Scope and definition of the concept of operations for the project

Deliverable D2.1

APACHE

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APACHE

ASSESSMENT OF PERFORMANCE IN CURRENT ATM OPERATIONS AND OF NEW CONCEPTS OF OPERATIONS FOR ITS HOLISTIC ENHANCEMENT

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Abstract

The APACHE project proposes a new approach to assess European ATM performance based on simulation, optimization and performance assessment tools that will be able to capture the complex interdependencies between KPAs at different modelling scales.

This document is the baseline for the Project and defines the operational context which encompasses the evaluation studies that will be carried out in the Project. The baseline and SESAR 2020 target operations definition within the context of APACHE will permit to settle the scope of the project and trace it within the context of the SESAR programme. This traceability is carried out as per SESAR solutions to be assessed, that could be assessed or that enable other solutions to be assessed within the Project.

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[1] The opinions expressed herein reflect the author's view only. Under no circumstances shall the SESAR Joint Undertaking be responsible for any use that may be made of the information contained herein.

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1 Introduction

1.1 Purpose, context and scope of the document

The APACHE Project covers the topic *ER-11-2015 – ATM Performance within the area of ATM Operations, Architecture, Performance and Validation* and proposes a new approach based on simulation, optimization and performance assessment tools, which aims to capture complex interdependencies between Key Performance Areas (KPA) at different modelling scales (micro, meso and macro).

This Deliverable *D2.1 - Scope and definition of the concept of operations for the project*, can be seen as the baseline document of the Project. It is the sole output of Project's work package (WP) 2: *WP2 - Scope and definition of the concept of operations* and aims to set the different contexts of operations that will be considered in the new APACHE system developed within the Project. From this operational context, the scope of the Project is concreted and a set of SESAR solutions is identified to be subject of study during the assessing activities of the Project. Finally, D2.1 aims to set up the pavement of the potential evolution of the concept towards higher levels of maturity.

This Document is the main input for WP3 - *Key performance indicators (KPI) review and definition of novel KPIs*, where a review of current KPIs for the contexts of operations identified in this D2.1 will be performed, together with a proposal for new indicators, which could be computed with the APACHE system developed in this Project. As result, WP3 will produce Deliverable *D3.1 - Review of current KPIs and proposal for new ones*. Moreover, D2.1 and D3.1 will provide with the essential information to identify the functional requirements for the APACHE framework. Thus, as final output for WP3, *Deliverable D3.2 - Functional requirements and specification for the ATM performance assessment framework* will be produced, serving as starting point for *WP4 - Development of the APACHE framework* (see Figure 1-1 below).

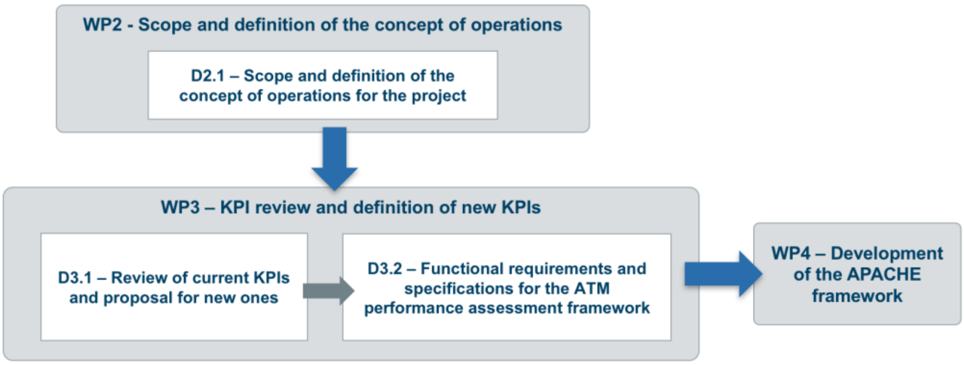

Figure 1-1. Context of deliverable D2.1

1.2 Document structure

The document is structured as follows:

- **Section 1:** Purpose, context and scope of the document; document structure; SESAR context and definitions, Glossary and definition of terms.
- **Section 2:** The APACHE Project is presented, summarising its background and motivation, its high-level objectives and outcomes and, briefly, the research approach proposed.
- **Section 3:** The APACHE system is described, including the basic elements of both the current ATM paradigm and the SESAR 2020 target ATM paradigm that should be modelled to capture the main actors and stakeholders of the ATM, together with their principal performance drivers and interrelations between the same.
- **Section 4:** concludes this report.

1.3 SESAR 2020 context and definitions

As the project is encompassed within the SESAR 2020 framework, some concepts need to be clarified in order to understand the context of this document. This section details several SESAR definitions and concepts.

1.3.1 SESAR Solution

The SESAR 2020 programme output is defined and packed in the form of “SESAR Solutions”. SESAR Solutions contain outputs from R&I activities which relate to either an Operational Improvement (OI) step or group of OI steps and associated enablers which have been designed, developed and validated in response to validation targets that when implemented, will deliver performance improvements to European ATM (SESAR Joint Undertaking, 2015b).

Appendix A of this document contains a complete list of the SESAR solutions that have been identified in the course of activities of APACHE WP2 (SESAR Joint Undertaking, 2016a, 2016b).

1.3.2 Capability

A Capability is the collective ability to deliver a specified type of effect or a specified course of action. Within the context of the SESAR Programme, a capability is therefore the ability to support the delivery of a specific operational concept to an agreed level of performance (EUROCONTROL, 2015e).

1.3.3 Operating Environments

The R&D solutions under SESAR 2020, will contribute to the improvements and benefits to be realised through the gradual implementation and deployment of the SESAR ConOps. The following aspects of four operational environments (airport, en-route, TMA and network) need to be considered for SESAR 2020 (SESAR Joint Undertaking, 2016c):

- Traffic Characteristics (including Airport) - Presented by Long term forecasting with horizons of up to twenty years, as indicated in (EUROCONTROL, 2013).

- Capacity Characteristics (SESAR Joint Undertaking, 2015a):
    - Airports: Combination of Utilisation / Layout.
    - TMA: Low Medium/High Complexity.
    - **En Route:** For En Route Operating Environments, the categories are based on the Complexity score (a composite measure combining traffic density (concentration of traffic in space and time) with structural complexity (structure of traffic flows) described in the PRR Report 2013 (EUROCONTROL, 2014). See Section 2.2.2 of this document for more information.
- Airport Capacity - Presented in (EUROCONTROL, 2013)
- Environmental Impact - Presented in (EUROCONTROL, 2013)

1.4 Glossary and Definition of Terms

A list of the important terminology and acronyms used in this document is presented below. They are taken, when available, from the SESAR ATM Lexicon (EUROCONTROL, 2015e).

Term	Explanation
(A)FUA	(Advanced) Flexible Use of Airspace
ACAS	Airborne Collision Avoidance System
ACC	Area Control Centre
ADP	ATFCM Daily Plan
ADS-B	Automatic Dependent Surveillance – Broadcast
ADS-C	Automatic Dependant Surveillance - Contract
AeroMACS	Aeronautical mobile airport communication system
AIRE	Atlantic Interoperability Initiative
AMAN	Arrival Management
ANM	ATFCM Notification Message
ANSP	Air Navigation Service Provider
AO	Aircraft Operator
AOC	Airport Operations Centre
AOP	Airport Operations Plan
APACHE	Assessment of performance in current ATM operations and of new concepts of operations for its holistic enhancement
A-PNT	Alternative Position, Navigation and Timing
ARES	Airspace Reservation/Restriction
ASAS	Airborne Separation Assurance System
AOM	Airspace Organisation and Management
ASP	Airspace Planning (APACHE system module)
ASM	Airspace Management
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATFCM	Air traffic flow and capacity management
ATFM	Air traffic flow management
ATM	Air traffic management
ATS	Air Traffic Service
ATSU	Air Traffic Services Unit

Term	Explanation
AU	Airspace User
CANSO	Civil Air Navigation Services Organisation
CASA	Computer Assisted Slot Allocation
CAT	Category
CCC	Continuous Cruise Climb
CCO	Continuous Climb Operations
CDM	Collaborative Decision Making
CDO	Continuous Descent Operations
CNS	Communication, Navigation and Surveillance
COBT	Calculated Off-Block Time
ConOps	Concept of operations
CORA	Conflict Resolution Assistant
CPDLC	Controller-Pilot Data-Link Communications
CTA	Controlled Time of Arrival
CTO	Controlled Time Over
CTOT	Calculated Take-Off Time
CWP	Controller Working Position
DAC	Dynamic Airspace Configuration
DCB	Demand and Capacity Balance
DCM	Dynamic Capacity Management
dDCB	Dynamic Demand and Capacity Balancing
DMAN	Departure Management
DOD	Detailed operational description
D-TAXI	Data-link taxi clearance delivery
DUC	Determined Unit Cost
EAP	Extended ATC Planning
ECAC	European Civil Aviation Conference
EN	Enabler
EOBT	Estimated Off-Block Time
EoSM	Effectiveness of Safety Management
ER	Exploratory research
ETD	Estimated Time of Departure
ETFMS	Enhanced Tactical Flow Management System
ETO	Estimated Time Over
ETOT	Estimated Take-Off Time
EU	European Union
FAB	Functional Airspace Block
FCI	Future Communications Infrastructure
FIR	Flight Information Region
FL	Flight Level
FLP	Flight Plan
FMP	Flow Management Position
FMS	Flow Management System
FOC	Flight Operations Centre

