronautical information service network, develop and apply advanced automation systems, exploit new aviation data service fields, improve the quality and ability of aeronautical information support, and promote the construction of information sharing environment.

Implementation path:

(1) Short term (before 2025): Establish a perfect aeronautical information raw data collection mechanism and aeronautical information quality safety management system, improve aeronautical information operation management system, realize digital raw data collection, and strengthen the quality control of aeronautical information data; establish a national aviation intelligence database with global aviation intelligence data exchange capability to provide digital aviation intelligence services for domestic and foreign users; build a digital navigation notice system and issue digital navigation notices; carry out navigation data coding and provide airborne navigation data products; build a flow management operating environment database to provide basic operating environment data for the flow management system and ATM operation of China's civil aviation.

(2) Medium and long term (before 2035): Fully promote digital aeronautical information management services, explore the application of new generation information technologies such as artificial intelligence and big data in aeronautical information management and services, and further improve the efficiency and level of aeronautical information services.

Key task 4 (FF-ICE): Construct Flight and Flow Information for a Collaborative Environment (FF-ICE)

Task description:

With the collaborative sharing of flight and flow information among ATM, airlines, airports and other related parties, build a Flight and Flow Information for a Collaborative Environment (FF-ICE) based on system-wide information management (SWIM) platform architecture and flight information exchange model (FIXM) to completely replace traditional information exchange modes such as AFTN, and realize efficient sharing and collaborative decision-making of flight plan before take-off, flow management information, flight dynamics after take-off, and four-dimensional trajectory.

Implementation path:

(1) Short term (before 2025): Formulate the implementation manual of FF-ICE Stage I flight plan service before take-off, carry out the test and verification of the take-off and flight plan service in conjunction with airlines, airports and other units, and promote FF-ICE Stage I flight plan service before take-off based on SWIM platform; carry out the test and verification of flight dynamics and four-dimensional trajectory information service in the process of FF-ICE Stage II flight.

(2) Medium and long term (before 2035): Build a digital, networked and standardized collaborative service environment for flight plans to gradually replace the AFTN telegraph network, support the services such as flight plan planning, sending, testing, notification and release among ATM, airlines, airports and other related parties; promote the flight dynamics and four-dimensional trajectory information service in the process of FF-ICE Stage II flight to fully support the operation based on four-dimensional trajectory.

Key task 5 (NSEC): Construct network security assurance system

Task description:

According to the national network security level assurance system and aiming at meeting the security requirements of different types of information systems and information system life cycle of ATM, adopt management measures and technical prevention measures at different levels to protect ATM information system and information resources from being invaded, implement security protection measures from the perspective of actual operation, systematization and normalization, and build an all-in-one network security integrated guarantee system.

Implementation path:

(1) Short term (before 2025): Strengthen network security infrastructure, build a civil aviation ATM information and network security management system, form a management information sharing platform covering the whole system with overall planning and use, and unified access, and realize cross-layer, cross-regional, cross-system, cross-department and cross-business collaborative management and decision-making through service bus, information sharing, big data analysis and cloud resource scheduling, provide network security protection and situational awareness management that comply with the national level protection system, and strengthen the ability to resist risks and malicious attacks.

(2) Medium and long term (before 2035): Optimize the information system architecture, make full use of situational awareness, trusted computing, machine learning and other technologies, build a defense-in-depth system, and establish a safe, reliable, efficient, open and flexible overall framework for information system security protection. Strengthen the research on the security protection of core production and operation system, and ensure the safe and efficient operation of core business. Endeavor to transform from passive to active defense, from static to dynamic defense, from single point protection to overall prevention and control, from coarse to precise protection, and strengthen the ability of ATC system to cope with network threats.

3.4. COMPARISON OF SESAR AND CAAMS STRATEGIES (T2.1.4)

This section summarizes the commonalities and differences between the future ATM programs in Europe and China, namely SESAR and CAAMS, which are described respectively in the chapters 3.2 and 3.3. This analysis aims to reach a common awareness about the tasks, procedures and solutions being deployed and planned to be deployed on both sides. On the one hand, some of these solutions are identified as pre-conditions and prerequisites to the implementation of the greener concepts such as datalink capabilities, CNS infrastructure improvements, etc. On the other hand, it is also necessary to ensure that the concepts to be developed within this project will be consistent with the strategic goals and visions of these programs. Not forgetting, that, above all, a potential benefit will be gained from exchanging ideas and experiences about the performed research activities.

It should be also noted that both programs are aligned with ICAO Global Air Navigation Plan (GANP) [ICAO 2016]. It inclines to believe that there are more commonalities than differences between them. The following analysis will shed light on this statement and will focus mainly on comparing the research activities and solutions related to trajectory-based operations.

The following analysis is very much based on chapters 3.2 and 3.3, and has been worked out in several online workshops that were attended by European and Chinese partners of GreAT.

3.4.1. THE OVERALL ATM DEVELOPMENT STRATEGY

As per [EUROCONTROL 2019a], the European ATM system is reaching its limits und becoming inadequate to address crucial European network issues. It is facing in the first place the following challenges:

- Steady increase in conventional traffic,
- Growing environmental concerns,
- Emergence of new entrants into the airspace.

As per [CAAC 2016], CAAMS is motivated by promoting China as a leading country in aviation field and by accelerating the development and modernization of ATM system.

Still, one of the first priorities from both sides is to reduce flight delays and to overcome capacity crunch, while coping with the traffic growth. This will already contribute to address another common challenge, namely to make the aviation sector more sustainable. The GreAT project is one of several initiatives launched in both world regions for this purpose. It can be concluded that SESAR and CAAMS share the same challenges. Nevertheless, it seems that less priority is given to the integration of drones and other emerging Unmanned Aerial Vehicle (UAV) in the Chinese ATM system, compared to SESAR who plans to reach full U-space by 2040.

Vision and strategical goals

To better grasp the vision and strategical goals of each program, it is equally important to understand the limiting factors of each ATM system. The main limiting factors from both sides are mainly:

- Non-optimal organization of airspace,
- Limited use of data communication,
- Limited automation in ATC provision,
- Limited predictability of air traffic,
- Limited information sharing and interoperability, etc.

Certainly, these factors are impacting the two ATM systems in different ways and due to different reasons. The comparison between both ATM systems helped to identify the areas where great benefit could be reached when improved. From European side, it is mainly linked to the high airspace fragmentation and the non-share of the available material and human resources. From Chinese side, the use of free routes and more flexible airspace restrictions and segregations could potentially increase the flight efficiency and punctuality as well as the overall airspace capacity. These differences in the solutions to be urgently deployed may lead to differences in the priorities set by SESAR and CAAMS.

Table 15 gathers the visions and strategical goals targeted by SESAR and CAAMS. It is worth noting that compared to CAAMS which has just started, SESAR has been running since 2004 and has a larger overall time horizon. This may also explain the very ambitious goals set by SESAR with regards to the targeted level of automation as defined in the European ATM Master Plan [EUROCONTROL 2019a]. Provided that the current level of automation is approximatively level 1 to 2, reaching automation level 4 to 5 in 20 years is really very challenging. Based on the description of its research activities, it is suggested that CAAMS is targeting automation level 4 named "high automation" by 2035.

Table 15. Visions and strategical goals of SESAR and CAAMS

	SESAR	CAAMS
Strategic goals	Four phase approach to improvement:	Two strategic goals:

	- Phase A: Address known critical network performance deficiencies - Phase B: Efficient services and infrastructure delivery - Phase C: Defragmentation of European skies through virtualization - Phase D: Digital European sky More detailed definition is provided in chapter 3.2.1.1.	- Build a modern civil aviation ATM system - Complete a performed-based operation
Time horizon	From 2004 to 2040	From 2020 to 2035 (published on 2016)
Implementation steps	- Definition phase (2004–2008): ATM master plan for the development and deployment of the next generation of ATM systems - Development phase: SESAR 1 (2008–2016) and SESAR 2020 (2016-2024): Development of the new technological systems and components - Deployment phase (2014–2040): Implementation of the new air traffic management infrastructure	- Stage I (2020-2025): Strengthen the foundation and make up the shortcomings - Stage II (2026-2035): comprehensive promotion (collaborative environment to support TBO, space-air-ground integration…)
Targeted automation level	Automation Level 4 to 5 (full automation) by 2040	No level of automation is defined

To sum up, SEASR and CAAMS are dealing with similar issues and targeting similar solutions. They promote the innovation as a key enabler for the ATM modernization and place the TBO at the heart of their development strategy. Nevertheless, there are some differences about the overall duration, the limitations related to the current ATM system and the importance attached to certain research and development activities.

Key performances areas and indicators

To achieve the previously highlighted vision and goals, it is highly important to identify and set relevant KPAs and KPIs. SESAR and CAAMS have defined respectively seven and six KPAs (refer to Table 16). From these KPAs, different KPIs were derived by each program, revealing a specific focus on some strategic and operational improvements. These sets of KPAs / KPIs enable defining the targets (the desired level of performance) and tracking the progress against that target. The analysis of Table 16 enables to make the following assessments:

- The KPA 'Capacity' is identified in both programs with the same target value for 2035.
- The KPA 'Cost efficiency' in SESAR is equivalent to the KPA 'Management' in CAAMS. Different KPIs and ambition values are identified related to this KPA. China is aiming to use more systems manufactured locally to lower the overall ATS costs. Europe is

more acting on different fronts, namely enhancing the ANS productivity and introducing significant organizational changes.

- The KPA 'Operational efficiency' in SESAR is equivalent to the KPA 'Efficiency' in CAAMS, but it includes more operational aspects: fuel efficiency, and time efficiency though shorter gate-to-gate flight times and higher on-time performance. SESAR is intending to reduce delays caused directly or indirectly by ATM- and weather-related factors.
- The KPA 'Environment' in SESAR is equivalent to the KPA 'Service' in CAAMS. The reduction of the gate-to-gate CO_2 is already captured by the KPI 'Operational efficiency'. This KPI covers then the other aspects of the aviation impact on the environment in terms of noise and local emissions.
- The KPA 'Safety' is identified in both programs with similar ambitious values. Nonetheless, SESAR had set a very ambitious goal of zero accidents as consequence of ATM/ANS. This goal goes beyond the SES high level goal of 10% improvement in safety.
- There is no KPA equivalent in CAAMS to KPA 'Security' defined in SESAR. Nevertheless, several tasks launched in CAAMS aim to improve the security.

Table 16. KPA and KPI defined in SESAR and CAAMS programs

SESAR (SES high level goals)		CAAMS	
KPA	**Ambition (2035) compared to baseline (2012)**	**KPA**	**Ambition (2035) compared to baseline (2015)**
Capacity	Enable 3-fold increase in ATM capacity compared to 2012	**Capacity**	Enable 3-fold increase in ATM capacity compared to 2015
Cost efficiency	• Reduction of ANS costs per flight by 30-40 % • Reduced ATM services unit costs by 50% or more	**Management**	• Reduce cost of ATS per flight by 20% • Raise the rate of medium and small equipment produced locally over 80% and the rate of large equipment up to 50%
Operational efficiency	• Reduction of 250-500 kg in Gate-to-gate fuel burn per flight[53] • Reduction in additional gate-to-gate flight time of 50-55 %[54]	**Efficiency**	Average delay due to ATC is less than 5 minutes
Environment	Enable 10% reduction in the effects that flights have on the environment	**Service**	Reduce the carbon emission of flight operation by 10%

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[53] The fuel efficiency performance ambition addresses the average gate-to-gate fuel consumption per flight

[54] From an ECAC-wide, the average value of 8.2 minutes for an average flight in 2012

Safety	Improve safety by factor of 10	**Safety**	- reduce the rate of incidents due to ATC by 90% - reduce the error rate due to ATC by 20%
Security	No significant disruption due to cyber-security vulnerabilities	Ø	No KPA or KPI is specified for security

Although there is no metrics set for the effectiveness of the civil-military interoperability and cooperation, SESAR gives prominence to the fundamental role of the military aviation and considers that as crucial to achieve the target objectives and performances. It is essential to involve military aviation with the whole SESAR lifecycle. This is the only way to achieve the SESAR vision outlined in the Master Plan.

State of work

To date and as evaluated in European ATM master plan [EUROCONTROL 2019a], one third of the SESAR Solutions have been delivered for deployment, while one third are in development and in the pipeline towards deployment. Both together, these two thirds will allow the delivery of up to phase C of the vision (defragmentation of European skies through virtualization). The remaining third are those solutions to be undertaken in future research and development to deliver phase D (digital European sky) [EUROCONTROL 2019a]. In total, 153 projects out of 343 are delivered on October 2020. The projects brought already benefits to the environment by saving around 25k tons of fuel and 79k tons of CO_2[55]. In the other hand, Figure 36 shows the progress made in the implementation of ICAO ASBU as part of CAAMS activities. Being just started, CAAMS is smoothly and considerably progressing (see Figure 38).

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[55] See SESAR Deployment Manager - Home | SESAR DM

Figure 36: CAAMS implementation progress

3.4.2. DESIRED SOLUTIONS FOR FUTURE ATM

Operational concept

On one hand, SESAR had identified nine essential operational changes (EOCs) as enabler to deliver Phase C of SESAR vision termed the defragmentation of European skies through virtualization. On the other hand, CAAMS had structured the operational concept into eight topics. A mapping of SESAR EOCs to CAAMS operational concept is proposed in Table 17. This table attempts to match together similar operational concepts from both programs for comparison purposes.

Table 17. Mapping between the EOCs defined in SESAR and the operational concepts laid down in CAAMS

ID	SESAR EOCs	CAAMS
(1)	**Fully dynamic and optimized airspace (EOC dA)**	Airspace Organization and Management (AOM) & Collaborative management of Traffic Flow (CMTF)
(2)	**Airport and TMA Performance (EOC ATp)**	High-density Airport Operation (HDAO)
(3)	**Trajectory-based Operations (EOC TBO)**	Trajectory-based Operations (TBO)
(4)	**CNS Infrastructure and Services (EOC CNS)**	Performance Based Service (PBS)
(5)	**ATM Interconnected Network (EOC iN) & Digital AIM and MET (EOC dS)**	Information Management (IM)
(6)	**U-space services (EOC U-s)**	∅
(7)	**Multimodal Mobility and Integration of All Airspace Users (EOC M^3)**	∅

(8)	**Virtualization of service provision (EOC vS)**	∅
(9)	∅	Multi-mode Separation management (MMSM)
(10)	**∅ (already implemented)**	Civil-military Joint Operation (CMJO)

Further explanations and discussions to the individual lines of Table 17 are provided below:

(1)

The first EOC listed in Table 17 is the implementation of a fully dynamic and optimized airspace (dA). This EOC aims to push further the implementation of free-route airspace (FRA) in Europe, to cover large-scale cross-border FRA, and to ensure smooth transition between FRA and highly structured airspace, based on dynamic airspace configuration (DAC) principles [EUROCONTROL 2019a]. To achieve full dynamic airspace configurations, it is equally important to move from ASM collaborative processes to ASM reconciled with ATC and ATFCM into a fully integrated ASM, ATC, ATFCM and collaborative decision-making layered process. It allows so the implementation of the user-preferred routing. The EOC dA seems to cover the same topics as the concepts Airspace Organization and Management (AOM) and Collaborative Management of Traffic Flow (CMTF) defined in CAAMS research program. AOM and CMTF intends among others to [CAAMS 2016]:

- promote the establishment of a national airspace system,
- classify and designate the different airspace classes as per international standards,
- release more low-altitude airspace,
- construct a national airspace system management information platform to conduct a full-process monitoring of airspace distribution and usage (like the Network manager in Europe),
- optimize route structure continuously with new technology,
- reduce lateral separation of routes,
- Promote the establishment of multi-type conditional routes as an effective supplement to fixed routes based on airspace utilization in different regions and periods,
- Give priority to the implementation of user alternative routes between high-density airports,
- Explore multi-mode operations on major routes,
- Study and improve the flexible use modes of airspace,
- Promote the comprehensive flexible use of airspace,
- guide the dynamic adjustment and optimal design of airspace and collaborative decision-making.

Compared to EUROCONTOL member states where the adoption of FUA concept became mandatory on 2006, China has recently started to explore and investigate the implementation of more flexible ATS routes (conditional routes). As a first step, CAAMS is investigating the implementation of the conditional routes category three (CDR3) which could be used by ATC Units only in tactical stage. These CDR will supplement the set of temporary routes. It is understood that, within the framework of CAAMS, it is not yet planned to implement the FUA and FRA concepts as defined and implemented in Europe. Instead, it is intended to provide the airspace users with more choices among a set of defined routes and make possible the use of additional conditional routes upon request and under certain circumstances. This is a significant difference between SESAR and CAAMS.

(2)

The second EOC listed in Table 17 is Airport and TMA Performance (ATp). It matches with the operational concept High-density Airport Operation (HDAO) identified in CAAMS as both are seeking to:

- Improve the planning and execution of operations at and around airports, such as traffic sequencing, reduced separation, reduced and more predictable runway occupancy time, and enhanced management of taxiway throughput, for both arrivals and departures,
- Address the required coordination with TMA operations,
- Increase the safety of operations,
- Reduce environmental impact at or near airports,
- Enhance navigation and improve accuracy in low-visibility conditions on the airport surface enable safe maneuvers while maintaining the capacity.

The comparison between the current ATM systems in Europe and China (refer to chapter 2.3.3) showed the challenges facing airports and TMAs in both regions are quite comparable. Likewise, the targeted improvements foreseen in SESAR and CAAMS in this regard seem also to be consistent.

(3)

Being the core of SESAR and CAAMS, TBO is listed in the desired operational changes by both programs. A more detailed comparison about the way how TBO will be implemented from both sides is be provided in chapter 3.4.3.

(4)

Another matching is also identified between the EOC CNS Infrastructure and Services (CNS) and the concept Performance Based Service (PBS) of CAAMS. Both research programs are intending to transform the CNS infrastructure to meet the requirements necessary to implement TBO. However, SESAR is targeting, in addition to the performance-based approach, a service-based approach to decouple the CNS service provision from the supporting infrastructure. These additional improvements are highly required in the context of Europe, where very large number of heterogenous equipment is deployed by different member states and airspace users. In fact, the available human and technical resources are not optimized and rationalized and in lot of cases, they are either overlapping or inefficiently distributed. Moreover, some other initiatives in SESAR are launched to reach a high civil and military interoperability with maximal dual use.

(5)

Another aspect handled by both programs is the requirements related to the ATM network used for the provision of the ATS as enabler for planning, decision-making and the implementation of flight- and flow- centric operations. This is covered by the EOCs ATM Interconnected Network (iN) and Digital AIM and MET (dS) from European side, and by Information Management (IM) from Chinese side. They aim to build a performant System Wide Information Management (SWIM) enabling dynamic share of up-to-date digital aeronautical and meteorological information between all actors in a timely manner.

(6), (7)

Table 17 shows also that some concepts from both sides could not be mapped together due different reasons. The EOCs U-space services (U-s) and Multimodal Mobility and Integration of All Airspace Users (EOC M^3) could not be compared with similar concepts defined within CAAMS. The emergence of drones in Europe has been of major concern for ATM over the past years. As both the supply and the demand for drones are accelerating, there was a pressure to create a system that allows the use of drones for both private and business purposes. Their integration became then an urgent matter which led to the creation of U-space as a framework to cope with the emergence of this new entrants.

(8)

Similarly, the EOC Virtualization of service provision (vS) could not be linked to one of the operational concepts of CAAMS. In the same time, there is no reason for China to put it in the list of the most significant operational changes. The Chinese ATM system performances are not highly impacted by the fragmentation of the ATS service provision, as it is the case in Europe. The ATM baseline comparison showed that, in contrast to China, Europe is facing a high fragmentation of service provision historically established at state level. This was identified as a major issue facing the European ATM system, critical in addressing the current and future capacity challenges. Moreover, CAAMS is promoting the use of remote towers for small airport and intends to popularize the idea of virtual services to reduce costs. The fact that it did not appear in the list of high-level operational concepts does not mean that it is not being implemented. It reveals only that the situation in China does not require an urgent action related to the virtualization of the ATS provision like it is the case in Europe.

(9)

The Multi-mode Separation management (MMSM) concept defined in CAAMS framework aims to make a comprehensive usage of strategic and tactical level for the separation management toward an autonomous mode of ATC. There are no specific EOC identified in SESAR to cover this topic. However, several solutions are being explored to better manage the separation and the safe operation for all the airspace users.

(10)

The concept named Civil-military Joint Operation (CMJO) part of CAAMS CONOPS is not identified in SESAR EOC because it is already implemented in Europe. This can be also seen as considerable difference between the two research programs.

Link to the global context (ICAO Global Air Navigation Plan)

As stated in [EUROCONTROL 2019a], SESAR has continuously and actively contributed to the development of the ICAO GANP and the aviation system block upgrades (ASBUs). It is also affirmed that the GANP aligns well both in vision, performance ambitions, structure and technical content with the Master Plan and SESAR Solutions. It should be also noted that SESAR proposes some additional solutions that have no corresponding ASBU Element identified. This covers mainly the solutions related to the U-space services.

In Figure 18, the concepts proposed by CAAMS are compared with the concepts from ICAO GANP [ICAO 2016]. This comparison shows that CAAMS is in most cases in line with ICAO vision despite some differences mainly related to the cooperation between civil and military, Performance Based Service and TBO.

Table 18. Comparison between CAAMS and ICAO GANP

ID	ICAO GANP	CAAMS	Comparison
(1)	**Airspace Organization and Management (AOM)**	Airspace Organization and Management (AOM)	in compliance
(2)	**Demand and Capacity Balancing (DCB)**	& Collaborative management of Traffic Flow (CMTF)	The concept CMTF is compliant with DCB
(3)	**Aerodrome Operations (AO)**	High-density Airport Operation (HDAO)	HDAO is compliant with AO but its scope is reduced compared to AO

(4)	**Traffic Synchronization (TS)**	Ø	TS is covered by other several concepts in CAAMS
(5)	**ATM Service Delivery Management (ATM SDM)**	Trajectory-based Operations (TBO)	TBO is different from ICAO GANP
(6)	Ø	Performance Based Service (PBS)	PBS is different from ATM SDM
(7)	**Information Management (IM)**	Information Management (IM)	In compliance
(8)	**Conflict Management (CM)**	Multi-mode Separation management (MMSM)	MMSM is compliant with CM and it has a larger scope.
(9)	Ø	Civil-military Joint Operation (CMJO)	CMJO is not covered by ICAO GANP
(10)	**Airspace User Operations (AUO)**	Ø	

In addition to the comparison with ICAO GANP, the concepts from CAAMS are mapped with the ICAO ASBU (refer to Figure 37). This mapping proves that all the ASBU defined by ICAO are covered by CAAMS although the differences in the global repartition of the operational concept components per ASBU. In fact, different ICAO ASBUs could support the same operational concept component which is not the case in CAAMS. Moreover, the two concepts Civil-military Joint Operation (CMJO) and Performance Based Service (PBS) are additional concepts proposed to support the implementation of the other blocks. The need to introduce them is triggered by the specificity of the current ATM system in China.

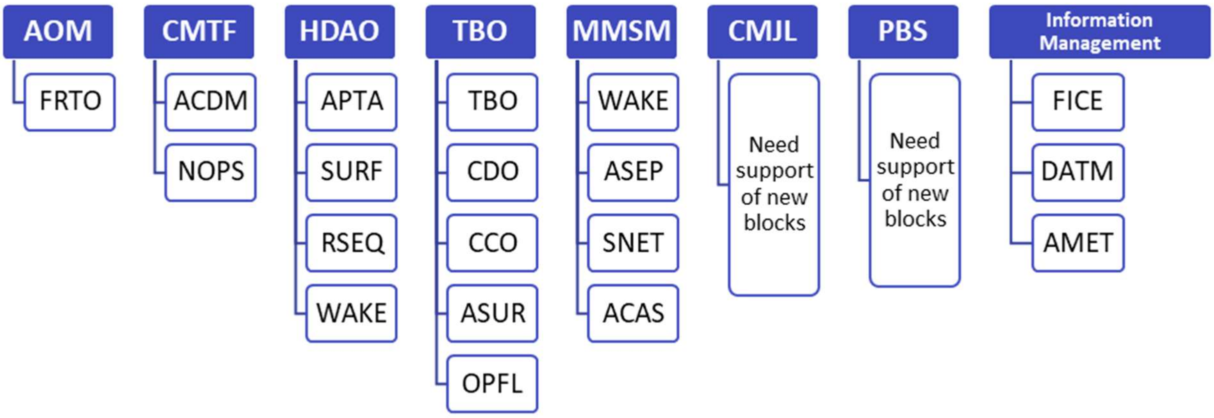

Figure 37: Mapping between ICAO ASBU concept components and CAAMS concepts

The results of the comparison between ICAO and both future ATM programs SESAR and CAAMS confirm the differences between these two programs identified in the previous chapter.

Key tasks/ Solutions

The SESAR solutions (more than 300 solutions) are organized in the 4 cornerstones

- Optimized ATM network services,
- Enabling aviation infrastructure,
- High-performing airport operations
- and Advanced air traffic services.

The CAAMS tasks are defined in the 3 areas

- Information Service,
- CNS
- and ATC Operation.

The two ATM research programs are organized and structured in different ways which make it difficult to perform a detailed comparison of the proposed solutions and performed tasks.

3.4.3. CURRENT RESEARCH PROJECTS ASSOCIATED TO TBO

TBO is considered as the key to an evolutionary transformation of the ATM System. The goal of TBO is to achieve an optimum system outcome with a minimum deviation from the user requested flight trajectory. SESAR and CAAMS are developing all capabilities and processes essential to TBO. They are advancing towards the 4D trajectory concept. Flight plan and constraints information will be exchanged between stakeholders before departure and during the flight. Cockpit connectivity to Flight Operations Centers (FOC) and ground systems are being enhanced to be able to downlink the trajectory updates, including additional information such as aircraft performance and weight information. ATM actors on the ground need also to upgrade their systems to integrate the extended flight plan information for more accurate trajectory computation that will be shared and dynamically updated by all actors. All other flight and flow related information, including airspace and aerodrome operational information, meteorological information, and operational constraints, should be shared among all stakeholders to provide a consistent view to enable collaborative decision making. A Flight and flow Information for a Collaborative Environment (FF-ICE) and System-Wide Information Management (SWIM) will deliver necessary communication capabilities to share real-time information between concerned ATM actors. The roadmap set by SESAR and CAAMS for the implementation of TBO is showed in Table 19.

Table 19. Roadmap related to TBO tasks and projects in SESAR and CAAMS

	SESAR	CAAMS
Initial trajectory exchange (i4D/EPP)	Several projects are launched to develop, validate and certify an airborne processing unit capable of downlinking the EPP to the ground systems: • **Flight trials** in 2014 and 2016 • Providing Effective Ground & Air data Sharing via EPP (**PEGASE**) • Initial Trajectory Information Sharing (**PJ31 DIGITS**): 2016-2021 • **PCP (AF6):** 2014-2027	A key task called "promote the integrated application of TBO is launched by CAAMS. It intends to in **short term (before 2025):** • Select typical test air routes to demonstrate and verify the i4D operation of small-scale flights • Access airborne 4DT to the flight flow management system, and carry out integrated application verification such as free air

4D trajectory Management	The extended flight information shared between airborne and ground systems will be used to improve the trajectory accuracy. This process is being developed and explored within SESAR though several research activities and projects such as the 4D trajectory management (**PJ18 4DTM**) planned from 2016 to 2020.	route selection and optimal flight altitude allocation • Encourage airlines to upgrade aircraft avionics systems to have 4D trajectory operation capability • Select multiple air routes in a region and typical terminal areas to carry out large-scale demonstration and verification of TBO, • build the FF-ICE collaborative information environment before take-off, and initially realize the sharing synchronization and collaborative management of air-ground and ground-to-ground 4D Trajectory. **Medium and long term (before 2035)**: • Build FF-ICE collaborative information environment • Realize 4D trajectory collaborative management in the whole operation cycle, and verify the capabilities of control operation, flow management and traffic sequencing based on 4D trajectory in turn • Demonstrate and verify the practical application in major airports and air routes in China.
FF-ICE	The project optimized airspace users' operations (**PJ.07**) performed from 2016 to 2019 has contributed to the development of FF-ICE standards for trajectory exchange processes and FIXM information. In addition, **PJ 18 4DTM** is specifically tasked with supporting the future development of FF-ICE and FIXM on a global level. it is expected to deliver validated inputs to FF-ICE/FIXM for aspects related to the planning phase. The project also includes a contribution to FIXM for aspects related to the execution phase. It will, therefore, help pave the way for the early support of FF-ICE Step 2 concepts in the medium- to long-term.	
SWIM	The PCP/iSWIM is being developed from 2016 to 2027.	

The different solutions and tasks related and around TBO are being / are implemented in SESAR and CAAMS with varying levels of maturity. Through these research activities, Europe and China are progressing towards TBO and getting one step closer to more efficient ATM systems.

3.4.4. SUMMARY OF SESAR/ CAAMS STRATEGIES COMPARISON

The summary of the comparison between SESAR and CAAMS programs is provided in Table 20. It could be concluded that there are more commonalities than differences between both future ATM programs. The identified differences are strongly linked and derived from the differences identified between both current ATM systems. But, one thing is certain, SESAR and CAAMS will help eventually to blur the difference between both ATM systems in the future.

Table 20. Summary of SESAR/ CAAMS comparison

Topic	**Assessment**				**Comments**
	Commonalities	Difference			
		Low	Medium	High	
Challenges		X			Common challenges are facing both future ATM program.
Vision and strategical goals			X		SESAR and CAAMS support the same ideas and follow similar vision and strategical goals. However, and because of the differences in the way the current ATM systems in Europe and China are working, different priorities and focuses are set by both programs. They are also both following stepped approaches. As known, technological and operational changes in ATM are usually made at a slow pace. Certainly, there are more steps defined in SESAR due to the huge number of entities and states involved. In Europe it takes probably more time to put in place new procedures or technologies than in China. That explains the larger overall time horizon defined for SESAR activities compared to CAAMS.
KPA/ KPI		X			Similar KPAs and KPIs are defined from both sides
State of work			X		The state of work of SESAR and CAAMS could not be compared as they have completely different time frames. In fact, CAAMS has just started on 2020 and SESAR has started on 2004.
Operational concepts				X	SESAR and CAAMS share a set of operational concepts and ideas mainly related to the improvement of airport operations, the upgrade of CNS infrastructure, the building of interconnected network, etc. Still, they have a significant divergence regarding the optimization of the airspace organization and management. The flexibility in the use of the Chinese airspace is not based on the same principle and ideas as the European concept FUA. Moreover, the principle of free routes in CAAMS is quite different from SESAR. It means the free choice among defined set of predefined routes. In other words, the route structure remains and there is no intention to implement Free Route Airspace within the framework of CAAMS.
TBO		X			Similar steps are followed to implement TBO, although there are differences in the progress made and the maturity level reached by the described operational or technical solutions.

4. CONCEPT FOR GREENER AIR TRAFFIC MANAGEMENT

The purpose of the remaining parts of this deliverable is to work out and describe the basics of ATM concepts that are optimized towards lowest CO_2 and greenhouse gas emissions and consequently, the lowest environmental impact. This is based on the current practices as described in section 2, and considering the steps already taken as described in section 3, to reach comparable situation to the best case scenario presented in section 4.1. Further, this is done using concept elements summarized in section 4.4 to build greener concepts as per the examples provided in section 4.5. The goal is to collect, formulate and define principles for greener ATM concepts in general, which are universal and not necessarily restricted to the detailed concepts that are going to be developed and validated later in the project.

This section starts with a flight-centered analysis of the best possible and most fuel-efficient way of conducting a flight. This is relevant because fuel consumption is directly linked to CO_2 emissions and other greenhouse gas emissions. For example, according to [ICAO 2017] the mass of fuel consumed is linked by the factor of 3.16 to the mass of produced CO_2.

Short- and medium-term effects that can be exploited by focusing on non-CO_2 effects, and by taking also the altitude and location of emissions into account, are investigated in detail by the other projects which belong to the same H2020 project cluster together with GreAT, especially ACACIA [CORDIS 2020]. Those effects are initially neglected here, and will in any case lead to a trade-off decision between

1) intentionally producing more emissions than necessary, to exploit positive effects of producing those emissions, especially those with a short life time, at a certain position and altitude,
2) and intentionally accepting the long-term consequences of increased long-living emissions in the atmosphere.

. As soon as the positive effects of 1) are clearly understood and quantified, they can immediately be included as additional optimization parameter.

Based on the flight-centered analysis in section 4.1, building blocks for greener ATM concepts are derived, which are forming a framework and a toolbox for setting up greener ATM concepts inside (but also outside) of the GreAT project.

Finally, this section provides examples on how these building blocks can be used and assembled to new procedures or improvements that are enabling a greener ATM for a specific use case. This can also be understood as an outlook to MWP3 and MWP4, where these examples are worked out in detail.

Whenever feasible and appropriate, an estimation of the potential to effectively contribute to reducing the emissions of aviation is provided for the aspect or element concerned. This estimation is based on expert judgement and expectations, but not (yet) on scientific evidence. This estimation further uses the states ‘low potential’, ‘medium potential’, or ‘high potential’, referring to the contribution of this measure to the estimated maximum possible improvement in terms of saving emissions.

4.1. BEST CASE SITUATION FOR A SINGLE FLIGHT

In this chapter, the theoretical “best case” situation in terms of fuel consumption is determined. This “best case” is seen as the case with the maximum possible fuel efficiency.

All thinkable circumstances, like the needs of ATM, avoiding hazardous areas or even airline specific flying practices can basically lead to a deviation from this "best case" situation, and to a decrease of fuel efficiency.

The following assumptions are considered in this chapter:

- The analysis is done from a flight-centric perspective.
- Other possible air traffic and the effects of encountering other aircraft are neglected.
- For the analysis we assume a full freedom to move within the airspace.
- All ATM-related measures, like separation constraints, airways, flight level allocation and navigation requirements or obstacle clearance are completely neglected.
- The only constraints to be considered for the analysis are safety constraints to always guarantee a safe and stable status of the aircraft.
- Ideal atmosphere conditions are assumed (no wind, no weather effects, standard atmosphere).

The theoretical best-case conditions demonstrated here might not be fully practicable today, but can nevertheless be useful for validation purposes, especially to find out the limits of counteracting climate change by trajectory optimization, and for a comparison with current situation and after having new concepts implemented.

4.1.1. START-UP / TAXI-OUT PHASE AND TAXI-IN PHASE

The theoretical best-case situation with the lowest possible fuel consumption, producing the lowest possible emissions during the start-up / taxi-out phase is given under the following conditions:

A. **Minimum holding time with running engines** (Best case: zero holding time after start-up at the gate, on taxiway intersections or at the runway holding point); as engines running in idle on ground burn fuel without making any use of the energy gained from the burned fuel.

B. **Minimum turns, acceleration and braking** (Best-case: only one acceleration phase when leaving the gate for departures, and only one braking phase when reaching the gate for arrivals); avoidance of braking and acceleration at own power again, e.g. at taxiway intersections, at airplane queues or sharp taxiway turns; as braking and acceleration at own power requires to absorb kinetic energy, and to gain it again afterwards by burning extra fuel. It must be considered that one very long turn (>100°) can be more fuel consuming than several small turns.

C. **Appropriate taxi speed** (Best-case: most fuel-efficient taxi speed); as especially higher taxi speeds need more fuel to counteract the drag. This optimum speed is currently unknown and needs to be specified for every aircraft type and wind situation. In today's aviation practices, the taxi speed is mainly driven by schedule or traffic flow constraints (e.g. departure slots to be met, absorption of delay), as well as safety and passenger comfort.

D. **Shortest possible taxi route** (Best-case: (almost) direct route to the nearest suitable runway and nearest suitable runway holding point for departures / (almost) direct route from the runway exit that is closest to the allocated gate); as the fuel needed for the taxi process is directly linked to the taxi distance.

E. **Limited propulsion** to produce just the energy needed for the taxi movement (Best case: use the minimum required propulsion for taxi, considering the power needed for taxiway slope, runway crossings and turns); to achieve the best degree of efficiency from the fuel burned during the taxi process.

F. **Optimized aircraft weight** (Best-case: to avoid unnecessary fuel / payload on board); Unnecessary fuel / payload on board means systematically unnecessary additional aircraft weight because it takes fuel to carry it.

G. **Appropriate runway direction** (Best-case: Runway direction matches the destination direction, if possible); the choice of runways to be used for a flight depends on multiple factors and configurations. It is not always possible to meet this optimal configuration and for all flights which leads to longer flight trajectory in the air.

The sketch below (Figure 38) can be understood as an attempt to summarize the theoretical best-case taxi movement under "laboratory" conditions, taking the runway layout of a European airport as an example, assuming full freedom to move on ground in a first step (left column); and taking the (may be non-optimal) taxiway layout into account in a second step, trying to hit as best as possible the direct line (right column). In this best-case scenario, the taxi movement would always start immediately after the engines produce just enough power to be able to commence it; the most efficient taxi speed is chosen; no braking and acceleration except when required to safely taxi along taxiway turns, and the start-up of the remaining engine power and remaining pre-flight activities are done just in time before take-off. The possibilities of new concepts like electric taxi are neglected here, as the work in GreAT shall not change the aircraft and its components or ground equipment.

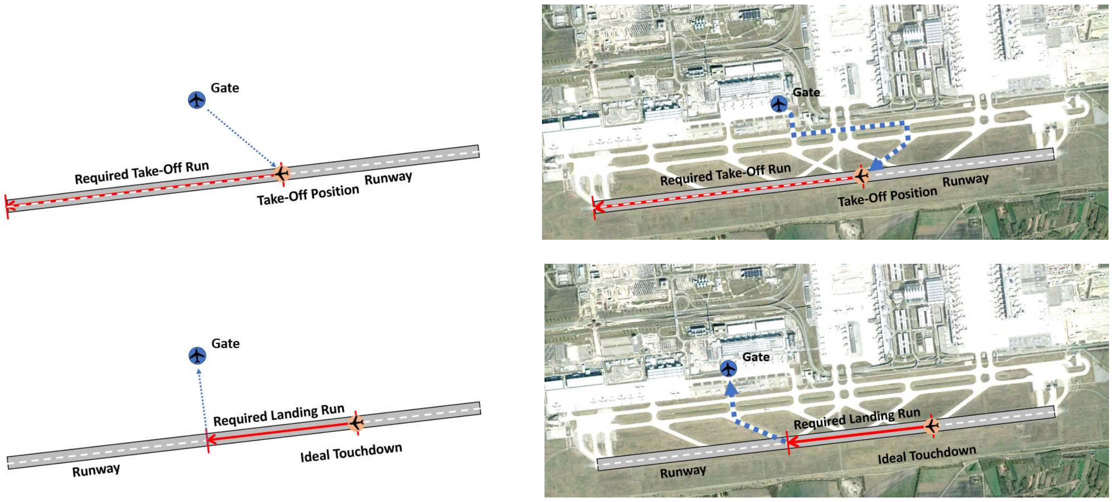

Figure 38: Theoretical best-case taxi movements for a departing (upper row) and an arriving flight (lower row) on a European sample airport, without (left column) and including (right column) consideration of the taxiway layout

4.1.2. DEPARTURE PHASE

Together with the en-route phase, the departure phase can consume a significant part of the fuel needed to conduct a certain flight. The theoretical best-case situation with the lowest possible fuel consumption, producing the lowest possible emissions during the departure phase is given under the following conditions (take off opposite to active runway direction to shorten the flight track during the departure phase is not considered here):

A. **Adopt rolling take-off** instead of static take-off (Best case: avoid spooling up engines while holding in take-off position); the rolling take-off consume less fuel but it is highly dependent on the runway conditions and length as well as the aircraft performance. Nowadays, one of the decisive factors influencing the chosen maneuvers is the runway occupancy time and consequently the runway throughput.

B. **Take-off with adapted thrust setting** of the engines: (Best case: thrust setting with the best energy efficiency of the engines, which is usable considering the available take-off run); this is because fuel consumption may not be in linear relation to the produced thrust.

C. **Early cruise flight aircraft configuration:** (Best case: immediate acceleration and early switching to cruise flight aircraft configuration / reducing to ‘climb thrust’ instead of ‘take-off thrust’); as extended flaps / slats, which are needed for low speeds, increase the drag and therefore the fuel consumption. However, depending on the engine power and weight of the aircraft, the climb phase is always a trade-off between using the produced energy to gain altitude or to gain speed.

D. **Early turnout to destination:** (Best case: turnout direct to destination when reaching a safe turning altitude, when speed allows a turn and when obstacle clearance is guaranteed); to perform the climb to the cruising level while already making distance towards the destination, and to avoid flying too long into the ‘wrong’ direction after takeoff.

E. **Continuous unrestricted climb:** (Best case: aircraft type specific continuous climb profile with optimal fuel conserving climb rate); including free speed profile, to allow the pilot to use the optimum rate of climb and rate of acceleration.

F. **‘Energy management’** techniques when a continuous climb is not possible (Best case: burned fuel equals the sum of gain in potential energy and the gain in kinetic energy, divided by an engine / aircraft type specific degree of efficiency); with the goal to use mandatory level flight in the departure phase for acceleration.

The sketch below (Figure 39) can be understood as an attempt to summarize the theoretical best-case departure movement under “laboratory” conditions. In this best-case scenario, the take-off is performed with the most efficient thrust setting, or with the thrust setting that allows a lift-off within the available take-off run (whichever is more restrictive). An acceleration phase follows, to allow an early retraction of flaps / slats. Then a climb with a free climb rate and free speed is conducted. As much as possible, this climb starts with a reduced climb rate, as long as a turn towards the destination is performed.

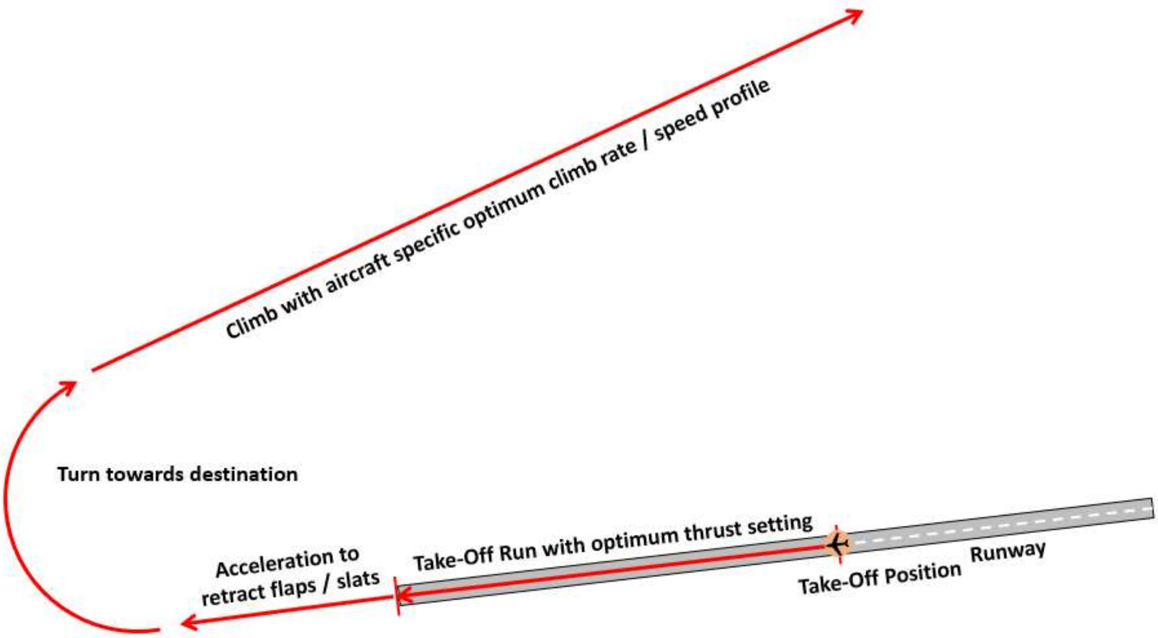

Figure 39: Visualization of the theoretical best-case departure movement profile

4.1.3. EN-ROUTE PHASE

At the beginning of the en-route phase, the aircraft has reached the cruising level and speed, and is overcoming the distance to destination. Nowadays, the route, speed and level during cruise flight are chosen according to several indicators, that are summarized in a so-called cost index. This cost index is calculated differently from airline to airline, depending on the valid operating procedures and airline policies. However, this already shows that the cruise flight of modern airliners is often optimized towards economic interests of the airline, i.e. lowest costs, but not necessarily towards lowest fuel consumption. Flying outside most fuel-efficient conditions, e.g. to catch up some delay by flying a higher speed, is common practice. In this flight phase, the need for a paradigm shift from prioritizing economic interests towards prioritizing environmental benefits is most obvious.

The optimization potential towards a theoretical best-case situation stems from the following measures:

A. **Appropriate cruising speed:** (best case: maintain most fuel-efficient speed during the whole en-route phase), as higher speeds may increase fuel consumption due to a higher drag, but lower speeds may also increase fuel consumption due to engine efficiency at cruising altitude. Further, the optimum cruising speed may be aircraft type specific, and may depend on the altitude and aircraft weight.