Term	Explanation
FRA	Free Route Airspace
FRT	Fixed Radius Transition
G/G	Ground-to-Ground
GA	General Aviation
GBAS	Ground Based Augmentation System
GLS	GNSS Landing System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICAO	International Civil Aviation Organisation
IFPS	Initial FPL Processing System
IFR	Instrument Flight Rules
ILS	Instrument Landing System
INAP	Integrated Network Management and Extended ATC Planning
INP	Initial Network Plan
KPA	Key Performance Area
KPI	Key Performance Indicator
LoA	Letter of Agreement
LPV	Localizer performance with vertical guidance
LTM	Local Traffic Management
LVC	Low Visibility Conditions
LVP	Low Visibility Procedures
MCP	Mandatory Cherry Pick
MDI	Minimum Departure Intervals
MET	Meteorology/Meteorological information
MIT	Miles in Trail
MO	Management Objective
MSP	Multi Sector Planning
MTCD	Medium-Term Conflict Detection
NM	Network Manager
NMF	Network Manager Function
NMOC	Network Manager Operations Centre
NMPP	Network Manager Performance Plan
NOP	Network Operations Plan
NSA	National Supervisory Authority
NSP	Network Strategy Plan
OE	Operating Environment
OFA	Operational Focus Area
OI	Operational improvement
OIs	Operational Improvements steps
OSED	Operational Service and Environment Definition
P&S	Processes and Services
PBO	Performance Based Operations
PCP	Pilot Common Project
PRB	Performance Review Body

Term	Explanation
PRU	Performance Review Unit
RA	Risk Assessment (APACHE system module)
RBT	Reference Business Trajectory
RMT	Reference Mission Trajectory
RNP	Required Navigation performance
RPAS	Remotely Piloted Aircraft Systems
SBT	Shared Business Trajectory
SES	Single European Sky
SESAR	Single European Sky ATM Research
SJU	SESAR Joint Undertaking
SMT	Shared Mission Trajectory
SPR	Safety and Performance Requirements
STAM	Short Term ATFCM Measures
STCA	Short Term Conflict Alert
SWIM	System wide information management
TAP	Trajectory and airspace planner
TBO	Trajectory Based Operations
TCP	Traffic and Capacity Planning (APACHE system module)
TC-SA	Trajectory Control by (Ground Based) Speed Adjustments
TCT	Tactical Controller Tool
TMA	Terminal Manoeuvring Area
TP	Trajectory Planning (APACHE system module)
TRACT	Trajectory Adjustment through Constraint of Time

Table 1-1. Glossary of terms

2 The APACHE Project

At present, the European Air Traffic Management (ATM) is evolving in a coordinated manner aiming at improving the overall efficiency of air navigation services across several **key performance areas (KPAs).** In this context, novel operational and technical concepts are proposed in the SESAR programme, and the evolution of these concepts is driven by the European ATM Master Plan through a set of EU-wide performance targets with the help of the Single European Sky (SES) Performance Scheme, which establishes an agreed methodological framework for performance targeting, measuring, baselining and benchmarking in ATM.

The APACHE project proposes **a new approach to assess European ATM performance based on simulation, optimization and performance assessment tools** that will be able to capture the complex interdependencies between KPAs at different modelling scales (micro, meso and macro).

This section details the scope of the APACHE project. First, some background is given on the Single European Sky (SES) programme, introducing the motivation for the current project. Then the APACHE project and objectives are presented, along with the proposed research approach.

2.1 Background and motivation

The International Civil Aviation Organization (ICAO) launched in 2003 a worldwide initiative to ensure that the future global ATM system is performance based. For that purpose, ICAO has developed two documents: ICAO Doc. 9882 (ICAO, 2008) and Doc. 9883 (ICAO, 2009). Worldwide support to ICAO initiative is also given by the CANSO (Civil Air Navigation Services Organisation) which published a document: "Recommended Key Performance Indicators for Measuring ANSP Operational Performance" in March 2015. In line with this initiative, current ATM performance assessment is addressed in Europe through the **Performance Scheme** defined in the Implementing Regulation No 390/2013 (European Commission, 2013). As stated in such document, the performance scheme should contribute to sustainable development of the air transport system by improving the overall efficiency of air navigation services across the key performance areas of safety, environment, capacity and cost-efficiency.

The Single European Sky (SES) High Level goals are political targets set by the European Commission with the support of the Single Sky Committee. The scope of the SES High-Level Goals is the full ATM performance outcome resulting from the combined implementation of the SES pillars and instruments as well as industry developments not driven directly by the EU. In 2012, the Commission stated its political vision and set high-level goals for the SES to be met by 2035 and beyond. In (SESAR Joint Undertaking, 2015) these goals are updated, with respect the baseline year 2012, as:

- enable a 2-fold increase in capacity and thus reducing delays both on ground and in the air;
- improve safety by a factor of 3-4;

- enhance the operational flight efficiency by reducing the fuel burnt in a 3-6% per flight and the trip duration in a 5-10% per flight;
- enable a 5-10 % reduction in the effects flights have on the environment; and
- provide ATM services to the airspace users at a cost of at least 30-40% less.

These overarching goals are the initial foundation of the SES Package and thus must be always kept in mind when assessing Performance in ATM in Europe. SES High-Level Goals receive the contribution from all the SES Pillars, including SESAR and the Performance Scheme. As such, both will be analysed in APACHE project and considered when working on the definition of new Performance Metrics.

The SESAR 2020 Concept of Operations (SESAR Joint Undertaking, 2016c) refers to innovative concepts such as TBO and PBO **(Trajectory Based Operations** and **Performance Based Operations)**. Under these paradigms, a more dynamic optimisation and allocation of airspace to enable the airspace users to access required airspace with minimum constraints is also foreseen. It is expected that these new concepts will have a significant impact in ATM performance and **new metrics and models to capture it will be needed**. Moreover, it will also be essential to understand the **complex interdependences that exist among the different KPAs**, and how improving one particular area might eventually affect the performance of other area(s).

2.2 Project scope and objectives

The high-level objective of the APACHE Project is to provide with **new methodologies to capture the performance impact of ATM operations on different stakeholders**, in line with SESAR 2020 ConOps (SESAR Joint Undertaking, 2016c)**,** taking into account a wide range of KPAs and proposing innovative or enhanced metrics and indicators. In this context, specific objectives of the Project are:

- to **propose new metrics and indicators** capable of effectively capturing European ATM performance under either **current or future concept of operations**, fostering a progressive performance-driven introduction of new operational and technical concepts in ATM in line with SESAR goals;
- to make an (initial) **impact assessment of long-term ATM concepts** (in line with some relevant SESAR solutions), with the new APACHE Performance Scheme**,** measuring the impact on ATM KPAs under different assumptions and hypotheses; and
- to **analyse the interdependencies between the different KPAs by capturing the Pareto-front** of ATM performance, by finding the theoretical optimal limits for each KPA and assessing how the promotion of one KPA may actually reduce (and in which proportion) the performance of other KPAs.

2.2.1 Assumptions and limitations of the Project

Taking into account the exploratory nature of the APACHE project and its duration (2 years), the following assumptions are applied:

- Only the en-route airspace structure is considered: TMA operations differ significantly from en-route ones and are not to be considered. Since the limit between en-route and departure/arrival phases is not always the same and depends on the TMA configuration, as a first approximation, only those portions of trajectories above FL195 will be considered.

This corresponds with the upper altitude limit of the majority of TMAs in the ECAC. Table 2-1 below shows the upper limit of the main European TMAs and the FIR/UIR limits in the ECAC area. This assumption does not mean that aircraft climbing/descending are not considered, since at this altitude aircraft are certainly still climbing or already descending.

- Only Instrumental Flight Rules (IFR) traffic will be considered in the simulations, neglecting Visual Flight Rules (VFR) traffic.
- All simulated airspace (ECAC level) is considered for civil usage only and therefore segregated airspace or (advanced) flexible use of airspace (A)FUA concepts are not considered (no civil-military coordination will be considered).
- Remotely Piloted Aircraft Systems (RPAS) and Unmanned Aircraft Systems (UAS) operations will not be considered.
- Only nominal flight operations will be simulated: contingency or emergency procedures will not be taken into account.
- Interactions with airports will not be considered. Thus, all delays due to airport operations will be neglected. Similarly, all delay attributable to airspace users (such as maintenance issues) will also not be modelled. It should be noted, however, that these types of delay could eventually be introduced "manually" into the simulation platform by defining the accordingly some input scenario parameters and/or by modelling these delays as part of the uncertainty associated to the initial flight time-stamp. In other words, airport/airline delay could be considered as independent input variables in the simulations, but will not be modelled as part of the ATM process.
- Similar to previous point, interactions with TMA operations will not be considered. Thus, all delay and changes in the flight trajectory produced by arrival/departure managers (A/D-MAN) or by tactical ATC intervention (such as path stretching) will not be considered.

TMA	Upper limit	Reference	TMA	Upper limit	Reference
London	FL195	(EUROCONTROL, 2004)	Lisboa	FL245	(IVAO-PT, 2016)
Paris	FL195	(EUROCONTROL, 2004)	Stockholm	FL195	(Dervic & Rank, 2015)
Frankfurt	FL100	(EUROCONTROL, 2004)	Zurich	FL195	(Skyguide, 2016)
Madrid	FL245	(ENAIRE, 2016)	Brussels	FL195	(Belgocontrol, 2016)
Schiphol	FL095	(Air Traffic Control the Netherlands, 2016)	Copenhague -Kastrup	FL195	(IVAO Nordic Region)
Roma	FL195	(ENAV, 2014)	Scottish	FL195	(NATS, 2016)
Milano	FL195	(ENAV, 2014)	Athens	FL245	(IVAO, 2009)
Munich	N/A		Malta	FL195	(Transport Malta, 2016)
Barcelona	FL245	(ENAIRE, 2016)			

Table 2-1. Upper limit of main European TMAs

2.2.2 Operating Environments and Stakeholders

The SESAR **Operating Environment** (OE) applicable to the APACHE project and thus to the Operational Context defined in this document is **En-route**. The subcategories of this OE are **Low, Medium and High complexity** (SESAR Joint Undertaking, 2016c). These categories are based on the complexity score, a composite measure combining traffic density (concentration of traffic in space and time) with structural complexity (structure of traffic flows) described in the PRR 2013 Report (EUROCONTROL, 2014):

- low complexity en-route has a complexity score of less than 2;
- medium complexity en-route has a complexity score of between 2 and 6; and
- high complexity en-route has a complexity score of more than 6.

APACHE assessments will be done initially at functional airspace block (FAB) level; and a later stage, at ECAC level. Specific scenarios will be created to reproduce low, medium and high complexity operating environments.

Stakeholders are organisations and entities which are in charge of the deployment, the timeframe and the operating environments where the changes will impact and deliver benefits. The stakeholders relevant in the APACHE project are **ANSPs and Airspace Users.**

2.2.3 Link with SESAR Solutions

To trace the scope of the APACHE project within the context of the SESAR programme, a group of SESAR solutions have been identified as relevant in the framework of the Project. From the complete list of 151 solutions found (see Complete SESAR Solutions list in Appendix A), 23 have identified taking into account the project scope and limitations and considering only SESAR solutions proposed in the **SESAR 2020** program. Furthermore, another relevant aspect for this selection has been taken into account: the capabilities that are expected by the APACHE Framework, given the duration and planned effort of the Project.

Table 2-2 shows the list of solutions selected. The solutions have been grouped in **three** different categories, which correspond to the following criteria:

- **SESAR solutions to be (initially) assessed in APACHE**: Given the assumptions and limitations of the APACHE framework (see section 2.2.1), these solutions will be considered in the Project and modelled in the APACHE system. This will allow to perform an initial performance assessment of these solutions. The APACHE System will be able to enable/disable these particular solutions (or group of solutions). Specific simulation scenarios and case studies will be designed to carry out these assessments (see section 2.3 for details of the APACHE system and proposed scenarios).
- **SESAR solutions which impact could be assessed by APACHE if some extra modules and/or input data are provided:** solutions that are out of the scope of the Project, but which impact could be assessed with the APACHE System, providing that some extra modules and/or input data is given (such for example ATFM slot swapping algorithms, or UDPP mechanisms). Impact of some of these solutions could be eventually assessed if the effort and schedule constraints of the Project permit so. They also can be seen as possible future applications or studies of the APACHE System.
- **Supporting SESAR solutions for APACHE assessments:** Solutions which impact will be implicitly assessed in APACHE since they are considered as enablers for other SESAR solutions. However, they will not be modelled in APACHE (will be certainly assumed to be enabled in the context of operations) and therefore cannot be enabled/disabled in the APACHE framework.

Solution ID	SESAR Solution Name	Program	Remarks
SESAR solutions to be (initially) assessed in APACHE			
	Continuous Cruise Climb (CCC) Operations		Not identified as SESAR solution, but identified in other programs such as AIRE. Its impact can be assessed in APACHE and can serve as baseline for maximum fuel efficiency flights.
PJ.06-01	Optimized traffic management to enable Free Routing in high and very high complexity environments.	SESAR 2020	
PJ.06-02	Management of Performance Based Free Routing in lower Airspace	SESAR 2020	
PJ.07-01	AU Processes for Trajectory Definition	SESAR 2020	
PJ.08-01	Management of Dynamic Airspace configurations	SESAR 2020	
PJ.09-01	Network Prediction and Performance	SESAR 2020	
PJ.09-02	Integrated Local DCB Processes	SESAR 2020	
PJ.09-03	Collaborative Network Management Functions	SESAR 2020	
SESAR solutions which impact could be assessed by APACHE if some extra modules and/or input data are provided			
PJ.07-02	AU Fleet Prioritization and Preferences (UDPP)	SESAR 2020	Could be assessed with APACHE if the UDPP mechanism is provided and programmed into the APACHE-TAP tool.
PJ.08-02	Dynamic Airspace Configuration supporting moving areas	SESAR 2020	Could be assessed with APACHE if the DMA and some kind of civil-military coordination is implemented into the APACHE-TAP tool.
PJ.10-01a	High Productivity Controller Team Organisation	SESAR 2020	Could be assessed with APACHE if some extra modules and/or input data were provided (workload limit, tasks that influence workload, etc.) linked with MSP.
PJ.15-01	Sub-regional Demand Capacity Balancing Service	SESAR 2020	Could be assessed with APACHE if the configuration parameters of sub-regional DCB service are defined and the different services implemented into the APACHE-TAP tool.

Solution ID	SESAR Solution Name	Program	Remarks
Supporting SESAR solutions for APACHE assessments			
PJ.07-04	AU Trajectory Execution from FOC perspective	SESAR 2020	Enabler for strategic deconfliction, free routing, continuous cruise climbs, collaborative network management functions, etc.
PJ.10-02b	Advanced Separation Management	SESAR 2020	Enabler for strategic deconfliction, free routing, continuous cruise climbs…
PJ.10-04	Ad Hoc Delegation of Separation to Flight Deck	SESAR 2020	Enabler for strategic deconfliction, free routing, continuous cruise climbs…
PJ.11-A1	Enhanced Airborne Collision Avoidance for Commercial Air Transport normal operations - ACAS Xa	SESAR 2020	Enabler for free route, continuous climb operations (CCC), … as improved safety net mechanism.
PJ.11-A3	ACAS for Commercial Air Transport specific operations – ACAS Xo	SESAR 2020	Enabler for free route, continuous climb operations (CCC), … as improved safety net mechanism.
PJ.11-G1	Enhanced Ground-based Safety Nets adapted to future operations	SESAR 2020	Enabler for free route, continuous climb operations (CCC), … as improved safety net mechanism.
PJ.15-08	Trajectory Prediction Service	SESAR 2020	Enabler for collaborative network management functions, strategic deconfliction, demand and capacity balance, etc.
PJ.16-03	Work Station, Service Interface Definition & Virtual Centre Concept	SESAR 2020	Enabler for dynamic sectorisation regardless of country boundaries (FAB level or even SES).
PJ.17-01	SWIM TI Purple Profile for Air/Ground Advisory Information Sharing	SESAR 2020	Enabler for collaborative network management functions, strategic deconfliction, demand and capacity balance, etc.
PJ.18-02	Integration of trajectory management processes in planning and execution	SESAR 2020	Enabler for collaborative network management functions, strategic deconfliction, demand and capacity balance, etc.
PJ.18-04	Management and sharing of data used in trajectory (AIM, METEO)	SESAR 2020	Enabler for dynamic sectorisation, free routing, etc.
PJ.18-06	Performance Based Trajectory Prediction	SESAR 2020	Enabler for dynamic sectorisation, free routing, etc.

Table 2-2. SESAR solutions relevant to the APACHE project

2.3 Research approach

APACHE revolves around a **novel system** that is expected to generate optimal trajectories at microscopic level, with the consideration of the business models of the airspace users, and integrate them into a futuristic air traffic flow management scheme where trajectories are strategically de-conflicted at the same time than airspace complexity is also assessed.

This system will be capable of capturing complex interdependencies at different scales across the main KPAs that define ATM performance. The same system can be configured to reproduce current operations (structured en-route network, flight level allocation and orientation schemes, conventional air traffic flow management, static sectorisations, etc.). Figure 2-1 shows the overall concept of the APACHE simulator framework, which is summarised as follows:

- Different **scenarios** to be studied will be defined, setting up different options regarding the demand of traffic and airspace capacities; the SESAR solutions to be tested; and the level of uncertainty to be studied.
- The **APACHE-TAP** (trajectory and airspace planner) will be able to compute a set of **optimal (ideal) trajectories and airspace sectorisations**, as a function of the input scenario variables, in such a way that safety and complexity levels are maintained below an acceptable level. **This set of optimal trajectories and sectorisations will form the different baselines for the new indicators proposed in APACHE to assess ATM performance**. In other words, they will be the **reference** values where the different "Deltas" (deviations from actual operations) will be computed.
- The **performance analyser** module will be in charge of assessing these outputs (i.e. optimal baselines of traffic and sectors) generated by the APACHE-TAP and according to the different metrics implemented in the inner performance scheme (current and/or new indicators proposed in the APACHE).
- **This approach can contribute to generate knowledge on the complex interrelations among the different KPAs and may be useful to find the Pareto-front of the ATM performance.**

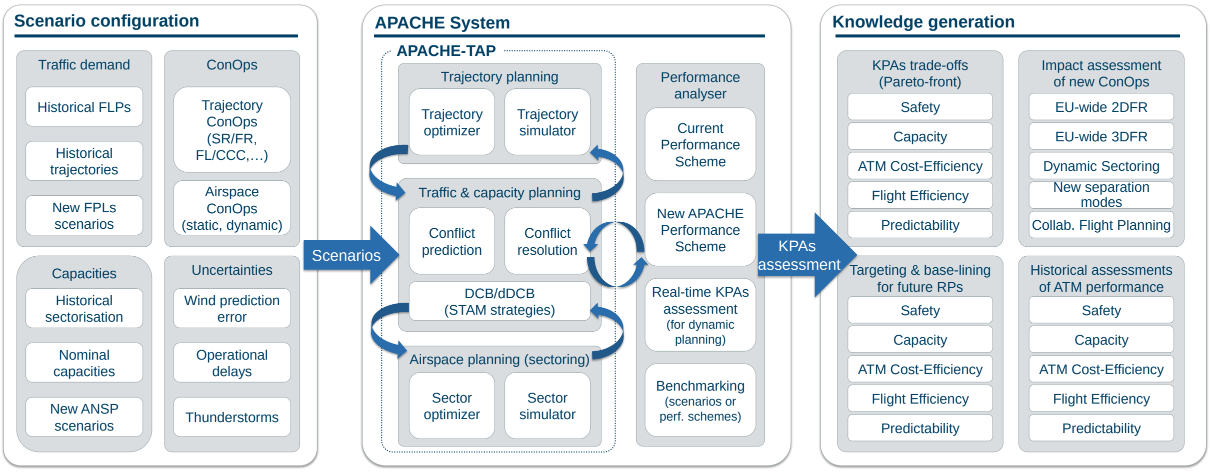

Figure 2-1. The APACHE simulator framework

It is important to point out that there must be a distinction between the "APACHE Concept" and the "APACHE System". The APACHE Concept could be thought as the description of an ideal system envisioned in a high TRL maturity (i.e., TRL9), in which by means of high-fidelity simulations and enhanced indicators the ATM performance could be measured accurately (and possibly in real time), enabling in this way the future paradigm of Performance Based Operations. The APACHE System (part of the simulator framework, as shown in Figure 2-1) is the tool that will be actually built during the scope of this Project, at an early TRL (thus far from the ideally described APACHE concept) and subject to some limitations (some identified in the present section and some in section 3).