B. **Appropriate cruising level:** (best case: maintain most fuel-efficient level during the whole en-route phase; in most cases this leads to a slow continuous cruise climb), as the aircraft, being lighter, needs to climb to a higher level, being more fuel-efficient. A cruise flight in lower altitudes leads to an increased drag, but a higher altitude leads to a different and less effective engine behavior. The result is a type specific optimum altitude with lowest fuel consumption, which depends on the current aircraft weight. The slowly decreasing aircraft weight caused by fuel burn usually leads to a slow increase of the optimum cruising level.

C. **Shortest travelling distance:** (best case: shortest great circle distance between two points, at first neglecting wind effects); as this reduces the travelling time through the air volume when assuming a given optimum cruising speed.

The fuel saving potential which is offered by optimizing speed and level, has been analyzed already by earlier studies [Lovegren 2011].

4.1.4. DESCENT PHASE

The theoretical best-case situation with the lowest possible fuel consumption, producing the lowest possible emissions during the descent phase, is given under the following conditions:

A. **Shortest travelling distance:** (best case: from the top of descent direct to the point where the final approach path is intercepted, considering an alignment turn beforehand), as this reduces the travelling time through the air volume when assuming a given optimum cruising speed. Wind effects are neglected as it is not expected that the wind situation changes significantly with changing aircraft position, apart from its dependency on altitude)

B. **"Energy Management":** (best case: use exactly the available potential energy of the aircraft to maintain the desired optimum speed during descent until final approach), to avoid the need for additional thrust (e.g. during level flight or to maintain a certain speed) or the need for using air brakes (which would absorb energy from the flight without using it)

C. **Minimum Drag and Late Landing configuration:** (best case: flaps / gear are extended at a late stage for instance during alignment turn or final approach), as extended flaps / gear increase drag and fuel burn; in case the engines itself significantly contribute to drag when running idle, it might be necessary to use a thrust setting reducing this drag to a minimum.

The sketch below (Figure 40) can be understood as an attempt to summarize the theoretical best-case descent under "laboratory" conditions. In this best-case scenario, the potential energy provided by altitude is continuously reduced and converted into kinetic energy. This is done exactly by the amount that is necessary to overcome drag and to fly the desired speed profile. At the same time, the aircraft flies directly to a point where the final approach begins. The landing gear and flaps are extended later during final approach.

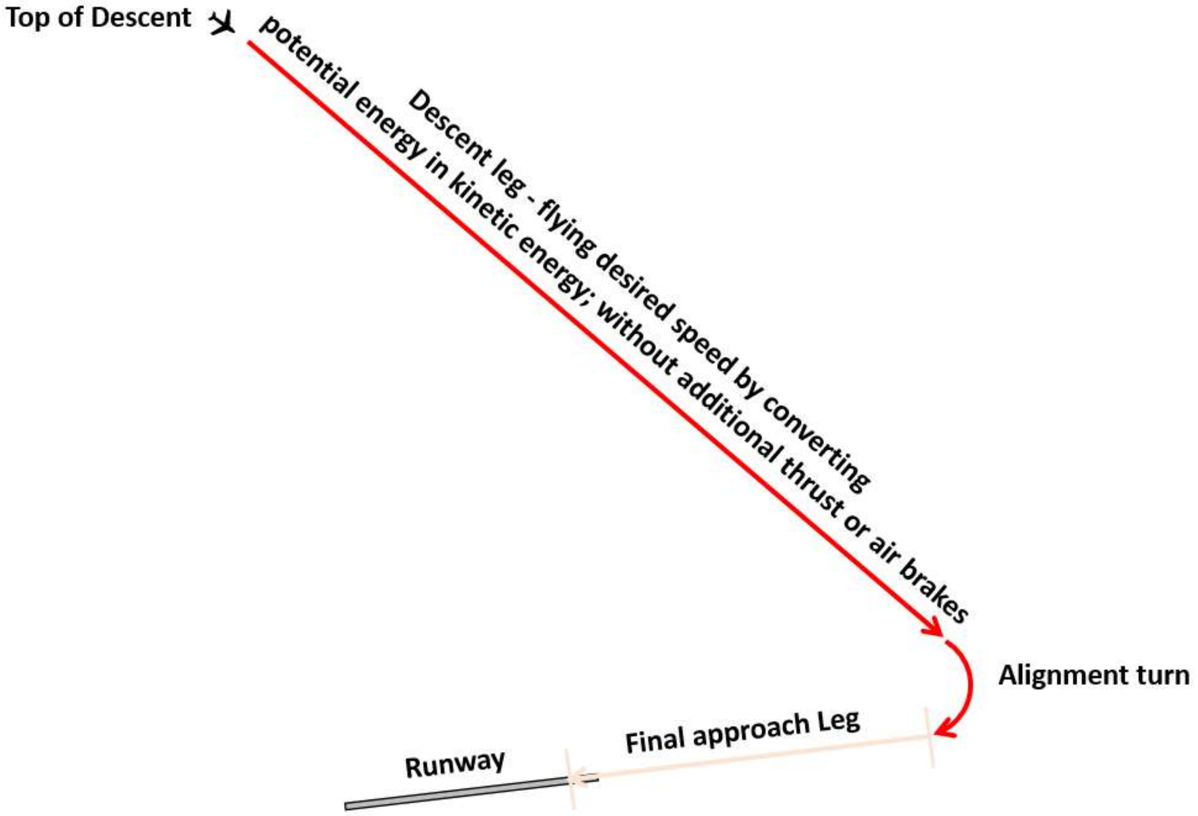

Figure 40: Best case descent towards the runway for landing

4.1.5. FINAL APPROACH PHASE AND LANDING

The theoretical best-case situation with the lowest possible fuel consumption, producing the lowest possible emissions during the final approach and landing phase is given under the following conditions:

A. **Short Final Leg**: (best case: shortest possible time prior to touchdown where the aircraft must be on a stable approach, as well as shortest possible time for reconfiguring the aircraft for landing beforehand), as the landing configuration leads to a significantly increased fuel burn. A short final leg reduces the time where the aircraft flies in this configuration. The minimum length of the final leg should be determined by the minimum time needed in stable approach conditions prior to touchdown, and the minimum time needed to reconfigure the aircraft beforehand. Depending on the aircraft type specific approach speeds, as well as the headwind situation, this will lead to different minimum lengths of the final approach leg from aircraft type to aircraft type. Whenever possible, the aircraft configuration should be changed during the alignment turn to further shorten the final leg.

B. **Reduced Drag Configuration:** (best case: Minimum required Drag / Flap setting), as flap setting results in an increase of fuel consumption due to the increase of drag. Landing with reduced flaps can be used as an alternative. The benefits are less fuel consumption, less noise and a steadier trajectory in turbulences.

C. **Zero-Emissions deceleration after touchdown:** (best case: braking methods are used that are producing any fuel consumption or emissions, e.g. high drag configuration and wheel brakes only), as for example thrust reversers increase noise, consume fuel and produce extra emissions.

D. **Avoid missed approaches:** (best case: no missed approaches) studies have been conducted to investigate possibilities to avoid missed approaches of flights from ATM side as much as possible [HSB 2017], as a complete missed approach and landing out of the next attempt is very fuel consuming and therefore produces a lot of emissions.

The sketch below (Figure 41) can be understood as an attempt to summarize the theoretical best-case final approach and landing under "laboratory" conditions as described above.

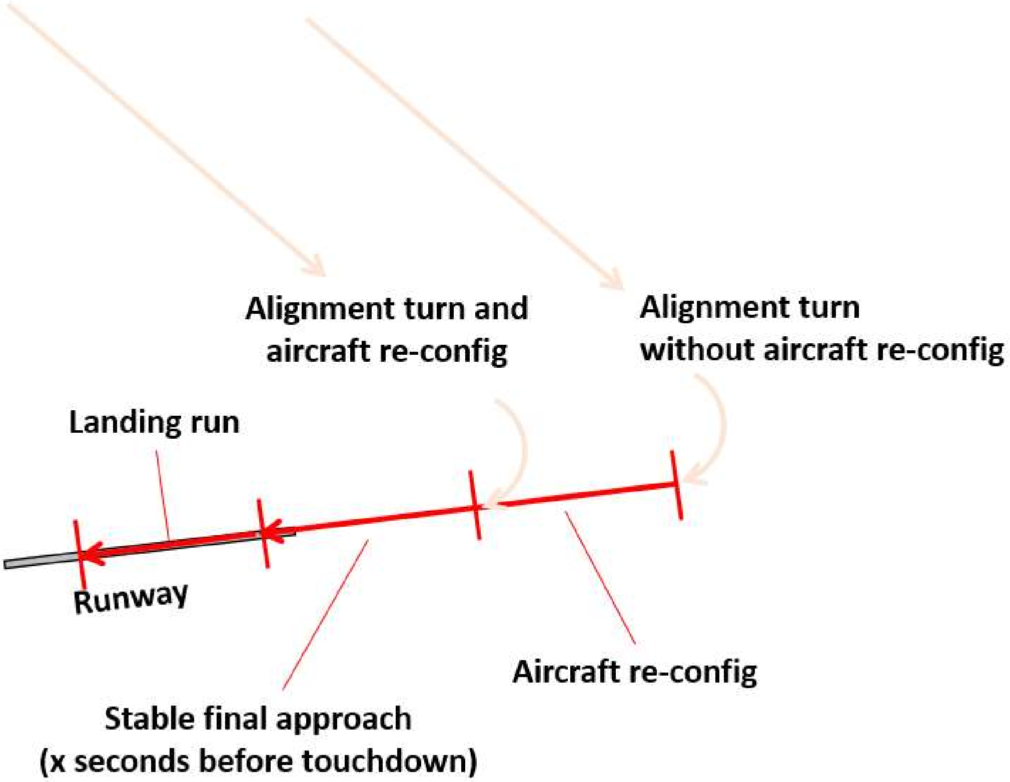

Figure 41: Best case final approach and landing

4.2. NATURAL INFLUENCING FACTORS

This section summarizes the major natural factors that influence a flight trajectory, and consequently, its fuel efficiency and emissions. These factors cannot be controlled. The only option is to make use of positive effects on fuel efficiency and emissions to the maximum extent, minimize negative effects or avoid natural phenomena completely.

4.2.1. WIND DIRECTION AND SPEED

The most obvious factor influencing the fuel and emissions efficiency of a flight trajectory is wind direction and wind speed. The wind behavior is variable with aircraft position, with altitude and with time. Its concrete future behavior is unknown and can only be forecasted with some uncertainty.

The local effect of wind on a single flight is very well understood and can be calculated with simple vector addition (see Figure 42), known as 'Wind Triangle'.

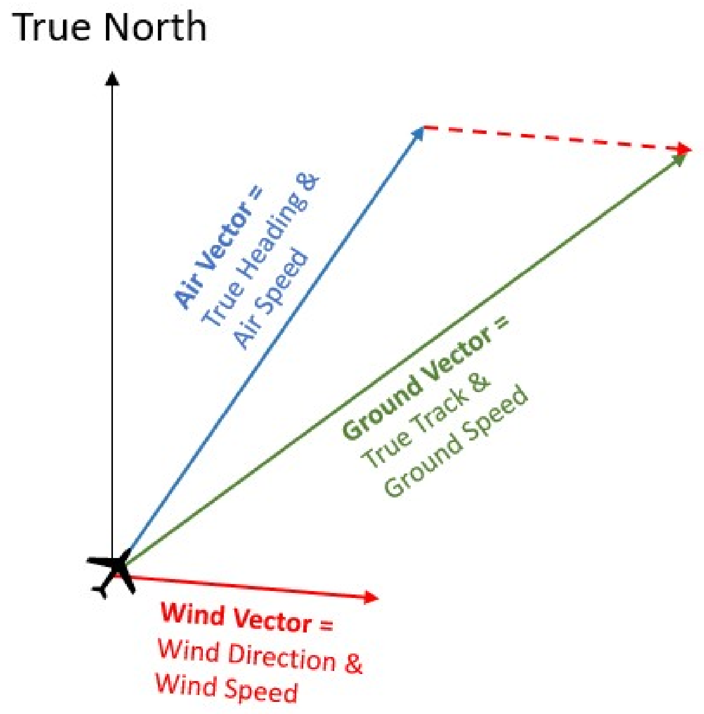

Figure 42: Wind Triangle: Ground Vector = Air Vector + Wind Vector

In this figure, the terms "air speed" and "ground speed" can also be replaced by "air distance" and "ground distance", when considering a certain flight time, which is equal for both. As a result, the distances travelled through the air (air distance) can be much longer or shorter than the distances travelled relative to the ground (ground distance) caused by the headwind- or tailwind components of the wind vector. In contrast to flight planning and flight management purposes, the distance travelled through the air (air distance) is the relevant term that is directly linked to fuel consumption and emissions. Consequently, the air distance should be kept as short as possible to maximize the fuel and emissions efficiency.

To avoid negative effects and to use positive effects of wind direction and speed, the flight trajectory should be planned and executed as much as possible in areas or altitudes with lowest headwind components, ideally with maximum tailwind components, in a trade-off relation with extra flight distance that must be flown to reach the areas with better wind conditions (e.g. by flying eastbound within the Jetstream needs a detour to reach it at first); and deviation from the optimum cruising level. Currently this can only be done on a strategic or pre-tactical level, as wind forecasts are currently mainly considered in the planning phase of the flight route. Currently, the possibilities of in-flight changes of the planned route due to a changed wind situation are very limited, and offer potential for improvements [Schrauf 2020].

4.2.2. AIR DENSITY

Another factor influencing the fuel efficiency, and therefore also the emissions produced by a flight, is the density of the surrounding air. Air density has a significant influence on the efficiency of airplane engines; influences also lift and drag, and consequently also the thrust level needed to produce enough lift and to overcome drag.

Air density is driven by the air pressure, the temperature and the exact composition of the air, according to the well-known gas equation (see right side of the following formula):

$$p.V = \frac{m}{m_M}.R.T \Leftrightarrow \rho = \frac{m}{V} = \frac{p.m_M}{R.T}$$

where p is the air pressure, V is a volume of air, m is the mass of this volume of air, ρ is the density and T is the temperature. The constant values are R= $8{,}31\frac{J}{mol*K}$, and $m_M = 29\ \frac{g}{mol}$ as molar mass of air.

Temperature and air pressure are on one hand determined again by the weather, and on the other hand by the level an airplane is flying at. A reduced temperature increases air density; a reduced pressure decreases it. Relative humidity decreases the molar mass of air and therefore also reduces air density

As a result, there is a time-dependent optimum level for every airplane with the lowest amount of fuel burned and lowest emissions. This optimum level also depends on the current weather situation. Consequently, the current optimum level should be exactly known and continuously updated for a specific flight, and should be considered as much as possible to maximize the fuel and emissions efficiency.

4.2.3. HAZARDS

The nature can also produce a lot of temporary or variable hazards to aviation, that cause the necessity to circumnavigate specific areas or to avoid specific levels. If the optimum trajectory leads through a hazard area, or if the optimum level lies in a level band with natural hazards, the specific flight cannot be conducted with these optimum conditions (route / level). This increases fuel consumption and consequently, emissions.

The impact on ATM is a reduced ATC capacity and / or airport capacity due to airspace / runway closures.

Phenomena which may lead to hazardous areas / levels, or to a restricted usability of ground infrastructure, are:

- Severe turbulences,
- Severe icing / ice crystal icing,
- Lightning,
- Hailstones,
- Volcanic Ash, heavy dust, sandstorm
- Very strong winds, and the objects that could be carried by that,
- Solar disturbances of satellite navigation / communication / data links,
- Birds, especially in concentrations,
- Slippery precipitation on runways.

Some of these phenomena are occurring at the same time in a thunderstorm or hurricane / typhoon.

The only options to counteract these effects are:

1) Reduce the vulnerability of aircraft against these hazards or
2) Circumnavigate / Avoid while reducing the deviations from the optimum trajectory to a minimum; or consider a completely new routing, offering the next best trajectory.

The latter one must be based on accurate information about the current and future hazard situation along the possible routes. Current weather forecasts do not provide the needed accuracy. This often leads to avoidance maneuvers on short notice, which are always worse than the best-case trajectory that would be theoretically possible when all circumstances would precisely have been predicted and considered beforehand.

As a result, the potential for trajectory optimization offered here depends on more accurate forecasts on the one hand, and on the other hand on precise and effective avoidance maneuvers that are initiated a longer time in advance before encountering the hazard.

4.3. ARTIFICIAL INFLUENCING FACTORS

This section summarizes all artificial factors that influence a flight trajectory, and consequently, its fuel efficiency and emissions. These factors are man-made and can therefore theoretically be controlled or changed in principle. However, any change to the existing situation / ruleset is often a long process, requiring conversation, discussions and negotiations between involved stakeholders, parties, authorities and countries. The GreAT project wants to contribute here to provide a scientific basis for these discussions - a guideline what should be changed, and a perspective what can be achieved when following these proposed changes.

4.3.1. POLITICAL / GOVERNMENTAL CIRCUMSTANCES

In this section, all circumstances and measures, that are related to political circumstances and that have an influence on fuel and emissions efficiency are discussed.

Political circumstances lead to measures that are issued in the form of constraints on the aircraft track and/or the level to be flown. Those constraints can range from level restrictions (e.g. a minimum level above a conflict area), a route to be flown within a certain airspace, up to complete prohibition of overflying a whole country. These constraints most probably lead to a significant deviation from the optimum route or level, and therefore to an increase in fuel consumption and emissions. In the worst case, it leads to a flight returning to its origin or diverting to another destination.

Depending on the size of the area affected by the constraint, the deviation can be very big, with an enormous increase in fuel consumption and emissions. In detail, the following circumstances are known in reality:

A. **War areas that need to be circumnavigated:** There are many areas with political instability. Airlines cannot overfly these countries based on Safety & Security instructions published by their own country or airline safety department. For the same safety and security reasons, the only optimization potential that is offered is to consider these constraints already in the planning phase of the flight and to find the next best routing. Being generally known at advance and for a long time, this constraint is already considered in most cases.

B. **Temporary Restrictions due to state visits or other governmental activities:** Temporary restricted areas can be initiated by local authorities. These can be in force during official state visits or large military exercises. Depending on the needed degree of security, there could be optimization potential for the situations where the restricted area is active but actually not yet or no longer needed. The European FUA concept is already a suitable measure to exploit this potential to a certain extent.

C. **Permanent Military areas:** Fixed military areas are basically closed for civilian airspace users. There could be optimization potential for the situations where the area is active but actually not yet or no longer needed. The European FUA concept is already a suitable measure to exploit this potential to a certain extent. For example, in some cases these areas (or part of the area) are opened for civilian airspace users. These can be conditional routes (CDRs) or complete areas. In Europe this is coordinated via Eurocontrol.

D. **Economic Sanctions:** Airlines will not overfly nations where economic sanctions are in place. In that case, it is not allowed for Airlines to pay ATC charges to these nations. Optimization potential is seen in a reformation of common practices if, when and how ATC charges have to be paid, preferably towards an international standard.

4.3.2. ECONOMIC CIRCUMSTANCES

In this section, all circumstances and measures, that are related to economic circumstances, and that have an influence on fuel and emission efficiency, are discussed. Airlines as companies, that are in competition against each other, until today have the primary goal of maximizing the profit. One contributing measure to achieve this goal is to minimize costs. In some cases, a more fuel consuming (and therefore more emissions producing) flight operation is cheaper than the same flight but optimized to lowest emissions. In these cases, the less expensive option is still preferred but at the costs of the environment. Examples for these cases are:

A. **Saving ATC charges:** ATC charges can influence route choices of airlines. Airlines use flight plan systems that take ATC charges into account. In some cases, airlines avoid overflying the countries with high charges and decide upon detours which might be more cost-efficient but certainly less environment friendly. The extra miles flown obviously entail additional CO_2 emissions. Optimization potential is seen in a reformation of the common practices, if, when and how ATC charges have to be paid. International standardization of these practices might also help to avoid this effect.

B. **Minimum cost index:** Airlines try to choose their level and speed to reduce the overall costs of the flight, which not necessarily corresponds to the lowest fuel consumption and emissions. For example, a higher (but more fuel consuming) cruise speed can be chosen to catch up some delay and to avoid indirect costs this delay would cause.

4.3.3. ATM RELATED FACTORS

In this section, all circumstances and measures, that are related to ATM and that have an influence on fuel and emissions efficiency are discussed.

ATM related measures are issued in the form of constraints on the aircraft track, the level or the speed to be flown. These constraints may lead to a deviation from the optimum route, level or speed and therefore to an increase in fuel consumption and emissions.

This increase caused by ATM measures is a composition of the additional fuel consumption and emissions caused by the maneuver that is necessary to comply with the constraints, the portion of the flight under these constraints, and the maneuver that is executed to return to the optimum route, level or speed as soon as the constraints are cancelled (see Figure 43).

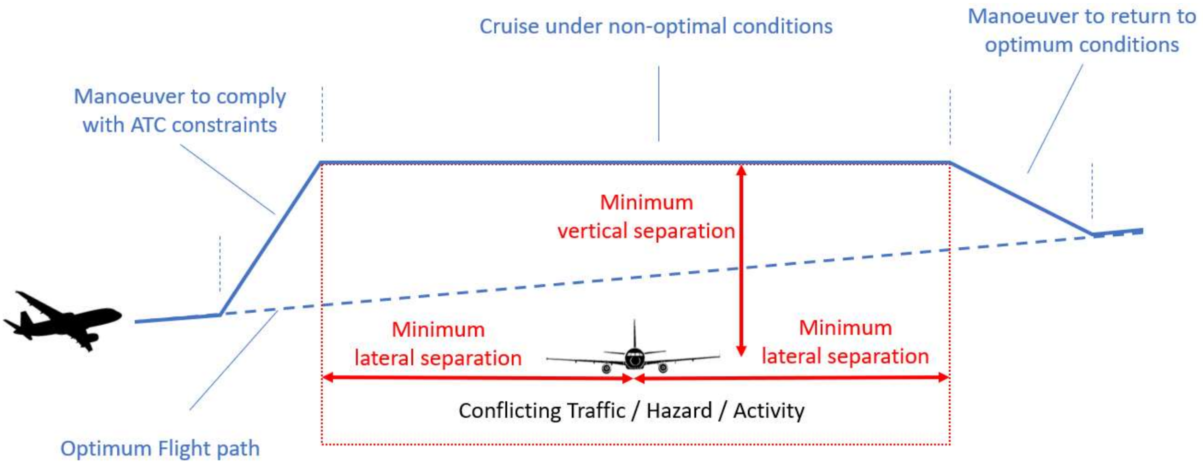

Figure 43: increased fuel consumption and emissions caused by ATM related measures

Those track, level or speed constraints coming from ATM measures can be caused by various reasons:

A. **Strategic / pre-tactical measures** to ensure safe separation between several aircraft or between an aircraft and a hazard area, and to support an orderly flow of air traffic:
    a. airspace management, conducted to provide a basic order of air traffic, to exclude danger areas or areas with special activities,
    b. level allocation and semi-circular cruising level system, to provide a basic vertical order between flights and to strategically reduce the risk of level conflicts,
    c. ATS route structure and approach / departure routes, to provide a basic lateral order between flights and to strategically reduce the risk of lateral conflicts,
    d. temporary closure of routes, airspaces and airports due to hazards.

B. **Tactical measures** to ensure a safe separation between several aircraft or between an aircraft and a hazard area, and to ensure an orderly flow of air traffic:
    a. heading changes, speed changes, shortcuts or re-routings to solve a conflict laterally,
    b. Climbs / descents to solve a conflict vertically.

C. **Sequencing**: heading changes, delay maneuvers or shortcuts to sequence the flights when they are entering the same route / arrive at the same point in the same level.

D. **Level of ATC service provision**: heading changes, delaying / holding flights or re-routings due to
    a. available CNS equipment and current failures / outages,

   b. ATC sector capacity and air traffic flow management (due to overdemand, traffic complexity or capacity shortages, caused by weather, airspace closures or ATC staff issues / strikes),
   c. airspace classification and the related service provision (the extreme case where constraints that impact the flight efficiency are caused by a low level of ATC service provision are surely the oceanic regions)

E. **Noise abatement**: Detours to avoid overflying populated areas, especially in lower levels.

The following measures can be taken to exploit optimization potential in terms of fuel consumption and emissions:

A. **Strategic / Pre-Tactical Measures**:

   Move away from strict and static airspace structures, level allocation schemes and fixed air traffic route networks towards maximum flexibility and freedom of the airspace user, and towards a targeted and specific use of these measures only when they are actually needed tactically. The optimization potential to reduce fuel consumption and emissions is estimated to be medium in Europe, Australia and the North America, as flexible use of airspace is already a basic ATM paradigm here. However, the level allocation procedures still produce a significant deviation from the optimum level, leading to a significant amount of extra fuel burned and emissions exhausted. In other parts of the world, especially those parts without flexible airspace use concepts, the optimization potential is estimated to be high.

B. **Tactical Measures**:

   1) Update the separation minima according to newest navigation and surveillance accuracy and communication performance, as well as according to the real safety needs. One first example in this direction is RECAT in case of wake turbulence avoidance. The basic idea is: the smaller the minimum safety distance, the smaller the measure required for de-conflicting, the lower the deviation from the optimum flight profile and the lower the additional needed fuel and emissions production. The optimization potential to reduce fuel consumption and emissions is estimated to be low to medium, depending on the amount of traffic.

   2) Apply those measures a longer time in advance, which can lead to less extra miles / a prevention of necessary vertical de-conflicting measures. This points towards trajectory-based operations. However, as air traffic is always experiencing smaller or larger unforeseen disturbances, those early measures (including TBO) can become inaccurate and even inappropriate with decreasing predictability. The optimization potential to reduce fuel consumption and emissions is estimated to be low, as the effect of disturbances and the lack of traffic predictability prevent a wide and early application today.

   3) Further, the amount of fuel to be burned to execute those measures also depends on the aircraft type, aircraft weight, and the concrete deviation from the optimum flight path. Therefore, it should be considered being more selective when issuing tactical measures, considering those factors. The optimization potential to reduce fuel consumption and emissions is estimated to be low, but not yet investigated.

C. **Sequencing**:

Use planning algorithms (e.g. for AMAN) to be able to establish the most beneficial sequence with the minimum of measures. The optimization potential to reduce fuel consumption and emissions is estimated to be low, because planning and sequencing tools are becoming more and more a standard and have been continuously optimized in today’s ATM.

D. **Level of ATC service provision**:

1) Use new CNS technology, especially ADS-B over satellite or data link to improve the provision of ATC service. This is either for contingency in case of reduced conventional CNS availability, or in regions where the provision of full ATC services has not yet been possible, e.g. oceanic regions. The optimization potential to reduce fuel consumption and emissions is estimated to be high, because large safety distances must be applied in such areas today, with only few options to deviate from the filed route.

2) Take measures to maximize ATC capacity, to maintain it and to make it more resilient. The optimization potential to reduce fuel consumption and emissions is estimated to be medium, as ATC staffing issues are usual daily reasons for a lack of ATC capacity.

3) Increase the accuracy of air traffic flow management, to avoid unnecessary delays on ground and in the air. The optimization potential to reduce fuel consumption and emissions is estimated to be medium, as current European ATFCM has an accuracy of about 15 min.

4) Harmonize and standardize airspace structures, as it is targeted for example by the SES initiative. The optimization potential to reduce fuel consumption and emissions is estimated to be medium, especially in Europe with its still very fragmented airspace. However, the optimization potential is estimated to be low in more harmonized airspaces, like in China.

E. **Noise abatement**:

In the recent years, noise abatement has been an important point to be considered, as it has direct influence on the acceptance of the public for commercial air traffic in general. However, noise abatement procedures are often complementary to the goal of reducing emissions and fuel consumption, and prescribe a lot of extra miles and detours to be flown especially near airports. With raising importance of climate protection, it should be considered to revise today’s noise abatement practices again, allowing more freedom to airplane routes. The optimization potential to reduce fuel consumption and emissions is estimated to be high, as noise abatement procedures are mainly applied in lower airspace during climbout of commercial airliners. In this flight phase and heights, the aircraft are far away from their optimum cruising level and speed, which is why extra miles should be especially avoided here.

4.4. GREENER AIR TRAFFIC CONCEPT ELEMENTS

Within this section, several concept elements are derived to improve environmental sustainability. This section uses the analysis conducted in section 4.1 to 4.3 as an input and starting point, and tries to transform the flight-centered measures to maximize single flight efficiency into principles for a greener air traffic management.

Following the performance-based paradigm of modern air traffic, these elements are described as functions and abilities of a more sustainable ATM system, instead of a concrete technology to be implemented. Note that all these elements are focusing on a change of the aircraft trajectory – laterally, vertically and in terms of speed. They do not include any changes to aircraft systems like engines, flaps or gear.

In the following section 4.4.1, a short consideration of interdependencies between different Key Performance Areas (KPA) is done. Sections 4.4.4 to 4.4.6 list and shortly describe identified concept elements, which contain the basic ideas for the further work in GreAT, especially in MWP3, MWP4, MWP5 and MWP6. The idea is to create a list of 'building blocks' which can be used to assemble detailed and more practical ATM concepts that focus on reducing environmental impact. This will be done for three examples in section 4.5, which at the same time can be understood as an outlook to the activities foreseen in MWP3 and MWP4.

4.4.1. INTERDEPENDENCIES OF KEY PERFORMANCE AREAS AND INDICATORS

As already mentioned in section 3.1.3, it is impossible to maximize all performance indicators and areas at the same time, because they are interdependent and influence each other. One example for this is that there is currently no possibility to maximize flexibility while keeping predictability also at a maximum, as explained in section 3.1.3.

It can further be expected that also the KPA 'Environment' will have relations to other KPAs:

- **KPA 'Environment' against KPA 'Capacity':** Especially in the TMA of large hub airports, the main goal in the past was to achieve a maximum runway throughput by reducing the separation between arriving aircraft to a safe minimum. This is achieved by starting to slow down arriving aircraft already on downwind prior base turn, when they are still during descent, to be able to turn them in more precisely. Slowing down aircraft early during descent is an inefficient maneuver for aircraft and might sometimes make the use of air brakes necessary. However, for the benefit of capacity, this is nevertheless often done. Improving the efficiency here could therefore lead to a decrease in capacity, and keeping this impact as low as possible is one goal for the concept development in GreAT.

- **KPA 'Environment' against KPAs (Flight) 'Efficiency', 'Predictability and Punctuality':** Flight Efficiency can be simplified as 'how much time did it take to fly a defined payload from one point to another'. To keep schedules and consequently improve the Punctuality, it might be necessary to fly faster as usual and thereby to increase flight efficiency. However, this has an impact on fuel consumption and emissions. Optimizing towards a minimum environmental impact could in turn lead to a new cause of delays in schedule, especially when the optimum cruise speed at the day of operation corresponds to a lower ground speed than expected.

- **Greenhouse gas emissions against noise abatement:** Noise abatement has been a prominent topic in the last decades, and has led to various additional detours around populated areas, which are understandable, but which also produce additional fuel consumption and emissions. Again, a trade-off situation occurs, which should be opened for discussion when reduced emissions play a more important role in the future.

4.4.2. INTERDEPENDENCIES BETWEEN DIFFERENT FOCUS AREAS

In the following sections, greener ATM concept elements are categorized as following:

1) General Principles

2) Ground Operations
3) TMA Operations
4) En-route Operations

There are known interdependencies between the focus areas 'Ground Operations', 'TMA Operations' and 'En-route Operations'. For example, using short cuts during en-route flight could lead to the situation that flights arrive too early in the destination TMA and cannot land due to traffic congestion, and they have to be delayed there again. Delaying flights in low altitude consumes more fuel and produces more emissions than delaying them at cruising altitude. As a result, saving fuel and emissions in one focus area could lead to an increase in another focus area, reducing the overall benefit again. Therefore, all concept elements listed below should be checked individually for those kinds of side effects when combining them to a full concept.

As an additional conclusion, overall flying efficiency needs a coordinated approach, which is best achieved by a study per city pair flown, taking into account the airport layout, terrain surrounding the airport, noise sensitivity and other relevant circumstances.

4.4.3. GENERAL PRINCIPLES

In this section, the concept elements that are applicable to all flight phases and all focus areas (Ground, TMA, En-route) are described.

4.4.3.1 LOWEST IMPACT OF DEVIATIONS

Here the starting point is the optimum trajectory for every single flight, which represents the best-case scenario described in section 4.1. ATM measures like de-conflicting, separation provision and flow management require deviations from these optimum trajectories to a certain extent [Rataj 2017].

These deviations cause an increased fuel consumption and increased emissions, but not in the same way for all flights. A detour for example may cause slightly increased fuel consumption and slightly increased emissions for a small business jet aircraft, but the same detour may consume hundreds of kilograms of fuel and may produce thousands of kilograms of emissions for a large long-haul passenger aircraft.

When optimizing towards minimum fuel consumption and minimum emissions, the logical consequence is that, there should be a change in the priority of service, away from a 'first come first served' principle. A flight specific energy performance indicator should be calculated for every flight instead, and used to decide which flight should be prioritized and stay closer to the optimum trajectory, and which flight could rather take a detour with lower overall environmental impact.

Here, the challenge for ATM would be to precisely identify and calculate this indicator, and have all information available for it. Further, it must be considered in strategic, pre-tactical and tactical planning algorithms and decision-making processes for all kinds of traffic guidance and flow management on local and global level.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic as a whole is expected to be medium to high, as priority of service based on environmental aspects is absolutely not yet considered in today's air traffic, and those kinds of de-conflicting actions are daily ATM business around the globe.

This change will contribute to greener ATM at the costs of access and equity KPA as well as the predictability and punctuality KPA, as light-weight or very fuel-efficient aircraft would be 'discriminated', and have to absorb the majority of delays. Therefore, an additional mechanism might be needed to compensate these economic disadvantages and to keep the interest of airspace users to buy and operate fuel-efficient aircraft types at a high level.

4.4.4. GROUND OPERATIONS

In this section, the concept elements that are applicable to operations on the aerodrome surface are described. The goal is to list all thinkable measures – even with a small effect on fuel burn and emissions - that can be part of an aerodrome operating concept, regardless of their current practicability and the effort needed to bring them into operation as this effort may be lower at some point in the future.

4.4.4.1 CONTINUOUS TAXI OPERATIONS

Although the trajectory for surface movements cannot be freely chosen because they are bound to the ground infrastructure and the pre-defined ground circulation rules, the variable ‘speed profile’ can be optimized.

As described in section 4.1 to 4.3, the main factors for additional fuel burn are avoidable braking and acceleration phases. The only unavoidable braking maneuvers are during landing run, as well as short before taxiway intersections to avoid a taxiway excursion during the turn, and when reaching the parking positions. Avoidable braking (and consequently re-acceleration) maneuvers are all maneuvers that are necessary because of a high taxi speed (e.g. to comply with a CTOT when taxiing out late), and for traffic de-conflicting and ATM (e.g. intersecting taxiways used by other traffic, waiting for line-up at the runway holding point, waiting for handoff to the next ground frequency).

When optimizing towards minimum fuel consumption and emissions, those avoidable braking actions should be prevented as much as possible.

The following challenges to the ATM system can be derived, e.g.:

- Trying to commence the taxi-out movement at a time when it is ensured that no braking maneuvers or at least no stops until take-off run (rolling takeoff) are necessary, which needs a very accurate prediction of the taxi trajectory before leaving the gate, and a synchronization with arrivals and departures.
- Taxi-in movements should be handled with “priority” by planning algorithms, as they should not brake to wait for the best opportunity to avoid other braking maneuvers later.
- Aircraft should be able to follow these 4D ground trajectories precisely.

Possible resulting measures could be for example:

- EL 1: On-board system support for taxi movements to ensure an accurate execution of the trajectory (similar to an autopilot).
- EL 2: The use of advanced integrated planning and scheduling tools, including at least arrival and surface management as well as runway scheduling / departure management to avoid holding times at the runway or queueing at the holding point. A-CDM, which is exercised already on various airports around the world, is a useful measure of this kind. To calculate reliable departure sequences, DMAN needs access to accurate information about the status of individual departing flights and airport resources from different systems. The airport collaborative decision-making (A-CDM) platform enable to support this information exchange. Interaction of AMAN and DMAN provides high benefit during mixed mode RWY operations. DMAN calculates the target take-off time (TTOT) into the gaps of arriving queue set by AMAN, reducing the waiting time at the runway holding points. Based on this DMAN TTOT, advanced AMAN may give an advice to approach controllers to modify the spacing on final approach leg to provide enough time to depart between two arrivals.
- EL 3: In case of occupied gates (i.e. arriving flights wait with running engines until the assigned gate has been cleared), a solution could be to shut down the engines

on the taxiway and to make a 'tow-in' maneuver as reverse procedure to a 'push-back' maneuver.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be low, as taxi processes are by far not as energy-demanding as airborne maneuvers. Just considering the fuel consumption during taxi process, the potential to reduce fuel burn for the taxi movement is expected to be medium, as especially on large and complex hub airports where several stops are necessary for various reasons, e.g. traffic de-conflicting, frequency changes, runway crossings etc.

This change could contribute to greener ATM at the costs of capacity KPA (more precisely: aerodrome capacity), as predicted ground trajectories will still have uncertainties. Those uncertainties might cause the situation that for example departing aircraft have not yet reached the runway at the time when they are scheduled for take-off. To achieve maximum runway throughput, the demand ("pressure") on the runway must be kept high, which might not be possible in the same way when following this procedure.

This concept element answers 4.1.1 A and B.

4.4.4.2 SHORTEST POSSIBLE TAXI ROUTE

Another possibility to optimize the emissions of taxi movements are to try to shorten the taxi distance itself, as less energy is then needed to conduct the whole movement. As the taxi movement is always strongly depending on the existing and usable ground infrastructure and the defined circulation rules, this approach directly leads to the general design of the taxiway system and the location of the runways used for take-off and landing. This possibility must therefore be understood as a long-term measure to optimize taxi movements and as guiding principle for future airport construction works. In short time horizons the aerodrome layout must be considered as given and unchangeable.

The challenges are to:

- Shorten the taxi route from the end of the landing roll to the gate,
- Shorten the taxi route from the gate to the take-off position on the runway at the same time.

In combination with point 4.4.4.1 and to reduce the need for repeated braking and acceleration again, the following additional conditions should be fulfilled as much as possible:

- Avoid crossing of other main taxiways and active runways at the same time,
- Avoid multiple frequency changes during taxi-in / taxi-out,
- Avoid sharp turns and preferably use slight turns

Possible resulting measures could be for example:

- EL 4: Use parallel runways (almost) in segregated mode (one runway for arrivals, one runway for departures); and place the parking area at the end of the landing runway and at the same time at the beginning of the runway used for departures
- EL 5: Use intersection take-off as a standard procedure whenever possible if the taxi route is shortened this way as shown in (Figure 36)
- EL 6: Late touchdown to finish the deceleration during landing roll at the desired runway exit without increasing runway occupancy times as also shown in (Figure 36). This could be achieved by introducing more flexible approach procedures with a variable touchdown point, which are basically enabled by new RNP procedures.

One example for a European airport where these principles can well be followed is Budapest (LHBP) (see Figure 44).

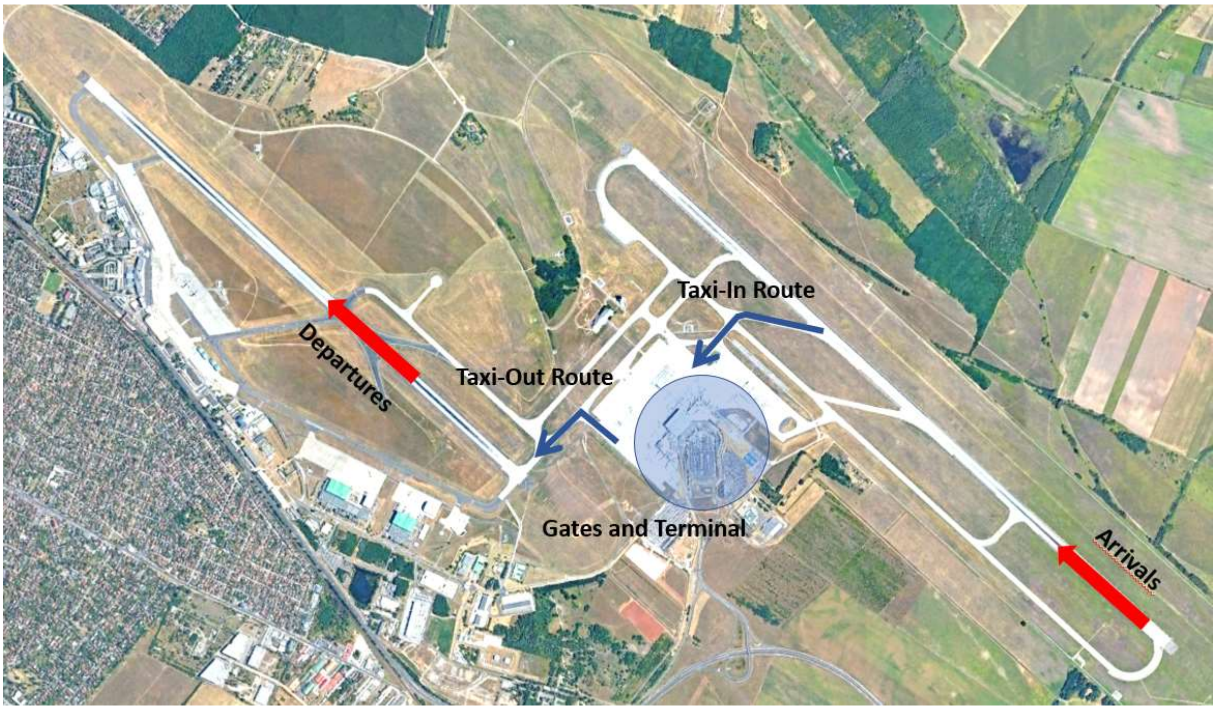

Figure 44: Short taxi routes at LHBP airport

Another example from Europe is the airport of Madrid-Barajas (LEMD) (see Figure 45).

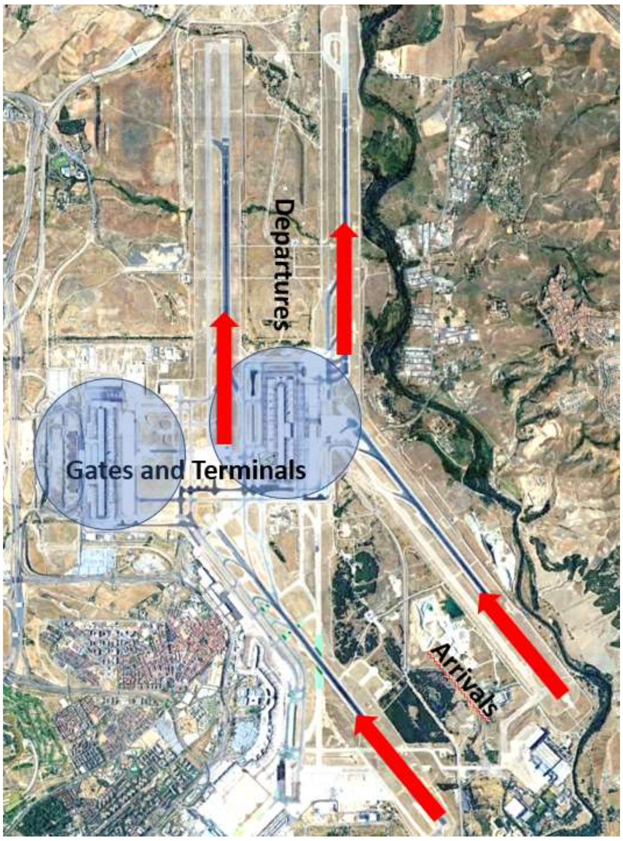

Figure 45: Short taxi routes at LEMD airport

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be low, as taxi processes are by far not as energy-demanding as airborne maneuvers. Just considering the fuel consumption during taxi process, the potential to reduce fuel burn for the taxi movement is expected to be high, as the length of the taxi route is significantly depending on the aerodrome layout, and can differ in a wide range. However, on very large hub airports, the taxi time can take a considerable part of the total time being off-block, especially for short-haul flights. Therefore, there should in any case be a strong economic interest to shorten taxi times.

This change could contribute to greener ATM at the costs of capacity KPA, as available runway capacity might not be fully usable. This is because a segregated use of runways might not support the highest possible aerodrome throughput. Further, also the environment KPA might be affected, as noise abatement might be an issue.

This concept element answers 4.1.1D.

4.4.4.3 ADAPTED PRE-/POST-FLIGHT ACTIVITIES

To further minimize the emissions of ground movements, the amount of activities that are done with running engines, but without performing any taxi movements, should be reduced to the absolute minimum. In turn, all pre-/post-flight activities, like for example system tests prior departure, or system shut-down procedures after landing, should either be done during the taxi movement, or before engine start / after engine shutdown.