The objective of this Deliverable D2.1 is to define the scope of the "APACHE System" (simulator) generating the right expectations in the context of the project, and setting up the pavement of the potential evolution of the APACHE Concept towards higher levels of maturity.

Table 2-3 provides an overview of the preliminary scenarios proposed to address the research objectives of the project and to illustrate the advantages of the APACHE System in assessing ATM performance. It should be noted that the APACHE system will also be able to partially assess the current ATM with the aim to establish a baseline for the operational concepts considered. The final list of scenarios and test cases (variants within the same scenario) will be established later on in the Project, within the activities of WP5.1: *Scenario and Case studies*.

	EU-wide ConOps	**Capacities**	**DCB/dDCB planner**	**Uncertainties**	**Main Interest**
id	**Traffic Demand: Historical trajectory records (recreation)**				
S0	Structured Route Flight Levels Static sectors	Historical nominal sectorisation (recreation)	Conflict detection and hotspot detection	No	**APACHE framework adjustment** (for benchmarking)
Traffic Demand: Historical FPLs (optimization: maximum flight efficiency given this ConOps)					
S1	Structured Route Flight Levels Static sectors	Historical nominal sectorisation (recreation)	Conflict detection and hotspot detection	No	**Baseline scenario** (for benchmarking and comparison with S0)
S2	Structured Route Flight Levels **Dynamic sectors**	**Minimize number of sectors** (balancing the complexity among sectors; max complexity from scenario S1)	Conflict detection and hotspot detection	No	**ATM Cost-Efficiency** (compare number of sectors needed in S1 with optimal in S2)
S3	**Free Route (FR)** Flight Levels Static sectors	Historical nominal sectorisation (recreation)	Conflict detection and hotspot detection	No	**Safety and capacity** ((How much the # of conflicts, the complexity and # of hotspots increase in S3 wrt S1&S3?)
S4	**Free Route (FR)** Flight Levels **Dynamic sectors**	**Minimize number of sectors** (balancing the complexity among sectors; max complexity from scenario S1)	Conflict detection and hotspot detection	No	**ATM Cost-Efficiency and Flight efficiency** (fuel burned, emissions and number of sectors required to support FR + CCC compared with S1)
S5	**Free Route** Flight Levels **Dynamic sectors**	**Minimize number of sectors** (balancing the complexity among sectors; max complexity from scenario S1)	Conflict detection and hotspot detection **Strategic trajectory de-confliction and STAM measures**	No	**Safety, Capacity, ATM Cost-Efficiency, Flight efficiency** (compare with S1, S3 and S4)

	EU-wide ConOps	Capacities	DCB/dDCB planner	Uncertainties	Main Interest
S6	**Free Route** Flight Levels **Dynamic sectors**	**Minimize number of sectors** (Balancing the complexity among sectors; max complexity from scenario S1)	Conflict detection and hotspot detection **Strategic trajectory de-confliction and STAM measures**	**Yes** (wind pred. errors & APT delays)	**Safety, Capacity, ATM Cost-Efficiency, Flight efficiency, Robustness/predictability** (compare with S1, S3 and S4)
S7	**Free Route** **No vertical constraints** Static sectors	Historical nominal sectorisation (recreation)	Conflict detection and hotspot detection	No	**Safety, Capacity** (How much the # of conflicts, the complexity and # of hotspots increase in S3 wrt S1&S3?)
S8	**Free Route** **No vertical constraints** **Dynamic sectors**	**Minimize number of sectors** (balancing the complexity among sectors; max complexity from scenario S1)	Conflict detection and hotspot detection	No	**ATM Cost-Efficiency, Flight efficiency** (fuel burned, emissions and number of sectors required to support FR + CCC compared with S1 and S4)
S9	**Free Route** **No vertical constraints** **Dynamic sectors**	**Minimize number of sectors** (balancing the complexity among sectors; max complexity from scenario S1)	Conflict detection and hotspot detection **Strategic trajectory de-confliction and STAM measures**	No	**Safety, Capacity, ATM Cost-Efficiency, Flight efficiency** (compare with S1 and S5)
S10	**Free Route** **No vertical constraints** **Dynamic sectors**	**Minimize number of sectors** (balancing the complexity among sectors; max complexity from scenario S1)	Conflict detection and hotspot detection **Strategic trajectory de-confliction and STAM measures**	**Yes** (wind pred. errors & APT delays)	**Safety, Capacity, ATM Cost-Efficiency, Flight efficiency, Robustness/predictability** (compare with S1, S3 and S4)
S11	Structured Route Flight Levels Static sectors	Historical nominal sectorisation (recreation)	Conflict detection and hotspot detection	**Yes** (hist. severe weather)	**Safety, Capacity, Robustness/resilience** ((How many sectors and traj. are affected? What is the associated risk? Compare vs S1)
S12	**Free Route** Flight Levels **Dynamic sectors**	**Minimize number of sectors** (balancing the complexity among sectors; max complexity from scenario S1)	Conflict detection and hotspot detection **Strategic trajectory de-confliction and STAM measures**	**Yes** (hist. severe weather)	**Safety, Capacity, Robustness/resilience** (How many sectors and traj. are affected? What is the associated risk? Compare vs S1)
S13	**Free Route** Flight Levels Static sectors	Historical nominal sectorisation (recreation)	Conflict detection and hotspot detection	**Yes** (hist. severe weather)	**Safety, Capacity, Robustness/resilience** (How many sectors and traj. are affected? What is the associated risk? Compare vs S1)

	EU-wide ConOps	Capacities	DCB/dDCB planner	Uncertainties	Main Interest
S2 - Traffic Demand: S1 + x2 traffic demand predictions (**optimization)**					
S14	Structured Route Flight Levels Static sectors	Historical nominal sectorisation (recreation)	Conflict detection and hotspot detection	No	**Safety, Capacity** (compare with S1)
S15	**Free Route** Flight Levels **Dynamic sectors**	**Minimize number of sectors** (balancing the complexity among sectors; max complexity from scenario S1)	Conflict detection and hotspot detection **Strategic trajectory de-confliction and STAM measures**	No	**Safety** **Capacity** (compare with S5 and S11)
S16	**Free Route** **No vertical constraints** **Dynamic sectors**	**Minimize number of sectors** (balancing the complexity among sectors; max complexity from scenario S1)	Conflict & hotspot detection **Strategic trajectory de-confliction and STAM measures**	No	**Safety, Capacity** (compare with S9, S11 and S12)

Table 2-3. Preliminary set of scenarios for research

Section 3 of this document presents the **APACHE System**, providing some background of the baseline operational concepts (i.e., **current ATM model**) that will be assessed in APACHE and stating the SESAR 2020 ATM target concept of operations (i.e., **future ATM**) that will also be assessed in the Project. For both current and future ATM paradigms, it will be outlined **how they will be modelled in the context of APACHE** and discussed **how far the APACHE system can reproduce and assess the ATM performance drivers and their interrelations and trade-offs**.

2.4 Research questions and expected outcomes

The effective integration of micro and macro models in the APACHE system will allow capturing the complex interdependencies among KPAs, which in turn will shed some light on the following (initial) research questions:

- Can the APACHE system provide new indicators to assess the impact of certain SESAR solutions across **all the KPAs proposed by the SESAR 2020 Performance Framework** (SESAR Joint Undertaking, 2016d)?
- With regards to the **limits of flight efficiency**, how much fuel and emission reductions can be achieved by enabling user-preferred free routes at EU-wide level? If the aircraft operators can fly their optimal trajectories without any fixed ATM or airspace constraint (i.e., free routing including continuous cruise climbs)?
- What is the expected **impact in safety and capacity** if free routing and/or continuous cruise climbs are implemented? **Which are the capacity needs** (in terms of number of sectors and configuration) to implement those in Europe if trajectories could be strategically de-conflicted to reduce complexity at sectors?
- With regards to the limits of **ATM cost-efficiency**, what is (approximately) the minimum number of sectors needed to support the current operations and traffic demand to minimize

ATFM delays? And to support Free Routing or continuous cruise climbs at EU-wide or FABs level? And what if the level of demand is a 50% higher, as forecasted for 2035?

- With regards of ATM KPAs, can the **Pareto-front** be estimated? That is, to obtain a representative set of Pareto-efficient solutions in such a way that it is impossible to make any improvement in one particular KPA without making at least one other KPA worse?
- In the presence of **typical sources of flight uncertainties**, such as wind prediction errors or airport delays, which might be the expected impact in **predictability and robustness** of the planning? Which strategies could be implemented to increase predictability and robustness and what might be the impact on other KPAs?

The APACHE system has several important features that are worth mentioning:

- the simulation and optimization tools included in the APACHE framework can be configured to represent different future hypothetical scenarios and operational capabilities;
- the APACHE system can be configured to reproduce historical scenarios (i.e., recorded flight trajectories and airspace sectorisations), enabling in this way the assessment of current ATM operations;
- the new (or enhanced) set of performance indicators that the APACHE system can compute might be useful to other institutions (such as the Performance Review Unit) to assess ATM performance.

The APACHE framework could be also set up as a real-time prototype for monitoring and targeting ATM performance. These real-time capabilities could contribute to the effective implementation of Performance Based Operations (PBO) in the future, i.e. could serve as technological enabler for future PBO paradigm.

Some tangible and practical outcomes of APACHE framework are the following:

- initial assessment on the benefits (and performance trade-offs) when introducing certain SESAR solutions at FAB or ECAC level;
- assessment how the new (or enhanced) performance indicators can capture the ATM performance under current and future ATM paradigms;
- quantitative approximation of the theoretical limits of each KPA in current and future ATM paradigms;
- generation of knowledge and identification of system bottleneck on the complex interrelations among KPAs at the Pareto-frontier; and
- provision of conclusions and recommendations to improve the ATM performance based on traffic patterns and sectorisations provided by the APACHE system.

3 The APACHE System

The purpose of this section is to identify the APACHE system top-level functional requirements (distinguishing between the modelling needs of current and future operations), as part of the project scope description. Such functional requirements will be aligned (as detailed below) with the high-level requirements defined by SESAR 2020 ConOps and for each of the SESAR solutions that will be (initially) assessed in APACHE. Figure 3-1 highlights the main modules of the system.

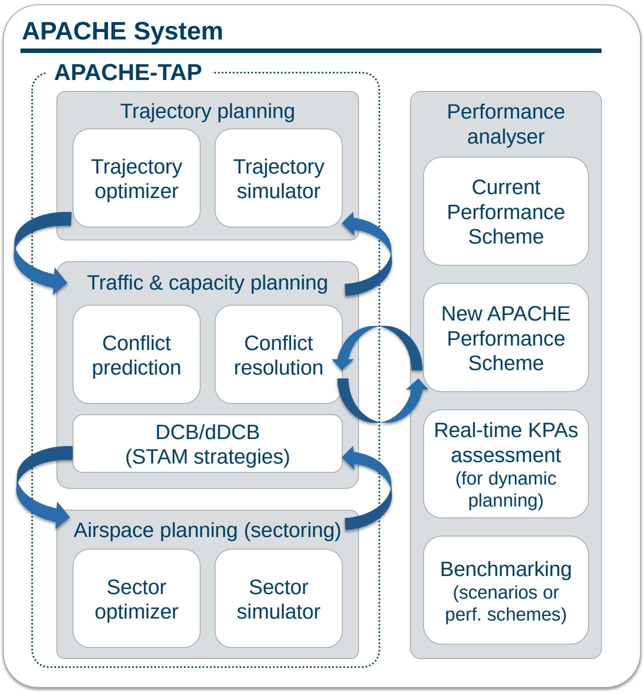

Figure 3-1. The APACHE System

Following section 3.1 introduces the existing tools that form the basis of the APACHE system. Sections 0 and 3.3 describe the basic ATM elements that should be modelled in the APACHE system (see Figure 3-1) in order to capture the main ATM actors/stakeholders and their main performance drivers, together with the interrelations and trade-offs among them. Section 0 explains how the APACHE system will be configured to reproduce the current (baseline) ATM operations, while Section 3.3 will show the way of modelling the future SESAR 2020 concept of operations. Section 3.4 gives details about the Performance Analyser module that will be in charge of applying the new APACHE Performance Framework and assess the current and future ATM operations for posterior analysis and discussion.

3.1 Background Tools

For the development of the APACHE system, a set of existing tools is brought in by the different partners that compose the APACHE consortium. These tools, so far developed separately, will be integrated in a single modular architecture.

Table 3-1 shows a summary of these existing tools, detailing the corresponding APACHE model supported (see Figure 3-1), appropriateness for the APACHE project and the high-level enhancements that will be required to implement to fulfil APACHE objectives.

Existing tool (partner)	Module supported	Appropriateness for APACHE project	Enhancements required for APACHE project
DYNAMO: dynamic aircraft trajectory predictor and optimiser (UPC)	Trajectory Planning	Trajectory estimation (based on flight tracks) and trajectory optimisation to compute preferred trajectories for the aircraft operators or environmentally optimal trajectories.	1.Allow for optimisation considering weather forecasts. 2. Allow for optimisation taking into account separation constraints (pair-wise) 3. Enlarge the set of aircraft types simulated.
Conflict Detection and Resolution integrated in Test-bed Platform for ATM Studies (TPAS) software (UPC)	Traffic and Capacity Planning (DCB and ATC traffic separation)	System able of detecting conflicts and de-conflicting trajectories in a few minutes or seconds with a global scope.	1. Add new functionality to detect hotspots and apply flow strategies (STAM) 2. Extend strategic trajectory de-confliction algorithms to take into account complexity of traffic (i.e., add de-complexification methods). 3. Enhance global deconfliction algorithms to provide with timely solutions for Continuous Cruise Climbs scenarios
Airspace sectorisation and dynamic configuration algorithm based on artificial evolution (ENAC)	Airspace Planning (sectoring)	System able to compute global optimum airspace sectorisation and to account for the dynamical aspect of the traffic with objective to minimize ATC controller's workload.	1. Full coupling of previously developed modules for airspace planning 2. Tool enhancement to adapt to the proposed new ConOps. 3. Advanced complexity metrics integration into objective function
Framework for airspace planning and design based on a conflict risk assessment (UB-FTTE)	Risk and Performance Assessment tools	System able to compute conflict risk, determination of task-load and number of conflicts in a given sector dependant of traffic flow and separation minima applied.	Enhance tool to enable computing of novel PI/KPIs and to tackle the proposed new ConOps.

Table 3-1. Summary of existing tools

Further details on the referred tools will be given throughout the following sections as corresponding functionalities of the APACHE system are introduced.

3.2 Baseline Operations (current ATM model)

Air transportation is enabled by a variety of Communication, Navigation and Surveillance (CNS) systems and human resources that compose the Air Traffic Management (ATM) system to guarantee the safe and efficient execution of flights from airport to airport. In this sense, the International Civil Aviation Organisation (ICAO) defines the ATM as *"the aggregation of the airborne functions and ground-based functions required to ensure the safe and efficient movement of aircraft during all phases of operations"* (ICAO, 2001).

According to the above, the ATM system can be seen as a service that aims to facilitate, above all, an orderly and safe air transportation system with a very high target level of safety for airspace users (AUs) operations. In order to model and capture these trade-offs among the main performance areas of the ATM, it is necessary to pay attention to the fact that the final clients are the airlines, the passengers and the society. On the other hand, the main constraint of the ATM is the capacity to allocate the flight trajectories demanded by the AUs with the available resources (CNS infrastructure, airspace and airport capacity, etc.) while the required levels of safety are provided. Operational capacity (often referred just as 'capacity') is therefore dimensioned with enough room to provide safety in a robust and resilient way, which indeed limits the maximum number of flights that can be operated in a given period. When the capacity limits are reached, and since AUs, passengers and society understand that 'safety is first', new ATM constraints are allocated to some flights, which may cause important operational costs to the final ATM service holders.

Figure 3-2 shows a simplified architecture of the main safety layers of the current ATM architecture using the well-known Swiss Cheese Model (Reason, 1990). As seen in the figure, currently there are four layers in the ATM that protect against incidents and accidents, sorted from more strategic separation of traffic flows up to the separation of trajectories during flight operations provided by Air Traffic Control (ATC) services, ending with a last-resort safety net layer that can help on avoiding imminent accidents if the rest of the previous layers fail.

By design and safety philosophy of the ATM, the safety net systems are considered as an independent safety layer that cannot be accounted nor integrated during the design and operation of previous layers, in particular with regards to the separation provision of flights (ICAO, 2008). This means that the three main pillars of current ATM are:

- **Airspace Organisation and Management (AOM)**, mainly in charge of developing ATS (air traffic services) routes and TMA (terminal manoeuvring area) procedures; designing and implementing ATS sectorisations; analysing the allocation of ATS sector capacities; defining the type and class of airspaces; and designing and modelling the airspace and coordinating civil and military airspaces.
- **Air traffic flow and capacity management (ATFCM)**, preventing air traffic demand exceeding declared capacities at airports or ATS sectors with the objective of improving safety, throughput and efficiency, but also aiming at using as much as possible ATS capacity.
- **Air traffic services (ATS)**, which is a *generic term meaning variously, flight information service, alerting service, air traffic advisory service, air traffic control (ATC) service (area control service, approach control service or aerodrome control service)* (ICAO, 2001). ATC has the main

responsibility to maintain separation among aircraft (airborne or in ground), and also to expedite and maintain an orderly flow of air traffic.

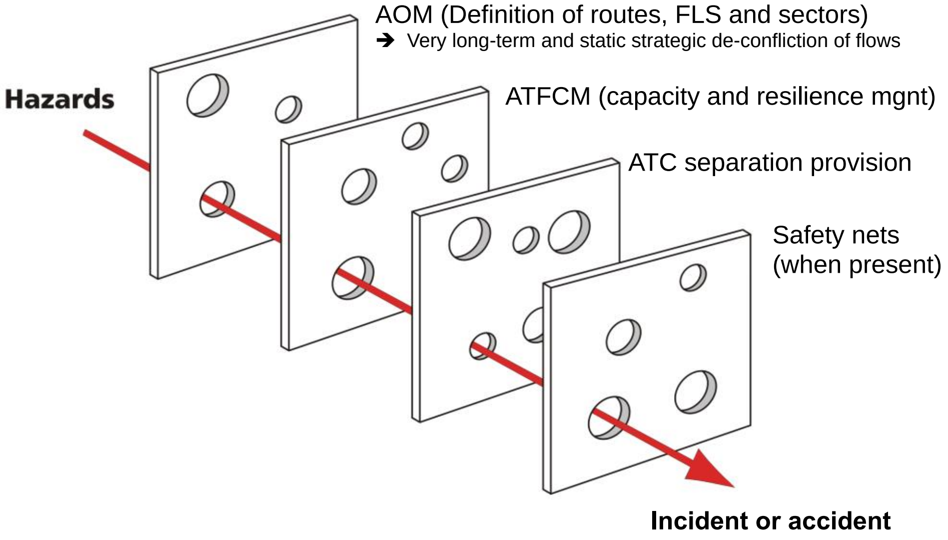

Figure 3-2. Swiss Cheese Model representing the main safety layers of current ATM

The AOM, ATFCM and ATC layers must be designed and operated to reduce the risk of accident to the required target safety level (TLS) without the consideration of any potentially existing safety net system. Therefore, **in APACHE only the main ATM layers, i.e., AOM, ATFCM and ATC, will be modelled,** while the safety net systems will be considered as complementary/re-enforcing layer that does not need to be included in the main safety performance analyses. Note that this is a conservative simplification that is valid for an ATM performance assessment, since the TLS value for the ATM system is set with no consideration of such last-resort safety net layer (i.e., safety nets must be independent from the rest of the ATM hazard mitigation layers).