The challenge is to:

- Ensure a completion of all these activities when the aircraft reaches the runway holding point in case of departures.

Possible resulting measures could be for example:

- EL 7: Adapt the procedures whenever possible, e.g. do the flight control checks during taxi out.
- EL 8: Consider this principle for future aircraft designs and operation manuals.
- EL 9: Consider the time needed to perform these activities in ground traffic planning systems when they are done during the taxi movement.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be low, as taxi processes are by far not as energy-demanding as airborne maneuvers. Just considering the fuel consumption during taxi process, the potential to reduce fuel burn for the taxi movement is expected to be low to medium, depending on the amount of pre- / post-flight activities usually performed with running engines while holding a position.

This change could contribute to greener ATM at the costs of capacity KPA (more precisely: aerodrome capacity), especially in case these activities cannot be completed during the taxi process, which would lead to additional holding time at the runway with a possible queueing effect on the other traffic.

This concept element answers 4.1.1A.

4.4.4.4 PROPULSION DURING TAXI

Another option to further reduce fuel burn and emissions are to decrease the available aircraft propulsion to the required minimum, provided that a basic level of fuel consumption would be burned just to keep full power available.

The challenges are to:

- Ensure that always enough power is available to conduct the taxi movement, considering turns, runway crossings or the taxiway slope,

- But avoiding to hold too much power ready which is not needed at the same time.

Possible resulting measures could be for example:

- EL 10: Individual engine start-up at the latest possible time (e.g. single engine taxi). Note that modern turbine engines need 2-3 minutes for thermal engine stabilization during start-up
- EL 11: Use of alternative propulsion techniques supporting the taxi movement, e.g. electric taxi (but out of scope of GreAT).
- EL 12: Use of external power supply as much as possible to reduce the need for power generation on board of the aircraft (but out of scope of GreAT),
- EL 13: Consider these changes, especially the possibility of single engine start-up and single engine taxi, in future aircraft designs and operation manuals,
- EL 14: Consider the restrictions on aircraft maneuverability in ground traffic planning systems, e.g. maximum speed or preferred direction of turns in case of asymmetric propulsion.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be low, as taxi processes are by far not as energy-demanding as airborne maneuvers. Just considering the fuel consumption during the taxi process, the potential to reduce fuel burn for the taxi movement is expected to be high, as modern engines already burn fuel in idle thrust, just to keep the engine running. Actually, only one single engine can produce more power than needed for taxi movements.

This change could contribute to greener ATM at the costs of capacity KPA, especially when engine problems are detected during taxi-out or start-up, forcing the aircraft to return to the gate. Moreover, such movements contribute to the increase of the overall ground traffic volume considering the additional vehicles eventually needed to support them which may cause additional workload for the ATC controller, and in some cases with an impact on ATC capacity.

This concept element answers 4.1.1E.

4.4.4.5 CONSIDERATION OF NATURAL PHENOMENA FOR TAXI MOVEMENTS

Although the effect of this element is expected to be very small to negligible, natural phenomena theoretically have also an effect on taxi movements, like wind and ground slope. On ground, the headwind has the same effect of increasing fuel burn than in the air, but much weaker. The consequence would be to avoid headwind for all taxi movements whenever possible, and / or to reduce the drag of the airplane as much as possible; while the opposite is done for tailwind situations. Another example would be the taxiway slope, enabling the airplane in some circumstances to taxi “downhill” with less engine power and consequently, with less fuel consumption and emissions.

The challenges are to:

- Avoid negative effects of natural phenomena, or at least reduce their effect on the aircraft.
- Make use of positive effects of natural phenomena, or at least maximize their effect.

Possible resulting measures could be for example:

- EL 15: Reduce drag of the airplane in headwind situations by retracting flaps / airbrakes during taxi as early / long as possible.
- EL 16: Increase drag of the airplane in tailwind situations by extending flaps and airbrakes during taxi as early / long as possible.
- EL 17: In case of an aerodrome in mountainous regions, the aircraft stands should preferably be located higher than the runway, to make use of the gravity for the taxi-out process when the airplane is fully refueled and heavy, and to limit the

opposite effect for the taxi-in process when the airplane is lighter due to the fuel burned in flight.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be very low, as taxi processes are by far not as energy-demanding as airborne maneuvers. Just considering the fuel consumption during taxi process, the potential to reduce fuel burn for the taxi movement is expected to be low, but detailed studies are not yet available.

No impact on other KPAs is expected.

This concept element answers 4.1.1B and E.

4.4.4.6 NO THRUST REVERSE DURING LANDING ROLL

Emissions can also be reduced by choosing an appropriate method for deceleration during landing roll.

The challenges are to:

- Ensure a deceleration within the available landing roll especially on short runways,
- Keep the runway occupancy time at a minimum on busy airports,
- Avoid other safety issues such as hot brakes.

Possible resulting measures could be for example:

- EL 18: The use of reverse thrust should be avoided as much as possible (e.g. by using wheel brakes only)
- EL 19: Idle reverse can be selected to change the flow of air in the engine, which increases drag but without increasing power and fuel consumption,
- EL 20: Consider these changes in future aircraft designs and operation manuals.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be low, as the landing roll is only a very short phase of the whole flight. Just considering the fuel consumption during ground movements, the potential to reduce fuel burn for the ground movement is expected to be high, as the thrust level during the use of thrust reversers is much higher than during taxi.

This change could contribute to greener ATM at the costs of capacity KPA, in case the runway occupancy time is negatively affected.

This concept element answers 4.1.1C.

4.4.5. TMA OPERATIONS

In this section, the concept elements that are applicable to operations in the airport TMA / aerodrome vicinity are described.

4.4.5.1 FREE ROUTE IN TMA

The TMA should basically allow a free routing for all flights, in order to support an early turn towards the destination as described in 4.1.2, as well as a direct flight to the beginning of the final approach as described in 4.1.4.

The challenges are to:

- Guarantee maintaining separation minima between succeeding departures, succeeding arrivals and between both all the time,
- Minimize the noise pollution,
- To guarantee obstacle clearance especially in mountainous terrain.

Possible resulting measures are to:

- EL 21: Move away from separated routes / airspaces which are exclusively allocated to arrivals / departures whenever possible,
- EL 22: Reduce the need to overfly or make detours to avoid certain points / areas as much as possible (e.g. for noise abatement)
- EL 23: Use automated planning tools to support air traffic controllers, like coupled arrival-departure managers, to ease separation provision and sequencing without a fix route structure,
- EL 24: Use as a future goal 4D trajectory-based operations which is applied locally around the airport,
- EL 25: Use coordination supporting systems whenever several controllers are responsible for guiding arrivals and departures in different parts of the TMA.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be high, as significant detours are currently flown in a TMA due to noise abatement, and to establish and guarantee separation minima.

This change could contribute to greener ATM at the costs of airspace and ATC capacity, as traffic complexity is increased. Also, even with tool support, it may lead to an increased controller workload. In addition, these solutions could have an impact on the environment KPA (noise). Nevertheless, by avoiding detours and longer routes, these measurements could improve the punctuality and costs KPI.

This concept element answers 4.1.2D and 4.1.4A and B.

4.4.5.2 CONTINUOUS DESCENT OPERATIONS

It is well-known that continuous descent operations have the potential to save fuel and emissions. However, current ATC procedures and separation provision practices often cause short-term route changes, inefficient speed constraints or portions in level flight. All these practices make the application of continuous descent operations difficult to impossible, especially on large hub airports.

The challenges are to:

- Enable continuous descent approaches for the majority of arriving traffic,
- By early allocating the route to be flown for the continuous descent procedure, and maintaining it except for safety reasons,
- While guaranteeing minimum separation all the time with a high reliability and predictability,
- Even at large hub airports.

Possible resulting measures are to:

- EL 26: use strategical measures to support continuous descent approaches for the majority of traffic, e.g. by defining approach procedures that can be easily flown as continuous descent, and that strategically contribute already to separation provision in general (e.g. procedural separation, aircraft separation points or Y/T-Bar arrival routes),
- EL 27: use tactical measures to ease separation provision, like advanced and precise AMAN systems or other planning tools, considering for example actual performance parameters or information gained from air-ground exchange,
- EL 28: use coordination support tools to easily coordinate CDOs across different sectors,
- EL 29: up to 4D-trajectory based operations in the TMA.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be high, as especially at hub airports a lot of ATM related measures, like speed constraints and level restrictions are common practice today.

This change could contribute to greener ATM at the costs of TMA / aerodrome capacity, as current ATC procedures (including speed constraints and level restrictions) stem from an optimization towards a maximum safety, and a maximum runway throughput at the same time. It can be expected – when optimizing towards lowest emissions – that TMA and/or aerodrome capacity may be reduced. To keep this impact as low as possible is one objective to be considered for the concrete GreAT concepts.

This concept element answers 4.1.4B.

4.4.5.3 LATENCY TOLERANT DELAY ABSORBTION

Approach control and sequencing procedures can involve different principles, such as the principle of a transition-to-final or point-merge procedure (see Figure 46). The goal of both principles is to line up arriving aircraft on final while guaranteeing the required minimum separation, but without unnecessary additional spacing to fully use the available aerodrome capacity. However, as turns to final are instructed by a controller via voice communication, the instruction might not be fully understood, blocked out or the execution might be delayed. As the angle between the path used for delay absorption and the final track is 180°, the transition-to-final procedure is more vulnerable against these disturbances than the point merge, and might easily lead to inadequate spacing or a complete miss of the gap in the final approach stream, and in the end to an unnecessary long final approach with increased fuel consumption and emissions. As a conclusion, however the sequencing procedure is done exactly, a tolerance against these latencies is desired.

The challenges are to:

- Organize the sequencing and delay absorption method in a way that is less vulnerable against these disturbances and latency effects.

Possible resulting measures are to:

- EL 30: Start a reliable sequencing process as early as possible rather than concentrating it in a small portion of the airspace,
- EL 31: Use target times over (TTO) rather than delay absorption by path stretching,
- EL 32: When delay absorption by using path stretching is unavoidable, the heading distance between two probably succeeding aircraft should be as low as possible,
- EL 33: Introduce an alternate and more reliable communication method (e.g. L-band Digital Aeronautical Communications System (LDACS)) to reduce any disturbances or latencies.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be medium, as this situation occurs only in high-traffic situations at hub airports, but may lead on the other hand to a considerable amount of extra miles to be flown close to the aerodrome.

This change could contribute to greener ATM at the costs of flexibility, as short-term sequence changes are more difficult in case of an early arrival planning and sequencing.

This concept element answers 4.1.4A.

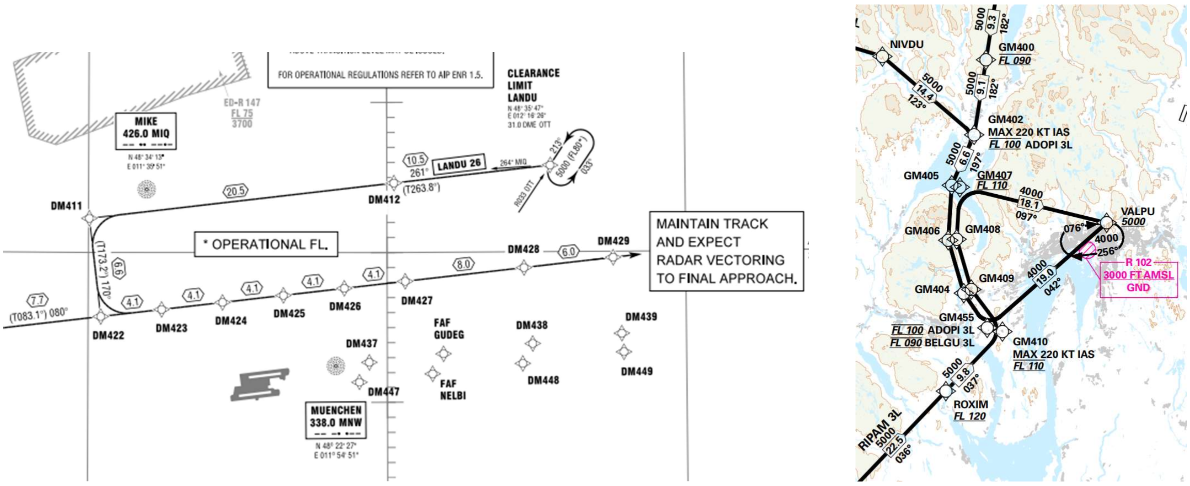

Figure 46: Transition-to-Final procedure in EDDM (left), and Point-Merge in ENGM (right)

4.4.5.4 INFINITELY VARIABLE AND LOW EMISSION DELAY ABSORBTION

To enable a more precise arrival sequencing in the TMA, but without unnecessary additional spacing, possibilities are needed to delay approaching aircraft by any desired amount of time with low additional ATCO workload. At the same time, this delay should be imposed in a reliable, precise and predictable way, as this would be required for a tight but nevertheless safe sequencing on final. To keep the controller workload low, it should be possible to absorb this delay through a low number of instructions (best case: just one instruction). In strong contrast to this, traditional standard holding patterns delay the aircraft by 4 minutes with one instruction, and it is usual that only complete patterns are flown. This leads to the constraint that the delay that can be imposed with standard holding patterns is always 4 min or a multiple thereof. This basic principle of infinitely variable delay absorption is already considered by modern procedures like the transition to final or Point-Merge, and it should in the same way be considered by future procedures.

The challenges are to:

- Choose a delay absorption method that provides the required precision and reliability,
- That in addition produces lowest possible emissions,
- Reduce the controller workload by keeping the number of instructions to implement the needed delay for one single flight at a minimum.

Possible resulting measures are to:

- EL 34: Move from standard holding patterns towards a more flexible path stretching to absorb delay,
- EL 35: Enable the aircraft to absorb delay within altitudes and speed ranges that produce low emissions. Note: Best holding altitude for modern jetliners is approximately 12000-18000ft MSL, without speed restrictions.
- EL 36: Use early speed advisories and target times over to support a precise delay absorption,
- EL 37: Use controller assistance tools to enable the controller to plan, predict and reliably implement the right measure at the right time (including ground-ground coordination tools)
- EL 38: up to trajectory-based operations applied locally in the TMA.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be low to medium, as there is already a trend towards absorbing delay with speed advisories and path stretching maneuvers other than standard holding patterns in current ATC practices. However, especially in very high traffic situations it might still be unavoidable to use holding patterns, as the handling of absorbing the delay with other means would be impossible for controllers. One example for this is the airport of London-Heathrow during peak times.

This change could contribute to greener ATM at the costs of ATC capacity, as nevertheless a certain increase of controller workload is to be expected. However, it is also expected that this increase can be compensated by tailoring the ATC workshare within the TMA to the new delay absorption method(s).

This concept element answers 4.1.4A.

4.4.5.5 LATE-MERGING-PRINCIPLE FOR ARRIVALS

Here the starting point is that different aircraft types may follow different speed profiles when they fly according to their calculated minimum fuel burn and minimum emissions trajectory. Nevertheless, they have to join the same route sooner or later when they intend to land on the same runway.

During single runway operations or high traffic situations, this can lead on one hand to the situation that a succeeding flight has to slow down out of the optimum speed to maintain separation to the preceding one. Or, on the other hand, this might make additional path stretching maneuvers necessary for the same reason. Both measures are increasing the fuel burn and emissions.

When optimizing towards minimum fuel consumption and emissions, the conclusion is that aircraft with different speed profiles should be guided to the same route (merged) at the latest possible time, which is at the latest short prior aircraft need to be stable on final approach. For feasibility reasons, a late merging could also take place short before commencing the final descent.

Here, the challenge for ATM would be:

- to precisely calculate 4D-trajectories that can be accurately flown by arriving aircraft.

Due to different aircraft equipment, this might not be the case, so:

- EL 39: a backup mechanism should be in place to handle and integrate less equipped aircrafts.
- EL 40: An automatic air-ground negotiation of this trajectory before entering the TMA is also seen as one needed enabler.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic as a whole is expected to be medium to high, as especially in high traffic situations almost all aircraft have to fly a path-stretching maneuver or a speed reduction for separation purposes during approach.

This change could contribute to greener ATM at the costs of access and equity KPA as well as the capacity KPA, as aircraft with a good and up to date equipment status could be prioritized. Nevertheless, this is only a temporary matter. In fact, the percentage of Data Link Services (DLS) compliant fleet with Implementing Rule (IR) (EU) N°310/2015 is expected to reach more than 84% by the end of 2020. Calculated trajectories might be exposed to uncertainties, which might lead to a slight loss in runway capacity as – with today’s possibilities – the spacing on final track can still better be kept to the needed separation minimum, and the ‘pressure’ on the runway can still better be kept at a high level with conventional guidance to exploit maximum runway capacity.

4.4.5.6 CONTINUOUS CLIMB OPERATIONS

The already known concept of continuous climb operations for departures is complementary to continuous descent operations, but with the difference that the route to be flown doesn’t necessarily have to be known well in advance to calculate the optimum climb rate and speed profile. This makes them more flexible than continuous descent operations, and more open to route changes on short notice.

The challenges are to:

- Guarantee separation minima, especially between descending arrivals and departures,
- Nevertheless, enable a broad application of continuous climb operations to a maximum number of departures.

Possible resulting measures are to:

- EL 41: Solve separation conflicts with heading changes rather than with level restrictions[56],
- EL 42: Consider the optimum climb profile in the departure sequence (high rate of climb is preferably preceding, low rate of climb is preferably the succeeding departure),
- EL 43: As mentioned in 4.4.5.1, use automated planning tools to support air traffic controllers, like coupled arrival-departure managers, use 4D trajectory-based operations which is applied locally around the airport, use coordination supporting systems whenever separate controllers are responsible for guiding arrivals and departures.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be high, as a significant part of the overall fuel consumed during a flight is caused by the departure phase.

This change could contribute to greener ATM at the costs of airspace and ATC capacity, as traffic complexity is increased. Also, even with tool support, it may lead to an increased controller workload.

This concept element answers 4.1.2E.

4.4.5.7 EARLY SPREADING OF DEPARTURES

This concept element can be considered as the opposite to the late merging principle. Similar to late merging, also the “early spreading” provides advantages for aircraft flying at different speeds, or rates of climb. It leads to the possibility to turn towards the destination and starting a continuous climb, while maintaining separation without extra miles or portions in level flight. This would increase fuel efficiency and reduce emissions. In contrast to late merging, the “early spreading” can be done not just laterally but also vertically, as the rate of climb in feet per nautical mile can differ significantly from aircraft type to aircraft type during the departure phase. The same applies to the flown speed.

The challenges are to:

- Gain / exchange detailed information about the current actual aircraft performance and climb rate during departure in advance, and to provide it to the controller / planning tools for consideration.
- Noise abatement.

Possible resulting measures are to:

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[56] This is not applicable in all cases depending on the aircraft type and payload.

- EL 44: Consider the lateral and vertical departure trajectory for the sequencing of departures.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be low to medium, as at least the lateral departure trajectory as well as the speed are already considered for departure sequencing, depending on the concrete airport. Further, it may compete with other factors to be considered for departure sequencing, such as wake turbulence separation. In addition, the possibilities of changing the departure sequence may be restricted due to the airport layout.

This change could contribute to greener ATM at the costs of access and equity, as aircraft with a better climb and acceleration performance might be advantaged and prioritized. However, apart from fuel and emissions efficiency, positive effects are also expected in terms of aircraft delay, runway throughput and aerodrome / airspace capacity.

This concept element answers 4.1.2C,D, E and F.

4.4.5.8 HIGHEST FREEDOM OF MOVEMENT WITH SHORTEST AIRSPACE BORDERS

The basic idea behind this concept is to keep the airspace boundaries as short as possible to reduce the need for coordination with neighbor airspaces. Airspace boundaries are at the same time possible positions where flights can enter or leave the considered airspace, therefore keeping them short reduces the traffic complexity. At the same time, the goal is to maximize the available airspace volume surrounded by these boundaries, to maximize the airspace capacity and the possibilities for a free movement and for lateral de-conflicting. From the mathematical point of view, and when considering today’s practices for altimetry, the best case in the sense of this concept element is a circular airspace with a defined upper limit. A circle is the only geometric figure which covers the largest area with the shortest border.

The challenges are to:

- Consider this point in combination with other airspace structure requirements, especially in metroplex areas or near a national border.

Possible resulting measures are to:

- EL 45: Use TMA airspace designs that are following this principle as far as possible, and use TMA airspace borders that are as close to a circle as much as possible.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be medium. A (close to) circular TMA does not directly lead to fuel benefits and lower emissions, but it supports the implementation of other fuel saving procedures like continuous descent operations.

This change could contribute to greener ATM at the costs of access and equity, small neighbor airports, that are currently outside of the TMA, may now be inside the TMA when following this design. Without suitable coordination procedures any air traffic flying to or departing from those airports might be disadvantaged, as hub airport traffic would be prioritized. However, apart from fuel and emissions efficiency, positive effects are also expected in terms of airspace capacity.

This concept element answers 4.1.2D and E as well as 4.1.4A

4.4.5.9 AVOIDANCE OF SPEED CONTROL

Especially at hub airports during peak hours it is usual practice to use speed control to sequence arriving aircraft and to line them up on final approach with a spacing close to the prescribed minimum separation. This is done to keep the “pressure” on the runway high, which is one prerequisite for a maximum use of available runway capacity. Extensive speed control is the most suitable way to achieve this today, and to guarantee that separation is always maintained. Other measures, like path stretching / radar vectors to not provide the same level of accuracy and predictability when applied without any speed restriction so far. One reason for that might be that optimum speed profiles depend on the aircraft type, the current aircraft weight and the atmospheric conditions, and might therefore be very different from flight to flight. Not all these variables are known to ATC and cannot be considered when pre-planning ATC actions.

The disadvantage is that reducing speed and altitude will trigger the use of flaps. Selecting the flaps as late as possible is therefore desired to minimize fuel consumption and increase of noise.

A freedom of choosing an appropriate speed would therefore enable the pilot to extend the flaps and the gear as late as possible on final approach, which further reduces fuel consumption and emissions.

The challenges are to:

- Establish the landing sequence by just using lateral and vertical control means instead of using speed control, but maintaining a close spacing on final at the same time,
- In case speed advisories are unavoidable, implement them as early as possible so that small decreases are sufficient to achieve the desired spacing later on, avoiding the need for an early selection of flaps.

Possible resulting measures are to:

- EL 46: Enable the air traffic controller to better pre-plan the traffic by providing him/ her with appropriate information about the best-case speed profiles and actual wind field data (air-ground data synchronization), which theoretically opens the possibility to establish close but safe spacings on final leg without using speed control,
- EL 47: Use planning tools / AMAN functions that allow an early consideration of these speed profiles for sequencing, and that are optimized to enable free speeds as much as possible,
- EL 48: Up to trajectory-based operations during the last portion of the flight.