Four main ATM components are therefore going to be modelled in APACHE to reproduce the current ATM operations, i.e., the AUs, who will try to optimise their flight operations, and the three main ATM hazard mitigation layers (AOM, ATFCM and ATC). The last three will be in charge of applying different ATM constraints to AUs during flight planning and flight execution processes to ensure the safety of the operations at network level.

Figure 3-3 shows the configuration of the APACHE system to model the above four ATM actors for the current baseline operations.

Note that the AOM constraints on airspace infrastructure, mostly airways structures and sector configuration designs, will be modelled as a given input of static data obtained from the EUROCONTROL’s Digital Data Repository (DDR). This is congruent with the fact that currently it is a very long-term decision-making and quite static ATM layer. The simulated AUs will optimise their operations based on realistic traffic demand (from historical flight plans) and the Network Manager (adopting the role of ATFCM) will perform the Demand and Capacity Balance activity to protect the potential overloading of sectors (thus protecting capacity and resilience of the system).

ATC separation instructions will be modelled to reach a realistic and meaningful set of 'executed' (and separated) flight trajectories from which the different performance indicators will be measured with the Performance Analyser. More details about the high-level requirements of models, limitations and performance trade-offs among each of the ATM actors are given in the following sub-sections.

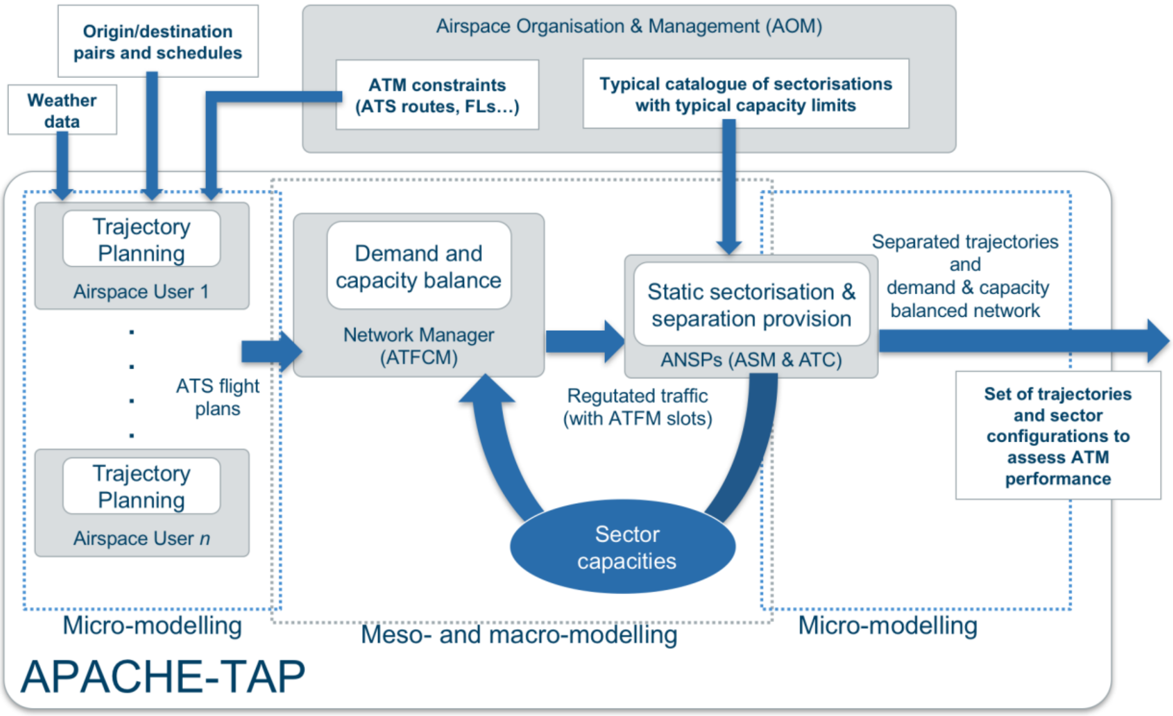

Figure 3-3. APACHE System configuration to model current ATM operations

3.2.1 Airspace Organisation and Management

3.2.1.1 Description of the concept, actors, performance drivers and trade-offs

Airspace Organisation and Management (AOM) services aim to improve airspace design and utilisation in order to ensure delivery of the performance targets for the ATM system while conciliating different types of airspace users and needs (i.e., commercial, general and military aviation). It is managed at several levels, each having an impact on the others: from strategic airspace infrastructure planning up to more pre-tactical and tactical day-to-day airspace allocation. General approach is presented in Figure 3-4.

Airspace infrastructure design

Airspace infrastructure design consists of planning and implementation of improvements in the ATS Route Network, and of optimised civil and military airspace structures and ATC sectors, that guarantee safe and expeditious traffic movement (EUROCONTROL - Network Manager, 2015c).

The objective of Airspace infrastructure design is to ensure an efficient, flexible and dynamic airspace structure, based on multi-option routeings and areas of Free Route operations, supported by adaptable ATC sectorisation, that can accommodate the expected future air traffic demand and meet the performance requirements. More specifically, the objective of ATS route network design is to provide airspace users with the possibility of choosing their preferred routes and calculate their preferred trajectories from origin to destination within the ATM network. Nevertheless, this level of service is usually confronted with the objective of airspace sectorization that has to ensure that the capacity and safety targets are met at network level.

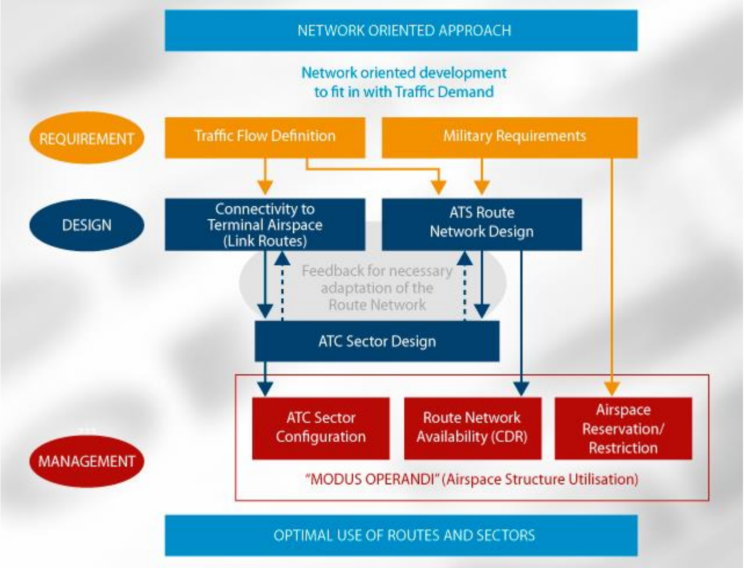

Figure 3-4. Network oriented approach for airspace organization and management (EUROCONTROL - Network Manager, 2015c)

The process of ATS route network design begins with the identification of known problems and uses forecast traffic demand to formulate route proposals for the major traffic flows, taking into account all civil and military requirements. Although all states in the ECAC area are responsible for their airspace, in order to fulfil both ANSP's requirements and broad operational requirements at the ECAC level, the development and implementation of airspace structures is carried out in a cooperative manner with support of the NM. ATS routes are therefore adapted to main traffic flows in ECAC and aim at including direct route segments to the largest possible extent to enable shortest possible route from any point of departure to any destination in the network.

Once the ATS routes have been designed and the navigation analysis of the design is complete, the sectorisation of the airspace volume begins. The airspace sectorisation consists of determining the geometric form of sectors which optimizes several criterions, such as ATCOs' workload balancing, transfer traffic minimization, etc., while respecting a number of geometrical and safety constraints. For detailed list of design principles, please refer to (EUROCONTROL - Network Manager, 2015a).

ATS route and ATC sector design requirements are usually confronted. Although it is accepted that a large number of ATS routes can improve route capacity and increase flight efficiency, it is also recognised that a large number of crossing points, especially in congested areas, can reduce sector capacity and have negative effect on cost-effectiveness. Therefore, airspace design is an iterative process where additional route network modifications may be required to enable better airspace sectorisation.

Airspace management

Airspace Management (ASM) is one of ATM services whose primary objective is maximising the utilisation of available airspace by dynamic time-sharing and, at times, segregating the airspace among various categories of users based on short-term needs (EUROCONTROL - Network Manager, 2015d).

Over the course of a day, traffic demand changes in volume and pattern of the major flows. This has influence on the control workload that fluctuates based on demand. Therefore, the main goal of ASM is to better adapt system capacity (route/sector capacity, arrival/departure airport capacity) to continuously changing traffic demand. Beside the general high-level objective, on the regional control level, ASM is responsible for providing a fair distribution of traffic load among the active ATC sectors, by balancing sector occupancy, minimizing traffic peaks and flight transfers, among other techniques.

ATC sector configuration is a part of ASM and it is performed at the level of regional control centre (ACC) in coordination with the NM. In order to adapt to the fluctuating demand, ATC sector configuration process uses a grouping/de-grouping principle, i.e., combining or separating pre-defined sectors into airspace configuration. During the period of low traffic sectors are grouped reducing a number of required control teams (thus, enhancing the ATM cost-effectiveness performance). Alternatively, when traffic demand is expected to increase some of the most overloaded sectors are split into smaller (pre-designed) sectors and a new airspace configuration is proposed. However, this sub-division of the airspace into smaller sectors is a finite strategy and a saturation point is reached when the benefit of further reduction is outweighed by other factors, particularly the corresponding increase in coordination workload. In addition, the opening of additional sector has a high economic cost, particularly in terms of ATC working positions required, which at the end is translated to the AUs in form of higher operational direct costs related to the ATM service provision. Therefore, an optimised airspace configuration schedule or sector opening scheme is calculated on a daily basis and published in accordance with the traffic forecasted and the number of controllers available on duty (shift planning).