A combination with the late merging principle as described earlier further supports this concept element.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be medium to high, as especially at hub airports the problem of speed reduction and early flap selection concerns numerous arrivals per peak hour.

This change could contribute to greener ATM at the costs of ATC capacity, as it is still unknown if the same close spacing can be achieved just with lateral and vertical control measures. Especially when the implementation of this improvement is not mature enough a slight negative impact must be expected, but this needs to be investigated in detail.

This concept element answers 4.1.4C and 4.1.5B.

4.4.5.10 FLEXIBLE FINAL APPROACH LEGS

As discussed in 4.1.5, the final approach leg itself should be kept as short as possible (as the aircraft flies in landing configuration with low fuel efficiency), but as long as necessary (to maintain safety and to guarantee a stable approach). Today's practice is that the length of the final approach leg for IFR arrivals is solely driven by the used instrument approach procedure. However, as VFR arrivals and visual approaches of IFR flights show, various aircraft types, including passenger aircraft, can safely land with a much shorter final leg. The new RNP procedures support those kinds of curved approaches and short final legs, and it is expected that precision and reliability will further be enhanced in the future to allow also safe landings under all weather conditions, including low visibility conditions.

The challenges are to:

- Move away from fix and rigid instrument approach procedures,
- Develop and implement more flexible approach procedures, offering a variable length of the final approach,
- Include and consider the possibilities offered by different aircraft types to shorten the final leg,
- Maintain a close but safe and reliable spacing on final at the same time.

Possible resulting measures are to:

- EL 49: Use planning tools in combination with data link technology to enable and allocate flexible RNP approaches to shorten the final leg while maintaining safety,
- EL 50: Ensure obstacle clearance by implementing additional obstacle clearance areas, defining the airspace where flexible RNP-based approach paths can be safely flown below MVA,
- EL 51: Up to the allocation of 4D-trajectories for the last miles to be flown.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be medium to high, as this would constitute a significant change in current practices, which seems to be feasible with the arrival of RNP-based approaches and data link technologies. Further, those flexible final approach legs can be implemented at IFR airports of all sizes, regardless of their actual traffic volume.

This change could contribute to greener ATM at the costs of ATC capacity, as it clearly increases traffic complexity in the vicinity of the airport. However, at the same time a partly compensating increase of ATC capacity can be expected, as the time the aircraft spend in the responsible sector is shortened, allowing a higher sector throughput.

This concept element answers 4.1.5A.

4.4.6. EN-ROUTE OPERATIONS

In this section, the concept elements that are applicable to operations at cruising altitude are described.

4.4.6.1 FREE ROUTE DURING CRUISE FLIGHT

Free routes do not only enable route planners to file the most efficient route, it also allows to efficiently and flexibly react to disturbances, hazardous areas, wind updates or ATC capacity shortages on pre-tactical planning phase. This motivated the introduction of Free Route Airspace in a lot of European countries as one specific form of application of this principle during the planning phase of flights. In the same way, also tactical applications are thinkable and already applied in a simple way (e.g. shortcuts), but are often restricted to a local area due to coordination effort. A wide standardized international application of this principle is therefore desirable and beneficial for all airspace users.

The challenges are to:

- Reduce constraints on the routing, e.g. implied by the airspace structure, to a minimum,
- Without infringing the interests of all other airspace users,
- And to maintain a safe and orderly flow of traffic.

Possible resulting measures are to:

- EL 52: Prescribe fix routes for the whole flight only when absolutely necessary,

- EL 53: Implement free-route airspace or similar concepts, as well as a more flexible tactical handling of aircraft routes by ATC,
- EL 54: Use coordination support tools / cross-sector planning tools to enable an application in a larger area, while respecting the air traffic flow and capacity management,
- EL 55: As a future concept use TBO applied locally in the airspace.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be high, as airspace structure and air traffic routes as well as the handling of it is neither standardized nor optimized worldwide, and sometimes cause significant detours.

This change could contribute to greener ATM at the costs of ATC capacity, as a route structure brings a basic order to the air traffic flows, and strategically reduces the complexity and likelihood of traffic conflictions.

This concept element answers 4.1.3C.

4.4.6.2 STANDARDIZED CROSS-BORDER ATM

Worldwide standardization significantly reduced the need to negotiate every single case, and made national air traffic systems and services compatible to each other. However, full standardization is not yet achieved, and further potential e.g. in Europe, has been identified. This led to the Single European Sky Initiative, which was launched in the early 2000’s. Regarding the further reduction of the environmental impact of aviation, various points can be identified where today national differences, bilateral agreements or simply the level of coordination between two different air navigation service providers lead to detours and therefore to increased fuel consumption and emissions.

The challenges are to:

- Drive this standardization in a reasonable time while respecting sovereignty of the states and local circumstances,
- Define standards that bring a benefit to all airspace users in the same way.

Possible resulting measures are to:

- EL 56: Share the responsibility of service provision (ATS delegation) between the respective national service providers along the common state boundary to reduce ATC coordination / preparation effort, frequency changes, or any other reasons that would make airspace users choosing to avoid a specific airspace,
- EL 57: Ease coordination between two different ANSPs and make their systems compatible with each other,
- EL 58: Standardize ATC fees,
- EL 59: Establish multi-national service providers, like EUROCONTROL with Maastricht UAC.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be medium, as the benefits are expected to differ from continent to continent.

This change could contribute to greener ATM at the costs of cost efficiency, as it can be expected that traffic flows will shift towards the airspaces that were avoided for any reason, which changes the distribution of ATC fees over the sectors and ANSPs in addition to a possible standardized ATC fee.

This concept element answers 4.1.3C.

4.4.6.3 IN-FLIGHT TRAJECTORY OPTIMIZATION

Today, the routes of flights are planned and filed at least several hours before departure. One constraint resulting from this is that this planned route can only be optimized according to the information available in real time during its execution (e.g. regarding wind field as well as expected head-winds / tail-winds, atmospheric conditions, airspace restrictions, etc.). Often this information is based on forecasts, which have an increasing uncertainty with increasing time horizon. In some cases, like air density, just average standard models are considered. The situation which the aircraft encounters at a defined position may still differ significantly from the forecast or standard model, which makes the optimization towards this “wrong” data basis less fuel and emissions effective as it would have been possible with more accurate information. An in-flight information update as first step, and a repetitive in-flight trajectory update as a second step, could therefore be a valuable improvement.

The challenges are to:

- provide the needed flexibility to the ATM system to enable repetitive in-flight trajectory updates. The current ATM system requires a predictable traffic picture to work properly (e.g. for traffic flow management); and predictability and flexibility are often opposite KPAs.
- Establish the needed data basis and data exchange infrastructure in all geographical regions of the world, as an in-flight optimization should cover the whole remaining route of the cruise flight.

Possible resulting measures are to:

- EL 60: Increase connectivity between airspace users and service providers as promoted by the SWIM approach,
- EL 61: let airspace users determine the current situation / conditions at their positions, and share it with other airspace users,
- EL 62: Install the possibility for airspace users to easily re-plan and re-file the flight route, the requested cruising level or the requested cruising speed for the remaining distance to destination,
- EL 63: Install the possibility for air navigation service providers to prioritize, accept or deny requested route updates, considering the impact on the overall (if possible: international) traffic picture,
- EL 64: Balance the update interval with the degree of flexibility that can be provided by air navigation service providers.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be medium, as especially for long-haul flights that are traveling through different world regions, the optimization potential is expected to be significant and exploitable. However, for short-haul flights, which are the major part of the air traffic, the optimization potential is low due to the low variance of conditions along the flight, and due to the shorter time horizon of forecasts used for planning the route of flight.

This change could contribute to greener ATM at the costs of predictability, as from the ATM perspective unforeseen changes in the routing become more likely.

This concept element answers 4.1.3C.

4.4.6.4 FREE VERTICAL MOVEMENT

Apart from the optimum route through the air volume, also the cruising level offers some potential for optimization. Currently, the choice of the cruising level is subject to several constraints, that are caused by the method of barometric altimetry as such, in combination with defined usable levels according to the semi-circular cruising level system. This traditional system offers a basic vertical de-conflicting of flights flying from east to west and vice versa, similar to a basic lateral de-conflicting provided by traditional ATS routes. However, due to the shift to lateral and vertical performance-based navigation, it should be discussed again if this system of level allocation could be replaced by a more free vertical movement (similar to the shift from fix ATS routes to free-route airspace for lateral movements), providing vertical separation only when two aircraft are actually in conflict to each other.

The challenges are to:

- Maintain current airspace capacity, as it is traditionally directly defined by the number of IFR levels available in the airspace,
- Guarantee vertical separation even when aircraft are flying at levels that are not a full multiple of 1000ft / 300m,
- Support a slow continuous and predictable climb / descent.

Possible resulting measures are to:

- EL 65: Allocate narrow level bands instead of defined levels whenever possible, to enable a slow continuous cruise climb,
- EL 66: Use conflict detection tools that are able to process flights cleared for those level bands,
- EL 67: Apply and establish vertical separation in the individual case on a tactical basis instead of doing it (sometimes without any real need) on a strategic basis by allocating full levels only.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is already well-known and is stated to be around 1.5% during the cruise phase [Lovegren 2011].

This change could contribute to greener ATM at the costs of capacity, as traffic complexity is increased. One challenge is to keep the impact on capacity as low as possible.

This concept element answers 4.1.3B.

4.4.6.5 FREE CRUISE SPEED

Nowadays the optimum cruising speed is often not only determined to achieve lowest fuel consumption and emissions, but also to reduce the costs of delays, missed connections etc. Airlines often accept a higher fuel consumption to reduce the delay of a flight when total costs would be lower. Just this fact shows that there is also some potential to reduce emissions by choosing another cruising speed, provided that economic interests are no longer prioritized over environmental aspects in the future. The optimum cruising speed, which allows to fly with the lowest emissions, depends on the aircraft type, the aircraft weight, atmospheric conditions, the cruising level and the wind field, and can vary during the whole flight. No ATM related restrictions in cruising speed is therefore the desired situation.

The challenges are to:

- Guarantee lateral separation even when aircraft are flying with totally different speed profiles,
- Support a speed change at own discretion to adapt to changing conditions.

Possible resulting measures are to:

- EL 68: Avoid speed restrictions at all,
- EL 69: Prefer lateral / vertical separation instead of using speed control,
- EL 70: Clear the aircraft for a lower and an upper speed limit if restrictions are unavoidable.

When applied consequently, the potential to reduce overall fuel burn and emissions of the air traffic is expected to be low, as optimum cruising speeds are very similar for modern airliners, and the range within which the cruising speed can safely be changed is very restricted. This allows to already provide airliners with a certain freedom to choose the appropriate speed. However, as mentioned, economic interests are currently prioritized, which is the main cause for the existing optimization potential toward lowest emissions. An estimation of the benefit is already contained in [Lovegren 2011], and is stated to be around 2.4% for the cruise phase.

Highest potential for reducing emissions is expected for flights within the oceanic area, as the expected time of exiting the oceanic crossing may constitute an additional speed constraint, which is just caused by the lack of surveillance and surveillance-based ATC service provision in that area.

This change could contribute to greener ATM at the costs of predictability, as especially for long-haul flights small speed changes can already lead to an Estimated Arrival Time (EAT) change of several minutes at the destination.

This concept element answers 4.1.3A.

4.5. EXAMPLES FOR FINAL APPLICATION OF GREENER ATM CONCEPT ELEMENTS

In the following sections, three high-level concepts are assembled from the concept elements described in 4.4, that serve on one hand as example how this assembly can be done. At the same time, this also serves as the starting point for working out the detailed concepts in MWP3 and MWP4, which are going to be validated in MWP6. This section includes also a preliminary assessment of the compliance of these examples with the overall ICAO operational concept analyzed in section 3.1. A mapping between the Concept Elements and the built concept examples is also provided in Annex B.

4.5.1. EXAMPLE 1: NEW TMA AIRSPACE DESIGN AND GUIDANCE PROCEDURES (DLR)

The first example focuses on the TMA of a hub airport, like Munich in Germany.

4.5.1.1 BASELINE SITUATION

Current operations performed in the broad Munich airspace involve a relatively small TMA, which is managed by several air traffic controllers (arrival/pick-up, director/feeder, departure for every runway). Regarding arrivals, Munich airport TMA uses STARs to enter it from upper airspace, and uses RNAV/GPS transitions as approach procedures. These transitions are in the form of a classical radar pattern (downwind, base, final) and involve several waypoints to establish lateral, vertical and speed profiles to be followed. Arrival (pick-up) controllers use shortcuts, vertical separation and, if necessary, additional radar vectors to pre-sequence aircraft on downwind. Usually abeam the airport, the flights are handed over to the director (feeder) controller, who instructs the base turn, the final turn and the clearance for the ILS final until handover to the Tower controller. The director controller uses vertical separation, radar vectors and speed control to establish arriving flights on final leg with a spacing close to the required separation minimum to achieve maximum runway capacity.

Departures are guided by the departure controller and usually follow standard instrument departures routes until they are free of conflict with arriving flights. Afterwards, they are handed over to the next en-route controller.

The measures that are already in place to save fuel and emissions are a modern arrival management, which shall help to reduce delay-causing measures like holdings or path stretching in low altitudes and thus reducing fuel consumption. Munich is one of the airports which is about to implement extended and enhanced arrival management, with the goal to further use speed advisories for delay absorbing during cruise flight. This will further improve fuel efficiency. CDAs as described in section 4.1.4 are possible, but often not feasible or successful due to separation needs. Therefore, further potential for improvement is seen here.

4.5.1.2 SPECIFIC IMPROVEMENTS

The idea is to combine several concept elements from section 4.4, to achieve a complete re-design of the TMA and corresponding ATM procedures, enabling a further reduction of fuel consumption and emissions.

In detail, the following concept elements for ground and air operations are combined here:

a) Continuous Taxi Operations: a coupling of arrival, ground and departure management shall reduce ground delays with running engines as far as possible (refer to EL 2);
b) Free Route in TMA: There shall be no STAR routes from upper airspace into the TMA, allowing the flexible circumnavigation of restricted areas, areas of bad weather etc. (refer to EL 21 and EL 22);
c) Continuous Descent Operations: CDAs shall be flown by as much aircraft as possible, provided they are equipped accordingly (refer to EL 26, EL 27 and EL 28);
d) Late-Merging Principle for Arrivals: approaching aircraft are joining fixed routes (e.g. approach procedures) at the latest possible point to allow a highly diverse air traffic (refer to EL 39 and EL 40);
e) Continuous Climb Operations (CCO) (refer to EL 41, EL 42 and EL 43);
f) Airspace Design for highest freedom of movement within shortest airspace boundaries: a circular TMA may be the best case to fulfil this element (refer to EL 45).

In more detail, this is achieved by the following implementation steps:

4.5.1.3 ADVANCED CONTROLLER SUPPORT SYSTEMS

For the implementation of new airspace structures and therewith-connected guidance and approach procedures, new controller support tools have to be developed, or existing systems regarding functionalities must be expanded and connected for cooperative optimization [Phojanamongkolkij 2014]. Today, the most instated advanced supporting tools are the Arrival Manager (AMAN) and the Departure Manager (DMAN), which are commonly used at many major ANSPs and airports [EU 2014].

Planning systems for air traffic controller support have been developed in the USA and Europe since the mid-1980s [Tamvaclis 2004]. These systems are tailored to the controllers at a specific workstation, although the individual controllers (ACC, APP, TMA, tower, apron) must work closely together and rely on the information they get from their colleagues due to the complex networking of larger airports.

The objectives in the development of controller support systems are numerous and diverse, but the most frequently cited are to increase safety and capacity utilization, while reducing costs and environmental impact [Tamvaclis 2004]. Today's expectations of the systems are usually aimed at reducing the workload of the controllers, as the volume of traffic has increased significantly worldwide in recent years, especially at major airports, and will continue to do so. However, planning systems do not only generate optimal sequences in which the aircraft are to be processed by the controller, but also attempt to carry out further optimization considering all known boundary conditions [Kjenstad 2013]. In this way, holding loops on both ground and air are reduced. This not only saves (flight) time and costs, but also reduces the pollution of carbon dioxide and nitrogen oxides as well as aircraft noise, which is a growing problem due to a sensitization of the population, especially at airports in urban areas.

However, the first planning systems initially developed in the 1980s were static: An electronical plan was created and then not changed, even if reality had in the meantime evolved in a completely different direction. If the controller wanted to bring plan and reality back into line, he had to enter manually all changed data into the controller support system – in this case, this name of the systems was often no longer justified. With the progressive development of planning systems and computing power over time, and the possibility of automated information acquisition and dissemination, many planning support systems became adaptive. This means that they create their own situation picture of a condition, generate and optimize their plans and observe further traffic events to see whether they still correspond to their own view. If deviations occur, many controller support systems today react independently to new traffic situations and adapt accordingly. However, support systems must also exhibit a certain degree of planning stability, even if this may sound contradictory at first. Once an order has been defined, plans should not be completely revised at the slightest change of a boundary condition. This unnecessarily complicates the work of the involved controllers and pilots, and does call into question the efficiency of these systems. The art of tuning adaptive planning systems now lies in fine-tuning when a changing situation actually requires re-scheduling.

It is very costly and challenging to prove supporting system's effectiveness. The simulation of coordinated AMANs and DMANs for a mixed-mode runway system alone is so complex, that, proving that a particular constellation of aircraft on the ground and in the air has actually been optimally handled by a planning system, requires a considerable amount of data accumulation and post-processing [Simons 2012]. Validation is made particularly difficult by the fact that contradictory parameters often have to be optimized, such as adaptability and throughput for the arrival manager or taxi-out times compared to throughput on the ground for the departure manager. Also challenging to validate are statements regarding a possible reduction of the radiotelephony effort and a better predictability of the traffic volume when expanding the scheduling horizon [DFS 2013].

In the GreAT project, three kinds of actual controller support systems will be used: Arrival Manager (AMAN), Departure Manager (DMAN), and Surface Manager (SMAN). They will be modified towards optimized (lowest emissions) guidance of air traffic, following the mentioned principles selected above.

4.5.1.3.1 ARRIVAL MANAGER

Arrival planning systems or Arrival Managers (AMAN) have the role of assisting approach controllers in guiding approaching air traffic in the vicinity of one or more airports. All systems implemented worldwide today have the task of making the work of air traffic controllers easier, by taking over the particularly difficult planning and optimization of approach sequences, considering all the given constraints, like separation minima as well as speed and altitude limitations. To support the center controllers for the time-exact handover, they are shown Time-To-Lose or Time-To-Gain suggestions for each aircraft, accordingly deceleration or acceleration times. With flow regulation, the inbound traffic control into the TMA takes place [Bergner 2013]. The arrival managers work purely as suggestion systems and have planning horizons between thirty minutes and more than two hours [SJU 2019]. The technical support in approach planning can have a clearly positive influence on the effectiveness of the controllers' work, since the approaching aircraft are integrated at an early stage into the arrival sequence [Boursier 2005]. The first arrival managers already developed the systematic basis for sequencing tools for controller support, which has basically not changed until today. The tasks of AMANs can therefore be divided into the four main levels sequencing, trajectory calculation, advisory generation and monitoring.

Sequencing

Sequencing determines the order in which arriving aircraft are to land on the different runways. For this purpose, target times are set for fixed points along the approach route, for example for entry points in the TMA, merging points within the TMA, and the runway thresholds. During sequence planning, different boundary conditions are taken into account, including the current sequence principle (e.g. first come – first serve), the actual operating mode of the airport as well as the wake vortex and radar separation, depending on the individual aircraft weight classes.

Trajectory Calculation

The constrain parameters for fixed points like Metering Fix, Merging Points and Threshold, which are determined during the sequence planning, constitute the frame for the trajectory calculation in addition to the aircraft-specific technical parameters and the current airspace structure. The precision of the 4D flight trajectory, calculated on the ground, depends decisively on the quality of the procedure used for flight path calculation, the availability of current meteorological data in the airspace and the existing technical parameters of the aircraft types.

Advisory Generation

Arrival planning systems that do not generate trajectories (e.g. 4D Planner) support approach controllers by generating an approach sequence, which must implement by controllers on their own. If the AMAN has the functionality of calculating precise 4D-trajectories, guidance instructions for the controller can be generated based on these trajectories. These instructions are displayed on the radar screen at precisely the right time and contain information on altitudes, speed as well as flight direction changes. Additionally, the advisories contain a every second countdown display, which controllers can use to estimate the time when to give the appropriate clearance to the respective pilot via voice radio communication.

Monitoring

Modern controller supporting systems are adaptive. This means, they change the route planning and scheduling for each individual arriving aircraft if the considered aircraft react other than expected, or the traffic situation changes in an unexpected direction. To detect the deviations between planning and reality, the system has to compare the available aircraft parameters with the planned trajectory regarding position, altitude, heading, and speed, and react if the discrepancy exceeds defined limits.

New Required Features

AMANs have to be adapted to new and established operational procedures with additional functionalities. These features should include optical as well as methodical support functions for RECAT I and II implementation, time-based flight guidance, late merging sequencing and spacing support, and integrating of aircraft with different capabilities and equipage. For the RECAT implementation, AMANs have to deal with extended weight class categories and new spacing regulations. For RECAT II, the aircraft type dependent separation has to be implemented for the scheduling, complemented by visual spacing aids for controllers, so they have the possibility to supervise the compliance of the separation on downwind and final. For implementing the late merging point principle, controllers need optical and mathematical support for the fluent integration of direct approaching inbounds and regular guided approaches on the final.

Today, air traffic controllers guide approaching aircraft with distance-based separation. They have full-scale separation markers on the display, which are used to evaluate the required distances between to aircraft. When applying time-based separations, the displays have to provide functionalities to translate the time-based separation, scheduled by an AMAN, into distance-based separation to monitor the aircraft behavior on the display.

4.5.1.3.2 DEPARTURE MANAGER

In contrast to arrival planning systems, departure planning systems or Departure Managers (DMAN) are developed less by research institutions, but are largely products of commercial software houses. Accordingly, little literature is publicly available on their development status and current progress.

As a corresponding counterpart to approach planning systems, Departure Managers calculate and optimize departure sequences and the corresponding departure times. They should provide consistent optimized planning of the airport's outbound traffic and accordingly optimized target times for runways, stands or deicing facilities. In this way, departure traffic is efficiently managed to ensure that the maximum available airport capacity is used, while constraints from the Air Traffic Flow Management (ATFM) are considered. For the implementation of the calculated sequences and clearances, DMANs generate advices for all controllers involved.

Both planning managers, AMAN and DMAN, work as pure suggestion systems: Sequences and target times can be adopted by the controllers. If the planning does not occur, it is always the system's task to reschedule and align with the behavior and wishes of controllers and pilots. Updates of the schedules are therefore event-driven. As soon as a DMAN receives the information that an aircraft can no longer meet its planned target time at any point in the departure preparations, or will not meet it due to a controller decision, the scheduling is adjusted accordingly, and a message is sent to the responsible controllers. In contrast to arrival managers, whose planning horizon may be more than one hour, DMAN can only plan up to about thirty minutes into the future, since reliable information on take-off preparations is only available at much shorter notice. Forward-looking planning also demonstrably reduces the amount of radio communication between the responsible controllers and flight crews.

Due to the complex interplay, departure managers have to take into account a number of boundary conditions, including planned runway and SID, airline priorities, CFMU-slots and controller inputs for individual sequences or runway assignments. Additionally, during mixed mode operations, DMAN's runway assignments may be influenced by runway allocations of the corresponding AMAN.

Using existing interfaces, automated information from and to other planning managers may also be provided. With a corresponding interface, Airline Operation Centers (AOC) also have the possibility to influence off-block times of their aircraft by assigning priorities. If take-off times are postponed, aircraft can be kept at the gate longer, so that they do not have to wait with running engines on taxiways or runway holding points, and pollute the environment with exhaust gases and engine noise.

4.5.1.3.3 SURFACE MANAGER

To date, no route planning system for controllers exists which supports the guidance of taxiing traffic through 4D-trajectories[57], although it was already clear in the mid-1990s that this kind of support was needed in poor visibility conditions, and useful to improve the efficiency of incoming and outgoing air traffic [Dippe 1995]. At most larger airports, ground situation displays based on A-SMGCS data are already in use, which can show controllers the current traffic situation even under low visibility conditions and in airport areas with limited visibility.

A Surface Manager (SMAN) automatically organizes and optimizes the taxiing movements of aircraft around the runways, taxiways and apron areas alongside defined parameters and constraints. Parameters may be taxi distances and times as well as number of runway crossings. To reduce the environmental impact of the taxiing process, SMAN should be able to estimate the aircraft individual fuel consumption during the roll-phase and generate fuel- and CO_2-optimized taxi-routes and procedures, including rolling speeds on different areas of the apron.

In this way, an SMAN forms a cooperative link between approach and departure management [Sinapius 2015]. The idea behind SMANs is the supporting of tower air traffic controllers by planning and monitoring aerodrome traffic on apron and taxiways between stand and runways. The SMAN assists apron controllers in managing taxiing traffic so that the "negotiated" departure times and sequence are achieved as far as possible [Bergner 2013]. The SMAN provides guidance and clearances instructions to guide aircraft along the planned route on a time basis. If the guidance is not time-based, no conflict-free trajectories can be guaranteed.

With the software tool Taxi Routing for Aircraft: Creation and Controlling (TRACC), DLR has developed a research SMAN prototype and has used it to realize a trajectory-based taxiing traffic guidance system. The goal of the SMAN deployment was to enable precise time-based taxiing guidance on the apron and taxiways. The taxiing-trajectory represents a section of a SESAR 4D-business trajectory and can be implemented, guided and monitored by controllers with the help of the SMAN.

During the evaluation by controllers, the novel concept of exact rolling speeds for moving flight traffic planning and conflict avoidance on the movement areas using 4D trajectories was extensive and successful tested and assessed [Schaper 2013].

The scheduling and trajectory generation of TRACC bases on three main principles [Gerdes 2012]:

- Cost-by-cause-principle: If an aircraft deviates from its assigned trajectory, the trajectory is re-planned only for this aircraft.
- Equality and reliability principle: A recalculated trajectory should deviate as little as possible from typical operational procedures.
- Stability principle: Changes to calculated trajectories should occur as rarely as possible. Speed changes or stopping instructions should be preferred to route changes.

Similar to an AMAN and a DMAN, the TRACC generates from the 4D-trajectory data guidance instructions for the controllers for transmission to the cockpit crew. For each aircraft, TRACC shows on electronic flight strips the callsign, optimal start time for maneuvers and clearances. Additionally, further freely configurable information is available. The controller can interact with the TRACC via buttons on his extended traffic situation display and other associated information windows, provided by the SMAN. This

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[57] Obviously, the position of ground moving air traffic can be described through the two dimensions in space and one in time. Nevertheless, in recent years it has become customary to speak of four dimensions in order to emphasize that time is taken into account in the calculation.

includes the possibility to enter whether a clearance was actually given or whether the SMAN's suggestion was ignored by the controller. The inputs are taken into account accordingly in the next planning cycle. For best timing, TRACC uses a countdown every second to indicate when a command should ideally be implemented, so that the tower controller can instruct the crews accordingly.

Calculating precise taxi times for all individual aircraft considering the complete apron traffic enables a DMAN to give timely precise clearances for pushback and taxi request to avoid standby times at gates, runway crossings and runway heads. The total taxi time of an aircraft consists of the taxi time and the waiting time. The taxi time depends on the taxi distance and the taxi speed. The taxi distance is a function of the stand or gate, the assigned runway, the chosen taxi route and possibly de-icing advices. The taxi speed depends on the route, the aircraft type and the meteorological and traffic conditions on the airport. The summarized waiting time for an aircraft is a function of the meteorological and traffic conditions, the runway queue and the number of runway crossings.

As a starting point for the taxi routes, the SMAN plans standard tracks used typically by the local tower controllers. For the route and time calculation, the runway- and taxi system of an airport has to be transferred into a mathematical graph. Evolutional algorithms are developed and implemented for the best-way calculation regarding the defined optimization criteria. In this way, the received taxiing-solution might not be the optimal solution every time, but the computational time is reduced from a few minutes down to some seconds.

4.5.1.4 COUPLING OF ARRIVAL, DEPARTURE AND SURFACE MANAGEMENT

In case of runways used in mixed mode (arrivals and departures use the same runway), gaps must be planned in the arrival stream to enable the take-off maneuvers of departing aircraft. At the same time, the goal is to optimize the timing of these gaps so that taxiing aircraft do not have to stop and wait with running engines at the runway holding point. For this reason, the planning functions of the arrival management, surface management and departure management must be coordinated like one system.

4.5.1.5 TMA AIRSPACE STRUCTURE

The next element which is implemented is an experimental TMA airspace structure, which exactly follows concept element f) described in 4.5.1.2 to its maximum. The goal is to investigate this theoretical best-case situation, knowing that for operational implementation local constraints have to be observed, which may reduce the benefit, depending on how significant the deviations from this best-case situation are. The proposed TMA airspace structure is displayed in Figure 47 and Figure 48.

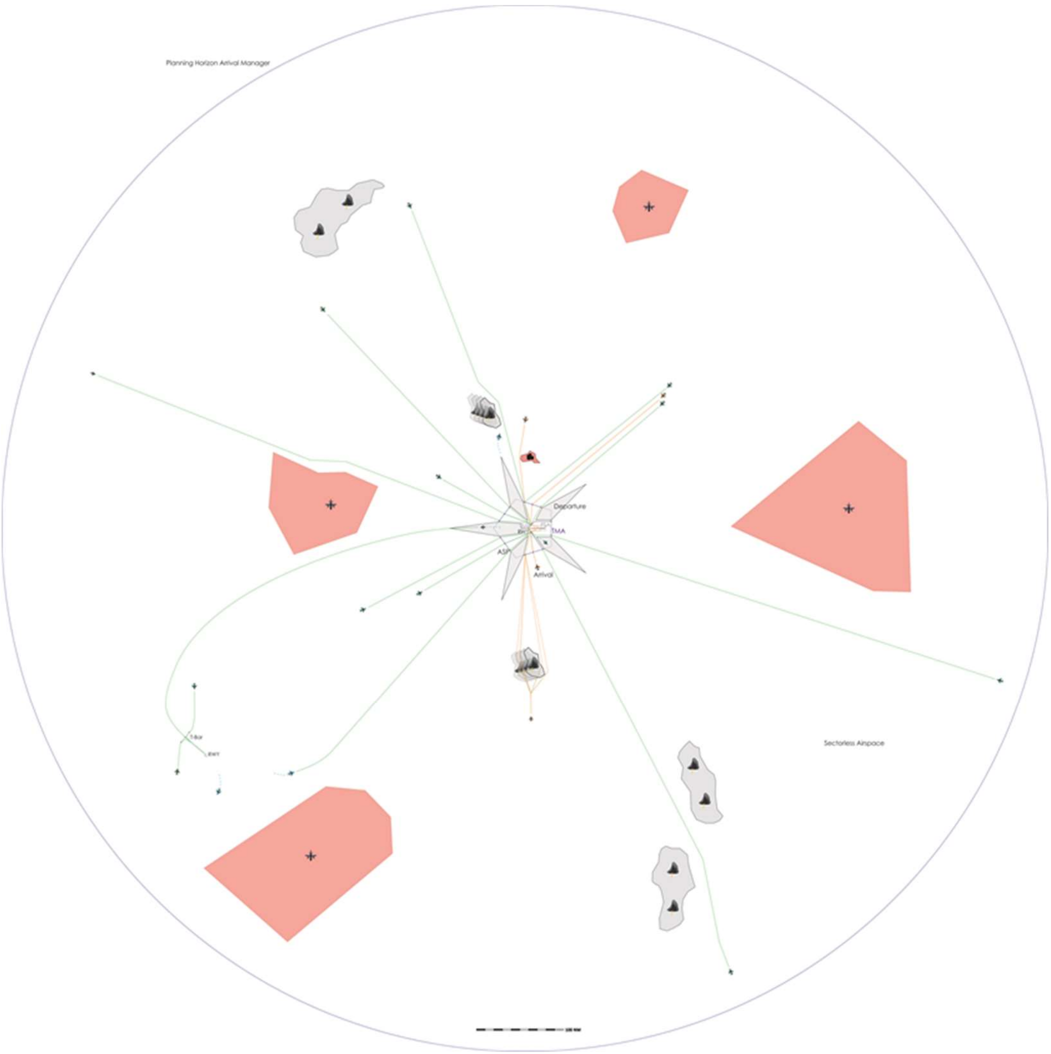

Figure 47: Proposed TMA airspace structure.

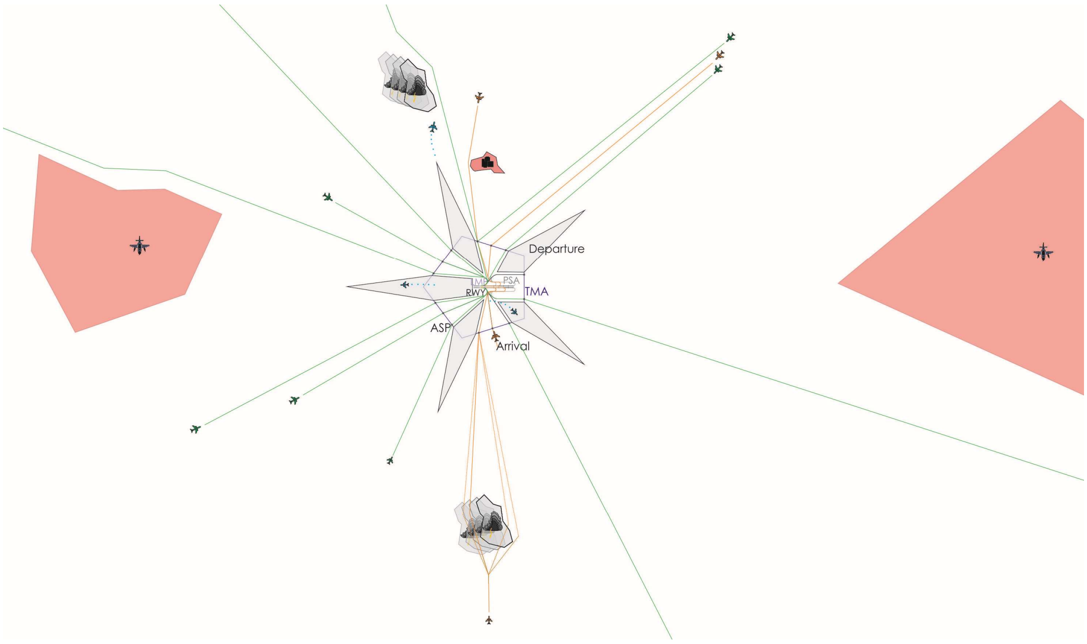

Figure 48: Proposed TMA airspace structure zoomed in.

In the outer area of the TMA, there is no prescribed route structure, which enables a fully free movement of flights (concept element b)in in 4.5.1.2). This freedom of movement enables short-cuts and appropriate circumnavigation of restricted areas (red polygons in the figures), high terrain and areas of bad weather (moving grey cells in the figures). Incoming aircraft departing at an aerodrome within this TMA are considered and precisely planned with an arrival route and time as soon as they are airborne.

In the center area of the TMA, where the traffic density is much higher than in the outer regions, arrival and departure sectors are foreseen as de-confliction mechanism. Further, several aircraft separation points (ASP) are introduced within every arrival sector to avoid overlapping tracks as long as possible, especially for different speeds. Then, the flights are guided from ASPs on a standard routing to a late merging point (LMP) on the final around six nautical miles before the thresholds. Short after the LMP, the aircraft start their final descent to land.

Due to the provided freedom of movement, and due to the fact that there are only two waypoints to be considered when planning a trajectory for an arriving flight, this airspace structure should enable the broad application of multiple CDAs at the same time, provided an air-ground trajectory exchange and negotiation as well as an AMAN-DMAN-Coupling has been implemented.

4.5.1.6 AIR-GROUND TRAJECTORY EXCHANGE AND NEGOTIATION WITH ARRIVAL MANAGER

To enable trajectory negotiation, a datalink between ground-based arrival manager and on-board FMS has to be available. The arrival manager asks in a first step for the "requested" arrival route, together with an earliest and a latest estimated time over a fix without changing this route of flight. This information is then used to establish a first planning. An iterative process starts to de-conflict the trajectories and to determine the best approach sequence. In a last step, the aircraft are cleared for the negotiated trajectories and are able to execute type-individual optimized approach procedures like CDA.

4.5.1.7 CCO ENABLING DEPARTURE ROUTES

New departure routes have to be designed, which enable continuous climb operations and prescribe fix routes only as long as necessary, i.e. as long as there is a potential conflict with arriving flights. These routes should avoid detours, which can be achieved by climbing above the arrival streams as fast as possible. An early split off to the desired direction also supports highly diverse traffic speeds and mixes.

Implementing all these measures (new TMA airspace structure, semi-automatic air-ground trajectory negotiation, AMAN/DMAN/SMAN coupling and optimized departure procedures) should lead to a much smoother traffic flow, enabling a broad application of continuous climb and continuous descent operations as well as continuous taxiing on ground, reducing emissions and the environmental impact while maintaining a high runway and aerodrome capacity.

4.5.1.8 TARGET TRL

This work is seen as fundamental research that investigates an approach, which differs from current practice significantly, but which promises the wide application of greener ATC procedures and fuel- and emission-saving trajectories. The target TRL is 4.

This approach will be further worked out in GreAT MWP4, and will be validated in MWP6 using real-time human-in-the-loop simulations.

4.5.2. EXAMPLE 2: ENHANCED SYSTEM SUPPORTED T-BAR APPROACH PROCEDURE (HC)

4.5.2.1 BASELINE SITUATION

TMA Airspace structure

Hungarian FIR and especially Budapest TMA experienced a huge traffic increase in the last 10-20 years (pre-COVID-19 situation). Substantial changes had to be made in the Hungarian airspace in the last 5 years to cope with this traffic situation, which involved, inter alia, the redesign of the busiest TMA of the Hungarian FIR, LHBP (Budapest Liszt Ferenc International Airport) TMA.

The redesign of Budapest TMA is carried out in three major phases. The first two phases were already carried out and implemented. These developments were aimed at trying to catch up with the ever increasing traffic demand without any support tool development. To understand the development HC aims under the GreAT project, the previous two phases have to be presented briefly. The common goals in these developments were threefold:

1) to maintain or increase the capacity of the airspace
2) to achieve this with the maintenance or increase of the safety level and
3) to at least maintain or decrease if possible the environmental impact (greenhouse gases and noise) of air traffic.

The first phase, was concluded on 26 May 2016. As a result of SESAR BUD 2.0 project, new instrument approach procedures were introduced in LHBP TMA based on RNAV T-bar procedure construction.

The bottom line of this concept is that arriving aircrafts receive direct to instructions to the nearest appropriate T-bar procedure’s Initial Approach Fix which then represents a closed path up to the landing threshold, so the actual flightpath is known prior to entering the TMA. This concept enables FMS the calculation of optimal decent profiles also enabling CDA.

Under the so-called T-Bar approach, the deviation of paths actually flown by aircrafts is less than prior to its introduction, and aircrafts may turn onto the final in predefined paths. Most airlines operating aircrafts to Budapest are familiar with this procedure as there are similar procedures in use at several European airports.

Another benefit of this procedure is that aircraft crew receive more precise information for optimal descent that may result in less level flights at low altitudes, which also translates into less fuel consumption and less noise disturbance.

In the second phase, these T-Bar procedures and associated arrival routes were revised in 2019 in the framework of the complete redesign of TMA airspace of Budapest Liszt Ferenc International Airport.

In the past, the legacy TMA airspace structure was redesigned in a patchwork-like manner. It means that all challenges raised by traffic increase were more or less duly addressed (capacity, procedure, safety etc aspects, consultations), but a systemic approach was always missing. With the redesign and optimization of the whole TMA and adjoining military airspace structure, arrival to LHBP became more predictable, plannable, which brings significant environmental benefits as well. If examined from environmental protection point of view, this new design enables the application of CDO (section 4.1.4.) and CCO (section 4.1.2), less level flight is expected, especially in low altitude, and less holdings. All this results in less fuel consumption and ultimately in less greenhouse gas emission.

This present GREAT project contributes to the third, final phase, which is the further development an in-house developed software visualizing all arrival aircraft on a timeline related to the Intermediate Fix of the instrument procedure.

MergeStrip

Merge Strip is one possible option to reduce fuel burn, CO_2, and noise and to facilitate continuous descent approaches. MergeStrip[58] is a new air traffic planning tool that helps air traffic controllers to sequence arriving traffic more efficiently, thereby reducing fuel burn, CO_2 emissions and the noise emissions. MergeStrip allocates aircraft preparing to land at an airport to a time line, considering their actual position and speed. This supports controllers to plan more effectively and makes their workflow more predictable. MergeStrip brings a new way of representing the current traffic sequence, both horizontally and vertically with the only requirement of three waypoints in the terminal maneuvering area. It has two functions:

- One for the pre-tactical sequencing, so the planning controller will know the traffic situation and what will happen in the next fifteen to twenty minutes.
  The other function is the final sequencing tool. This tool is useful in terms of compression during final approach. The radar controller sequences the traffic onto final and an extended visualization in the system shows the final separation by the threshold.

4.5.2.2 SPECIFIC IMPROVEMENTS

Considering the above described features of Budapest TMA, the following two concept elements will be used and combined here:

- Free route in TMA (4.4.5.1.) and
- Continuous descent operations (4.4.5.2.).

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[58] https://en.hungarocontrol.hu/solutions/merge-strip

4.5.2.3 ENHANCED CONTROLLER SUPPORT SYSTEM

The restructuring of airspace and the renewal of the relevant procedures are both necessary steps that supplement each other. However, there is another element that needs to be taken into consideration, and it is the controller support system together with different decision support tools. These tools enable the "finetuning" in the air traffic control system framework. The controller support system, MergeStrip 3.0 that is to be enhanced under the scope of this project, is a sequencing tool that can be effectively used in small and medium sized airports, like LHBP. For a very detailed theoretical description on controller support system and AMAN, please refer to 4.5.1.3 and 4.5.1.4 respectively.

New required features

The new functionalities that are planned to be developed are on the one hand have to address the functionalities that the ATCOs found the most needed, which are better sequencing and advisory generation. The functionalities named having the greatest added value with regards to the GreAT project's goals are as follows:

- the **improvement of the calculation of the Estimated Time of Arrival** allows ATCOs to precisely sequence the arrivals at a very early stage and consequently enhancing the use of full CDOs (starting as close as possible to the Top of Descent).
- the **conflict resolution recommendation** will recommend ATCOs more optimal solutions based on the application of speed control or target waypoint change at an early stage of the descent, and
- the **what-if probing support** feature will allow ATCOs to analyze the consequences of any potential action before executing it.

4.5.2.4 TARGET TRL

As described above, this development is considered as one complementing and finalizing the redesign of Budapest TMA. The smoother application of greener ATC procedures (most importantly CDOs) and consequently fuel- and emission-saving trajectories are highly expected from this development.

The target TRL is 4. This approach will be further worked out in GreAT MWP4 by means of user requirement workshops, and the related actual software development activities, and will be validated in MWP6 using real-time human-in-the-loop simulations.

4.5.3. EXAMPLE 3: FERA-WOC (CARERI)

This example focuses on illustrating the transition of en-route airspace in highly constrained area from structural routes to flexible network, taking en-route airspace in the west of China as an instance, which would support trajectory-based greener air traffic operation.

4.5.3.1 BASELINE SITUATION

Generally, civil aircraft fly along fixed routes in China's en-route airspace, where most of airspace resources belong to the military. Therefore, prohibited areas, restricted areas and danger areas are set up according to different purposes. In accordance with the relevant regulations of the State:

- No aircraft may fly into the prohibited airspace or temporary prohibited airspace without special approval,
- No aircraft without the permission of the military flight control unit may fly into the restricted area or the temporary restricted area within the prescribed time limit,

- No unrelated aircraft shall be allowed to fly into the danger area or temporary danger area within the prescribed time limit.

The China’s Air Traffic Service Route (hereinafter referred to as "ATS Route") is classified into domestic and international routes according to the nature and conditions of the flight operations carried out on the route.

The centerline of each route segment starts from one navigation facility or intersection point and ends at another. The central lines of each segment are connected to form the Central Line of the ATS Route. The width of the route is 20 kilometers, with 10 kilometers on each side of the center line. If a certain segment is restricted, the width may be reduced, but not less than 8 kilometers. When the route direction changes, the width of the route includes the airspace surrounded by the extension of the route boundary to the intersection point. The lower limit of the ATS route shall not be lower than the lowest flight level, and the upper limit shall be the same as the upper limit of the flight level. To guide the aircraft flying within the prescribed range, the ATS routes are equipped with the navigation system according to the performance requirements. The switching points and significant points are set up to help the aircraft fly accurately.

Performance-based navigation routes may be established in some certain airspace in accordance with regulations, depending on the capability of aircraft's onboard navigation equipment, the effective range of ground navigation equipment and the provision of air traffic services.