ASM and ATC sector configuration has a direct impact on ATM system capacity that should be sufficient to accommodate the demand without imposing significant operational and economic penalties. Therefore, any imbalance between capacity and demand materializes in ATFM delays or flight rerouting reducing flight efficiency and increasing airlines' operational costs. However, providing additional capacity has a cost, and the best solution is often found as a balance between user/ANSP cost and system benefits.

In the current operational system, ATC sector configuration is carried out empirically by each regional control centre, where experts managing the airspace group and ungroup sectors in anticipation of traffic flows. For each period, an operator selects the best configuration from a subset of possible configurations according to the number of available controllers. This is highly combinatorial multi-objective problem since the subset of configurations at each period depends on the choices previously made and it involves several confronted objectives. Due to obvious limitations of human operators, the set of possible configurations is rather small and the choice of the best configuration is subjective and usually subject to past experience of the operator (period of the day, day in the week, month/period of the year, etc.). With proper decision support tools, it would be possible to overcome this limitation and build dynamically configurations based on the pre-define ATC sectors, since today's ATCO cognitive process and operation are reliant on rigid route structures and pre-defined ATC sectors.

However, flight routing paradigm shift toward free flight, that enables more flexible/direct/wind-efficient route, is in direct conflict with use of predefined ATC sectors that has to be adapted to the ATS route network (flight trajectories). Since flown routes will constantly change, it will be impossible to design finite number of ATC sectors that are adapted to all unforeseen routes. Therefore, ATC sectors, as routes, have to become flexible allowing more dynamic change of their shape.

The introduction of the dynamic ATC sectors should be accompanied by introduction of highly-automatic decision support tools that will help controllers in their work.

3.2.1.2 APACHE high-level system requirements and scope

For simulation of baseline operations (current ATM model) by the APACHE system, the **airspace infrastructure design** will be introduced as a given **input from the DDR/NEST and/or National AIP** (see Figure 3-3). It should be noted that in the current ATM the airspace design processes are performed mainly by expert judgement, using empirical data and best engineering practices. The process is done with a long-term strategic perspective, and therefore the resulting routes and sectorisations are quite static once implemented. Therefore, the reproduction of current airspace infrastructures is expected to lead to more realistic results in the context of APACHE project.

For each traffic demand scenario simulated, the **Airspace Planning - ASP module** (see Figure 3-1 and Figure 3-3) will compute optimal Sector opening scheme per ACC by selecting best combination of **pre-defined sector configurations** for each period of time (usually 20-30 minutes, although a given sector configuration typically can be active for at least 2 hours), such that ATC sector capacities are respected. This process will be performed based on the set of flight trajectories provided by the Trajectory Planning (TP) and Traffic and Capacity Planning (TCP) modules of the APACHE system, using the existing ATS route network and pre-defined airspace configurations for each ACC in the observed area (FAB or ECAC). The way of modelling the airspace management functionality for the current ATM operations will be similar to the one detailed in section 3.3.3 for the future SESAR ATM but constrained to a limited catalogue of sector configurations available.

The resulting scheme will provide **optimal number of ATCO per period** for the given traffic demand. Note that the optimal number will not be always the minimum since other criteria like workload balance, traffic transfers, etc. will be taken into account. Therefore, this problem will be modelled as **multi-criteria optimization problem** and solved using **stochastic optimization techniques**.

Main **limitations** of the APACHE system in the context of airspace organisation and management, for the modelling of baseline (current) ATM system, are linked to the **infrastructure design** and **military operations**. Since military operation is out of the scope of APACHE project, activation of military zones, conditional routes and FUA concept in general are not considered. This limitation must be taken into account at the moment of interpreting the results of the performance analysis of the current ATM operations.

3.2.2 Demand and Capacity Balancing (DCB)

3.2.2.1 Description of the concept, actors, performance drivers and trade-offs

The air traffic flow and capacity management (ATFCM) service is provided by the Network Manager Operations Centre (NMOC) to the airspace users throughout the European Civil Aviation Conference (ECAC) states (presently 44 states). Nowadays, the key process of the ATFCM in Europe is the Demand and Capacity Balancing (DCB), also known as Load and Capacity Management (EUROCONTROL, 2013b).

DCB is an ATM process performed by the NMOC – through the Enhanced Tactical Flow Management System (ETFMS) – that compares the traffic demand with the available ATC (sector) capacity in order to detect potential overloads at airspace and/or airports, and mitigate them by enhancing capacity or regulating demand with enough anticipation. When the look-ahead time is in the same day of operations (most typically from 6-8 hours up to 30-40 minutes before the time of operations), the DCB process is said to be ‘tactical’ ATFCM.

To predict the potential sector capacity overloads (a.k.a. 'hotspots') the current DCB takes into account the prediction of sector entry and occupancy counts, which require anticipated flight profile calculations. Once a hotspot is identified, the ATFCM operator responsible tries to interact with the affected ANSPs in order to try to increase the capacity for such a period (e.g., changing the sector configuration). If the capacity increase is not possible or not enough, then the NM tries to offer the AUs new route and/or flight level alternatives to re-allocate part of the demand to other sectors. Finally, if no balance can be reached by these interactions, the NM can apply *regulations* that are also known as *ATFM delays*.

ATFM delays are consequence of a lack of capacity in the network and that is why they are often used as a metric of ATM capacity.

The prevention of hotspots in the network can be seen as a safety layer in which the ATFCM reduces the density of the traffic in congested sectors and, therefore it also indirectly reduces the probability of separation and the complexity for the ATC officers to manage the traffic in a safe way and with acceptable levels of workload. The main performance driver in this DCB process is therefore to preserve the traffic loads at each sector under the pre-declared capacity levels, with the aim to preserve the ATM safety and resilience (understood here as the capacity of the system to correct any trajectory deviation and/or conflict among trajectories).

ATFM delays cause large costs to the AUs and indirectly to the society. Tactical costs of delays are partially absorbed by the AUs by means of applying buffers to the flight schedules, however at the expense of increasing the strategic costs of the planning.

Higher predictability in the ATM operations might contribute to reduce the strategic and tactical costs of the operators while reduce the need for flexibility of the AUs. Due to the lack of predictability, the capacity estimated and declared by the ANSPs to the NM is today also subject to a lot of uncertainty and relatively large safety buffers are applied to the maximum number of flights allowed in a sector with the aim of maintaining the safety of the operations and the workload of the ATCOs under acceptable levels for all the likely traffic scenarios.

A precise operational capacity estimation (i.e., how many flights can be safely handled in a sector preserving the ATC workload at acceptable levels) is paramount nowadays to enable the usage of the actual/real capacity at any moment and therefore, to reduce the level of ATFM delays applied to the AUs. This is indeed one of the main purposes of the paradigm shift proposed by SESAR that introduces the concept of TBO as a way to increase the predictability of the operations and to increase the capacity of the ATM system.

The amount of delay in the last decade has been a major issue in the ATM, due to the high costs supported by the AUs that affects to the competitiveness of the European air traffic system and indirectly diminishes the macroeconomic indicators. A large increase of capacity (at least a two-fold increase) is required by SESAR for the next 2020+ horizons, in which the forecasted demand should be ideally allocated with minimum deviation with regards the AUs and passengers demand.

3.2.2.2 APACHE system high-level requirements and scope

The **DCB functionality** will be modelled in the APACHE system with similar but simplified methods as the **NM** uses today**.** This new functionality will be coded in the Traffic and Capacity Balancing module (see Figure 3-1 and Figure 3-3), that will be adapted as a traffic simulation tool generating and providing mitigation measures to model the current ATM concept.

The **sector configurations** used during the day of operations (**computed by the Airspace Planning module**) of the selected traffic scenario will be taken as a reference together with the sector capacities pre-declared for that day. The number of flights within a sector will be taken into account (occupancy count) at any moment of the predicted operations during the planning phase. For that purpose, the TCP module will be **fed with the trajectories calculated by the TP module** (models for trajectory estimation will be simplistically assumed to be the same for both NM and AUs sides).

Hotspot detection will be performed and regulations in a sector will happen if the forecasted occupancy count is greater than the capacities pre-declared by each ANSP. The look-ahead time will be adjusted from **2-3 hours up to 30 minutes in advance** of the taking-off of flights. Airborne flights and flights departing from airports outside the ECAC region will not be considered for the allocation of ATFM regulations (but they will considered in the occupancy of the sectors they cross).

The ATFCM model in APACHE will replicate the algorithm CASA (Computer Assisted Slot Allocation), with some simplifications, such as that in APACHE it basically will assign delays in form of departure slots to the flights in a **First Planned First Served order**.

One important simplification/limitation done in APACHE, due to its current maturity level, is the absence of uncertainties that can unexpectedly reduce the capacities available at sectors, for instance, severe weather, fog, or the unavailability of ATC staff. Therefore, hotspots will be found during the simulations only as a consequence of excessive demand trying to cross a given sector at same periods.

3.2.3 Flight Planning

3.2.3.1 Description of the concept, actors, performance drivers and trade-offs

Flight planning is the process in which the airspace user starts to decide which flight trajectory should be executed to enhance the operational efficiency according to their business needs.

Currently, the route field of a flight plan indicates each point at which either a change of speed or level, a change of ATS route, and/or a change of flight rules is planned, followed by the designator of the next ATS route segment, even if the same as the previous one (ICAO, 2001).

Moreover, en-route (and also departure, arrival and approach) procedures are published in the AIP (aeronautical information publication) by the corresponding aeronautical information services (AIS) of each country. When planning an IFR flight, the aircraft operator is responsible to check the latest AIP revision, plan the route(s) accordingly and file a flight plan. Flight plans are therefore used as a coordination tool between the AUs and the ATM services (NM and ANSPs), which therefore is used for airspace and traffic planning purposes.

With the information obtained from flight plans the network manager (the CFMU in Europe) is able to –roughly– calculate the estimated position and altitude of the aircraft at different time stamps and detect demand and capacity imbalances by counting occupancy at sectors. Moreover, ATC services also use flight plans (e.g., the estimated time of entering into the sector) to anticipate their tasks, such as early conflict detection, hand-off and hand-over conditions, etc.