In the west of China, some specific en-route airspace rules shall be applied, where military activities are highly frequent and of wide influence.

- Usually the flight trajectory can be offset from ATS route by maximum 3 nautical miles[59]. Temporary routes can only be used with authorization.
- In case of adverse weather, each flight should apply for its own airspace for rerouting, the application should include information such as call signs, transponder code, the amount of offset (in nautical miles), and follow-up intentions. Flights should get back to the course in time. In case of large-scale weather, a margin for airspace use can be applied, such as offset at own discretion within a defined number of nautical miles to the right until a defined waypoint.
- The flight level range is usually below 12500m, higher altitude requires special application. When the military has level requirements for the use of ATS routes, flight level constraints of En-route operation are imposed to the civil flights. Usually, NOTAMs are issued in advance to remind airlines to modify plans to avoid excessive delays.
- After the release of airspace (complete or partial) from military for civil use, direct flight is allowed. This operation is generally only allowed within the sector, up to the next report point outside the sector. Any other route change needs special coordination with other units.
- The intermediate airspace between parallel ATS routes can usually be used. However, if a flight is offset into the intermediate airspace (detour or direct), it may violate the lateral separation minimum, which will lead to additional operational risks.

4.5.3.2 GENERAL CONCEPT

ICAO clarified flexible flight trajectory as a field of technological improvement in the ASBU. Free Route Airspace (FRA) is a key element of future ATM architecture in Europe. Flexible

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[59] In practice, an offset of 5 NM could be also used.

En-Route Airspace in West Of China (FERA-WoC) is a form of en-route airspace with a higher degree of freedom operating in west of China, underpinned by Flexible Use of Airspace (FUA). The airspace can keep or adjust the original ATS route, and configure sector entry and exit points, conditional routes, and free maneuvering zones based on the availability of airspace resources. Here, the free maneuvering zone is defined as 3D space in which users may freely plan rerouting with or without reference to navaids according to their airborne equipment. It should be made clear that, to further enhance the flexibility of 4D-capable aircraft trajectory selection (such as adapting to high-altitude wind changes), the used sector entry and exit points could be either the published points, or arbitrary coordinates defined by latitude and longitude. It should be noted that any flight in FERA-WoC is always subject to airspace restrictions. In FERA-WoC, the ATC controller is definitely at the core of the operating loop.

FERA-WOC is a flexible (but not fully free) airspace model with specific characteristics based on the actual problems of China's en-route airspace and future development needs.

Compared with the FRA concept being implemented in Europe, their similarities are:

(1) The goals are both to improve the use of airspace resources and support more flexible 4D trajectory operations.
(2) Aircraft can dynamically plan flight trajectories in the internal airspace between available entry and exit points.
(3) Compatible with ATS routes and support aircraft operations without 4D capabilities.
(4) A complete mechanism of FUA is needed.
(5) Flights must follow the ATC controller's instructions.
(6) The issue of sector dynamic capacity and planning needs to be carefully reconsidered.

Considering the Specificity of China's airspace management system, the differences are:

(1) FRA adopts a mature FUA framework. Considering the characteristics of military activities in western China, FERA-WOC is a flexible transformation of traditional structural airspace under the flexible use of limited airspace. Therefore, according to the differences in the availability of airspace resources in each sector, we shall configure one or more elements (e.g., entry and exit points, conditional routes, and free maneuvering zones) as supplements to the ATS route, and design a corresponding FUA mechanism.
(2) FRA sector entry and exit points are generally predefined points, and in special circumstances, it allows significant points to deviate from sector boundaries. For the FERA-WOC, sector entry and exit points can be significant points, or any coordinates determined by the latitude and longitude. On the one hand, it is used to deal with the shortcomings of the lack of ground-based navaids in the west; on the other hand, it can also increase entry and exit points to make up for the insufficient flexibility in actual operations caused by airspace restrictions.

4.5.3.3 SPECIFIC IMPROVEMENTS

Compared with traditional structured en-route operations, FERA-WoC expands the spatial dimensions of operations by tapping available airspace resources and establishing a FUA mechanism, providing friendly airspace environmental support for flexible trajectory selection and green air traffic operations. The following two concept elements will be used and combined here:

- Free Route During Cruise Flight (4.4.6.1)

Specific improvements include:

(1) **Various ways to expand the lateral dimension of en-route operations**: FERA-WOC carries out the design by integrally considering the ideal economic trajectory including prevalent high-altitude wind, the boundary of east and west en-route airspace, the special used airspace and navaids, etc. In view of the inadequate ground-based navaids in western China and the complicated military flight activities, a variety of on-demand combinations of sector entry and exit points, intermediate points, conditional routes, and free maneuvering zones are used to supplement fixed ATS routes, which expand the solution space of en-route flight trajectory planning and handling, achieving higher operational flexibility and efficiency.

(2) **A richer mechanism for FUA in China**: FERA-WOC is based on a more dynamic and refined FUA mechanism. Considering the current overall principles of military and civil flight operations in China, as well as the restrictions in the western airspace, ways such as CAT I and CAT II Conditional Routes (CR), and Reduced Coordination Airspace (RCA) may be adopted to supplement the existing FUA mechanism with temporary routes as the main means.

(3) **Support aircraft with different onboard capabilities**: In view of the practical problems of insufficient ground-based navaids in western China, uneven capabilities of aircraft onboard equipment, and considering the current transition phase from traditional operation to trajectory-based operation, the designed FERA-WOC sector entry and exit points include predefined points and arbitrary coordinates. Aircraft that do not have 4D capabilities can choose to take significant points as the entry and exit points, or simply fly along the ATS route; aircraft with advanced 4D capabilities can fly between any feasible entry and exit points of FERA-WOC.

4.5.3.4 CHALLENGES

The realization of the FERA-WOC goal requires a more flexible airspace use mechanism on the one hand, and focus on the uncertainty of the traffic structure caused by the expansion of spatial dimensions and its impact on the ATC workload on the other hand. The above-mentioned concerns are also the main challenges faced by the operation of FERA-WOC.

(1) **The uncertain effect of the proposed FUA mechanism:** Establishing a military-civilian coordination mechanism and improving the ability of flexible allocation of airspace resources are the main ways to build FERA-WOC. The FERA-WOC concept clarifies the key elements to improve the utilization of airspace resources, such as increasing sector entry and exit points, conditional routes, free maneuvering areas, etc., but may be restrained by frequent military activities in local airspace that leads to the difficulty in airspace coordination. These obstacles that could jeopardize the full application of the mechanism will in turn affect the flexibility of trajectory selection in the overall western airspace, which is one of the main challenges faced the implementation of FERA-WOC.

(2) **Highly dynamic airspace traffic situation**: FERA-WOC is an adaptive combination of multiple types of airspace elements. The air traffic flow pattern has changed from a highly regular structure to a dynamic and random decentralized type. The complexity of air traffic situation awareness would increase, which in turn affects the workload of controllers and flight safety. How to accurately predict the operational capacity of the FERA-WOC sector is key element for carrying out Demand and Capacity Balancing (DCB) and trajectory planning, and it is also another key challenge facing the implementation of FERA-WOC.

4.5.3.5 TARGET TRL

Under the scope of this GreAT project, NUAA envisages to further develop metrics and algorithms to identify the boundary that divides China’s en-route network into the eastern (fixed route) and western (flexible route) region, and construct Flexible En-Route Airspace in the West of China (FERA-WoC).

The target TRL is 3. This approach will be further worked out in GreAT WP3.1 by means of user requirement workshops, and real-time human-in-the-loop simulations. The results of FERA-WoC studies will be the input for green trajectory optimization of long-haul flight in GreAT WP3.2 and WP3.3.

4.5.4. RELATION TO ICAO AND SESAR CONCEPTS AND TRENDS

This chapter assesses the compliance of the proposed concept examples described above with ICAO operational concept and requirements. The ICAO Global Air Navigation Plan Doc 9750 [ICAO 2016] is a strategic document that guides the efforts of States, Planning and Implementation Regional Groups (PIRGs), and international organizations in transitioning towards the global ATM system envisaged in the Global ATM Operational Concept Doc 9854 [ICAO 2005]. It introduces also the consensus-driven Aviation System Block Upgrades (ASBU) systems engineering modernization strategy. This helps to map the ICAO GANP vision with the research activities performed and being explored within SESAR and CAAMS programs, proving their consistency and alignment.

In addition, the ICAO Doc 9854 presents a vision for an integrated, harmonized, and globally interoperable ATM system and its high-level requirements are provided in the Manual on Air Traffic Management System Requirements Doc 9882 [ICAO 2008]. TBO is seen as the operationalization of Doc 9854.

Being at the very beginning of the GreAT project, the ideas and concepts presented in this deliverable are considered as steps towards the implementation of the principles and requirements defined by ICAO. A particular attention is also given to the consistency of GreAT project outcomes with the future ATM research programs and activities in Europe and China.

The concept examples 1, 2 and 3 defined in chapters 4.5.1, 4.5.2 and 4.5.3 are cross-checked against the concepts laid down in the ICAO doc 9854. The following Table 21, Table 22 and Table 23 present the results of these analysis. Being only high-level concepts, these examples are not assessed in regards to the 216 requirements identified in the doc 9882. This will be done at a later stage of the project, when appropriate and when these concept examples and ideas are translated in precise system requirements.

Table 21. Compliance of Example 1 with ICAO vision and roadmap

ICAO concepts (Doc 9854)	Compliance assessment	Example 1: New TMA airspace design and guidance procedures
Airspace Organization and Management	Compliant	The concept proposed in ICAO document is very ambitious especially with the targeted period (2005-2025). The new proposed design of the TMA as defined in concept Example 1 is simple and straight forward, allowing flexible planning of dynamic trajectories. It is compliant with the overall idea and concept of ICAO, despite it is fulfilling only parts and primarily focusing on environment impact.
Aerodrome Operations	Compliant	Concept example 1 contains A-CDM elements, such as the coupling of AMAN and DMAN, as well as the consideration of taxi routes and taxi times, to allocate target off-block times, and

		consequently, target start-up approval times. Although being comparable to that, the existing operational A-CDM standards are neither the driving principles nor are they explicitly implemented as such.
Demand and Capacity Balancing	N/A	Strategic and pre-tactical DCB is not part of this concept. However, due to the enhanced AMAN / SMAN functionalities, basic elements of tactical DCB are available in Example 1.
Traffic Synchronization	Compliant	Example 1 is compliant with this concept. With a larger horizon for AMAN and DMAN, an efficient taxi route planning system (SMAN) and a coordination between all these tools, the demand and capacity could be better balanced. However, it should be noted that in this optimization process, the priority is given first to the reduction of environment footprint and then to the capacity.
Airspace User Operations	Compliant	The concept example 1 is aiming to meet as much as possible the user preferred trajectory. Being the shortest and the most efficient, the green trajectories explored and evaluated within GreAT project match in most cases with the user preferred trajectory. The idea behind is to meet the most efficient and optimal trajectories so that to reduce the environment impact.
Conflict Management	Compliant	This ICAO concept defines three-layer conflict management: strategical level, a separation provision level and the collision avoidance level. The new airspace design of the TMA as per concept example 1 takes the conflict management into consideration to ensure safe aircraft operation and limits the risks of collision. However, it focuses more on the strategic conflict management.
ATM Service Delivery Management	N/A	This aspect is not covered by the concept example 1.

Table 22. Compliance of Example 2 with ICAO vision and roadmap

ICAO concepts (doc 9854)	Compliance assessment	Example 2: Enhanced system supported T-Bar approach procedure
Airspace Organization and Management	Compliant	This aspect is not covered by the concept example 2. However, example 2 will contribute to point b) and c) under Chapter 2.1.2. of ICAO doc 9854 [ICAO 2005].
Aerodrome Operations	N/A	This aspect is not covered by the concept example 2.

Demand and Capacity Balancing	N/A	This aspect is not covered by the concept example 2.
Traffic Synchronization	Compliant	This aspect is covered by example 2 and in line with ICAO prescriptions, as, quote: "…Arrival operations will also benefit from these tools; however, the primary task in this phase will be to plan and achieve optimum spacing and sequencing of the arrival flow.
Airspace User Operations	Compliant	The concept example 2 is aiming to meet as much as possible the user preferred trajectory. Being the shortest and the most efficient, the green trajectories explored and evaluated within GreAT project match in most cases with the user preferred trajectory. The idea behind is the same that in the case of example 1, to meet the most efficient and optimal trajectories so that to reduce the environment impact.
Conflict Management	Compliant	With redesign of Budapest TMA, conflict management was dealt with on procedure design level (SID, STAR, route structure, optimal crossing points).
ATM Service Delivery Management	N/A	This aspect is not covered by the concept example 2.

Table 23. Compliance of Example 3 with ICAO vision and roadmap

ICAO concepts (doc 9854)	Compliance assessment	Example 3: FERA-WoC
Airspace Organization and Management	Compliant	Dynamic and flexible airspace management is one of the key features of AOM proposed by ICAO. In addition, ASBU Performance Improvement Area 3, which is Optimum capacity and flexible flights, further states that introduction of free routing in defined airspace, where the flight plan is not defined as segments of a published route network or track system to facilitate, adherence to the user-preferred profile. The FERA-WoC defined in concept Example 3 aims to improve the flexibility of greener trajectory planning. It is compliant with the overall idea and concept of ICAO, despite it is not fully free for routing according to the current airspace management situation in China.
Aerodrome Operations	N/A	This aspect is not covered by the concept example 3.

Demand and Capacity Balancing	Compliant	Complexity and dynamic airspace capacity are one of the key issues that shall be considered in concept example 3, which is the foundation to implement air traffic flow management and trajectory planning. It is partially compliant with the overall idea and concept of ICAO on DCB.
Traffic Synchronization	N/A	This aspect is not covered by the concept example 3.
Airspace User Operations	Compliant	The concept example 3 is aiming to provide en-route airspace with higher-freedom to meet as much as possible the user preferred trajectory. Prevalent wind field will be taken into account in entry and exit point design. The idea behind is to meet the most efficient and optimal trajectories so that to reduce the environment impact.
Conflict Management	Compliant	With redesign of en-route airspace in west of china, conflict management will be dealt with on entry and exit point design level in terms of complexity.
ATM Service Delivery Management	N/A	This aspect is not covered by the concept example 3.

From the individual assessment of the three concept examples in regards to the compliance with ICAO (refer to Table 21, Table 22 and Table 23), it can be concluded:

- Either because of its high ambitions or because of local circumstances (for instance the current airspace management situation in China), the concept `Airspace Organization and Management (AOM)´ could not be entirely covered by the concepts being developed within this project. However, its overall idea is adopted while proceeding by steps.
- The second concept `Aerodrome Operations (AO)´ is not applicable to examples 2 and 3 which are dealing more with the approach and the en-route phases of the flight. However, example 1 supports this concept for instance by enhancing the coordination between the sequencing and planning tools.
- The concept `Demand and Capacity Balancing (DCB)´ could act in some cases against the environment. The targeted optimization as defined by DCB concept seeks, through CDM, primarily the maximization of the runway throughput and consequently the increase of the overall capacity. As evaluated in chapter 4.4 and summarized in Annex A, both KPAs `Capacity´ and ` Environment ´ often oppose to each other. Consequently, the concepts developed within Great could not be totally compliant with the DCB concept. Nevertheless, some aspects of this concept are considered in the concepts proposed in GreAT while balancing the impact on both capacity and environment.
- The concept `Traffic Synchronization (TS)´ is supported by the concept of the examples 1 and 2 in the related flight phase. In fact, an optimized flight sequence enables to avoid additional delays and detours, thus reducing the environment impact. The only difference here is that from GreAT perspective, more priority will be given to the environment aspects while limiting the impact on the capacity.

- All the proposed concepts in GreAT are in line with the concept `Airspace User Operations (AUO)´ as the user preferred trajectory is oft the most efficient, direct, optimized and then the greenest trajectory.
- The concept `Conflict Management´ is necessary considered in all the three examples because the safety of operation is above all the first element to be looked at when evolving towards new airspace design, tools, technologies or procedures.
- The concept `ATM Service Delivery Management´ is not covered by the three examples, being research activities at a very early stage.

To sum-up, the three examples described in this deliverable are compliant with ICAO, although they are not covering all aspects and concepts defined the Global ATM Operational Concept Doc 9854 [ICAO 2005]. This is quite understandable as GreAT project is mainly focusing in the optimization of the flight trajectories though the improvement of the airspace design and controller supporting tools towards trajectory-based operations. This only one of multiple fronts that should be addressed to fulfill the ambitious objectives and concepts defined by ICAO.

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6. ANNEX A – SUMMARY OF THE CONCEPT ELEMENTS AND THEIR POTENTIAL ENVIRONMENTAL IMPACT

This annex gathers all the concept elements described in chapter 4.4 Greener Air Traffic Concept Elements mapped with the best-case scenario. It shows also their potential impact on the environment and on the other KPIs.

Type of operation	Concept Elements	Related Best-Case situation	Environment Impact Evaluation[60]	Impact on the other KPAs
Ground Operations				
Ground operation	• EL 1: On-board system supporting 4D taxi execution • EL 2: advanced integrated planning and scheduling tools • EL 3: 'tow-in' maneuver	4.1.1 A and B	Low (medium)	• Aerodrome Capacity
Continuous taxi operations	• EL 4: Use parallel runways (almost) in segregated mode and place the parking areas in the nearest • EL 5: intersection take-off • EL 6: Late touchdown	4.1.1D	Low (High)	• Capacity • environment (noise)
Adapted pre-/post-flight activities	• EL 7: Adapt procedure for the Pre-/Post-Flight Activities • EL 8: Consider this procedure for future aircraft designs and operation manuals • EL 9: Consider the needed time for these activities in the planning tools	4.1.1A	Low (medium)	• Capacity
Propulsion during taxi	• EL 10: Individual engine start-up • EL 11: Use of alternative propulsion techniques (out of scope of Great) • EL 12: Use of external power supply (out of scope of Great)	4.1.1E	Low (High)	• Capacity • ATC capacity

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[60] The evaluation of the potential to reduce fuel is provided for the whole flight (except when the format Impact 1 (impact 2) is used; where impact 1 is the potential to reduce fuel burn for the whole flight and impact 2 only for the related phase)

	- EL 13: update future aircraft designs and operation manuals - EL 14: Consider these restrictions in the planning tools			
Consideration of natural phenomena For Taxi Movements	- EL 15: Reduce drag of the airplane in headwind situations - EL 16: Increase drag of the airplane in tailwind situations - EL 17: articular configuration depending on the topography and landform			- No impact
No thrust reverse during landing roll	- EL 18: avoid reverse thrust - EL 19: use idle reverse - EL 20: integrate EL 18 and EL 20 in the future aircraft design	4.1.1C	Low (High)	- Capacity
TMA Operations				
Free Route in TMA	- EL 21: avoid assign separate routes for arrivals and departures - EL 22: reduce overfly and detours - EL 23: use automated planning tools - EL 24: use 4D TBO around airport - EL 25: use coordination supporting systems	4.1.2D and 4.1.4A/B	High	- Airspace capacity - ATC capacity - Environment
Continuous Descent operations	- EL 26: use strategical measures to support CDA - EL 27: use tactical measures to ease separation provision - EL 28: use coordination support tools to easily coordinate CDOs across different sectors - EL 29: Use TBO in the TMA	4.1.4B	High	- TMA / aerodrome capacity
Latency tolerant delay absorption	- EL 30: early sequencing - EL 31: use TTO instead of delay absorption - EL 32: delay absorption procedure optimization - EL 33: alternate and more reliable communication method	4.1.4A	Medium	- Flexibility
Infinitely variable and low emission delay absorption	- EL 34: more flexible path stretching - EL 35: delay absorption with low-emissions flight parameters (altitude, speed) - EL 36: more precise delay absorption - EL 37: controller assistance tools - EL 38: TBO in the TMA	4.1.4A	low to medium	- ATC capacity
Late-Merging-Principle for arrivals	- EL 39: backup mechanism for less equipped aircrafts		Medium to high	- Equity - Capacity

	- EL 40: automatic air-ground negotiation of the trajectory before entering the TMA			
Continuous Climb Operations	- EL 41: Solve separation conflicts with heading changes - EL 42: Consider the optimum climb profile - EL 43: use automated planning tools	4.1.2E	High	- ATC capacity
Early Spreading of Departures	- EL 44: Consider the lateral and vertical departure trajectory for the sequencing of departures	4.1.2C,D, E and F	low to medium	- Access and equity
Highest freedom of movement with shortest airspace borders	- EL 45: airspace design with more freedom of movement	4.1.2D/E and 4.1.4A	Medium	- Access/ equity - airspace capacity
Avoidance of Speed Control	- EL 46: assist the ATCO to integrate the speed profile - EL 47: use planning tools that consider the speed profile - EL 48: TBO during the last portion of the flight	4.1.4C and 4.1.5B	medium to high	- ATC capacity
Flexible Final approach legs	- EL 49: shorten the final leg through flexible RNP approaches - EL 50: implementing additional obstacle clearance areas - EL 51: 4D-trajectories for the last miles to be flown	4.1.5A	medium to high	- ATC capacity
	En-route Operations			
Free Route during Cruise flight	- EL 52: avoid prescribing fix routes - EL 53: FRA and a more flexible tactical handling of aircraft routes by ATC - EL 54: Use coordination support tools / cross-sector planning tools for larger FRA implementation - EL 55: TBO applied locally in the airspace	4.1.3C	High	- ATC capacity
Standardized Cross-Border ATM	- EL 56: Share the responsibility of service provision - EL 57: Ease coordination between two different ANSPs and make their systems compatible with each other - EL 58: Standardize ATC fees - EL 59: Establish multi-national service providers	4.1.3C	Medium	- Cost efficiency

In-Flight Trajectory Optimization	• EL 60: enhanced connectivity between airspace users and service providers • EL 61: share real time position/ conditions with other airspace users • EL 62: possible re-plan and re-file of the flight in-flight • EL 63: enable the ASNP to prioritize, accept or deny requested route updates • EL 64: Balance the update interval with the degree of flexibility	4.1.3C	Medium (long-haul) / low (short-haul)	• Predictability
Free Vertical Movement	• EL 65: Allocate narrow level bands instead • EL 66: Use conflict detection tools using these level bands • EL 67: Apply and establish vertical separation on a tactical basis only when needed	4.1.3	Low (around 1.5%)	• Capacity
Free cruise Speed	• EL 68: Avoid speed restrictions at all • EL 69: Prefer lateral / vertical separation instead of using speed control • EL 70: Clear the aircraft for a lower and an upper speed limit if restrictions are unavoidable	4.1.3A	Low (around 2.4%)	• Predictability