Nevertheless, the participation of the AUs in current ATM planning is almost limited to the expression of their flight intents through (very basic) flight plans. It means that today AUs mostly are passive agents in the decision-making of the ATM, so any restriction applied to flights is taken without having clear awareness about the impact of such decisions on their operations, and without having fully into account their preferences and business needs. Due to that, the current organisation of the ATM layers to facilitate the navigation and the safety of the operations causes large distortions between what the AUs would like to fly and the actual trajectories flown. Once the flights are planned, there is little flexibility for the flight operators to re-plan their operations, thus causing large inefficiencies even when in some cases such planning modifications could impact positively in the safety, capacity and/or efficiency performances of the ATM operations.

The presence of uncertainties that affect trajectory prediction is propagated to the meso-scale affecting the accuracy of the predictions of the actual capacity that will be available at the moment of flights execution. On the other hand, the lack of situational awareness that the NM and ANSPs have regarding the AUs intents and preferences causes that the actual times of departure and accurate trajectory predictions are not available, thus forcing to take conservative measures regarding the estimation of sector capacities and demand and capacity balancing. This way of operating often causes the application of extra restrictions and constraints to the flights, thus increasing the operational costs for the AUs and introducing even more uncertainty in the trajectory predictions that re-enforces the problem.

The lack of active participation of AUs and the trajectory prediction inaccuracies also impact largely negatively to the ATC processes. In particular, the lack of predictability of traffic separation losses forces the conflict management to be activated with only some minutes of anticipation, thus forcing the ATCOs to dedicate a lot of workload to the monitoring of the traffic and the resolution of conflicts and therefore degrading the capacity at sectors. Since the conflict management is done in a time-critical phase, there is little room for the ATCOs to take into account the preferences of the AUs in the resolutions processes (thus most likely affecting negatively to the operational flight efficiency). The lack of coordination among AUs, ATCOs from different ANPSs and NM, causes the ATM operations to be more chaotic, thus impeding to have more proactive and robust traffic and network plans.

3.2.3.2 APACHE system high-level requirements and scope

Flight planning will be replicated by the APACHE system through the Trajectory Planning (TP) and Traffic and Capacity Planning (TCP) modules (see Figure 3-1, Figure 3-3). Particularly, the trajectory computed by the TP module will represent the airspace users planning their trajectories subject to airspace infrastructure constraints (mainly airways available and flight level allocation and orientation schemes).

This functionality of APACHE system is based on the background tool developed by UPC named **DYNAMO** (Dynamic Optimiser). The proposed Trajectory prediction sub-module generates and **simulates traffic scenario based on real or future traffic demand (flight plans) and weather data**. DYNAMO uses information and data from airspace infrastructure databases (WPs, routes, STARs, SIDs), and demand schedules in order to provide, as output, realistic flight trajectories that will feed the rest of the APACHE architecture modules.

In order to synthetize the trajectories, the TP system requires the following data:

- Database with aircraft performance data for all aircraft types considered (in .bin)
- Database with the schedules for each flight (in .xml). These will also include the ATM constraints coming from the airspace design and route structures. ATC trajectory amendments (if any) will be modelled as ATM constraints and thus will be introduced in the resulting flight plans in the form of waypoints and vertical, temporal and speed constraints.
- GRIB file for the weather
- Options file (to model the characteristics and configuration of each aircraft)
- ECAC graph in binary format

A bash script will launch an instance of DYNAMO for each flight of the traffic demand, each of them with the corresponding input files stated above. Some assumptions and simplifications will be made during the modelling of the different types of AUs (e.g., the usage of typical cost index and payloads for trajectory optimisation), but the trajectories computed will be assumed to be optimal for the airline operator (e.g., to assess operational efficiency).

The overall DYNAMO architecture is broken in four modules with different functionalities, whose interactions are depicted in Figure 3-5. The input files to DYNAMO are also shown in this figure along with their file type.

DYNAMO decouples the optimisation of the lateral and vertical profiles. The lateral profile optimisation module (LPOM) is in charge of optimising the sequence of waypoints from origin to destination and to model all the turns with a lateral aircraft dynamics model, while the vertical profile optimisation module (VPOM) optimises the altitude and speed profiles with a fixed lateral profile.

The core part of the VPOM is written in GAMS, given the facility and robustness it provides to implement OCP and the multiple NLP solver engines to which it seamlessly links. In the current DYNAMO configuration, the finite variable NLP problem is solved by using solvers CONOPT (as NLP) and SBB as MINLP (mixed integer nonlinear programming). All other VPOM components are written in C++, including a wrapper to the GAMS functionality.

The atmosphere and wind module (AWM) receives the weather data in GRIB formatted files and provides temperature, pressure, north wind and east wind data as a function of latitude, longitude, geopotential altitude and time (e.g., 4D position) to the LPOM and VPOM modules.

The aircraft performance module (APM) receives binary formatted files which encode the knots and control points of tensor product splines functions representing the thrust, fuel flow and drag coefficient and provides aircraft performance data to the VPOM.

Figure 3-6 shows an example of trajectory calculated by DYNAMO subject to ATS route constraints.

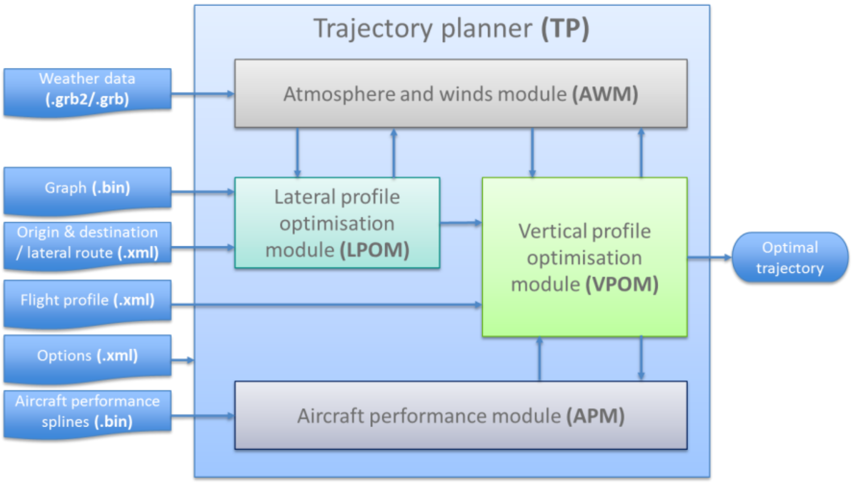

Figure 3-5. Dynamo architecture

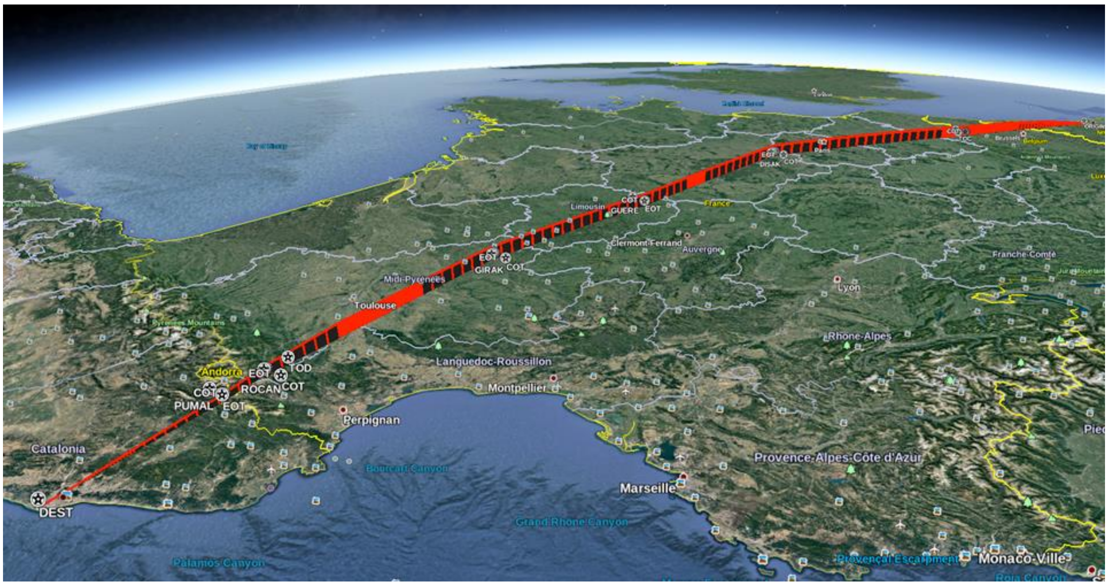

Figure 3-6. Example of trajectory calculated with DYNAMO

3.2.4 Separation and Conflict Management

3.2.4.1 Description of the concept, actors, performance drivers and trade-offs

Separation and conflict management is the process of keeping an aircraft outside a minimum distance (horizontally or vertically) from another aircraft to reduce the risk of mid-air collision as well as to prevent accidents due to secondary factors, such as for instance wake turbulence encounters. Separation is also applied to protect flights against terrain, obstacles, and restricted airspace.

This process is performed through different ATM layers starting from strategic level (airspace management, flow and capacity management and complexity management) and finishing at tactical level (tactical conflict management, consisting of conflict detection and conflict resolution within a typical look-ahead time from 20 up to 1 minutes).

Separation management starts at strategic level, with airspace infrastructure design, i.e., ATS route network design, flight level allocation schemes and flight level orientation scheme. Both ASM and DCB functions working together help to mitigate the hazards by protecting the sectors from over-congestion and too much traffic complexity for the ATC. On the tactical level (from 20-30 minutes up to 1 minute in advance) separation and conflict management are responsibility of the ATCOs. A team of ATCOs usually consisting of executive (EC) and planning controller (PC) are in charge of facilitating the navigation and providing the separation minima to the traffic flying within a sector. ATCOs apply pre-defined separation rules to keep aircraft at a safe distance from each other, horizontally and vertically, by applying various manoeuvres (heading, flight level, speed change) transmitted to the pilots.

Conflict management performed by PC is a continuous process triggered on a cyclical basis in order to detect and solve potential conflicts at every step of the coordination process (e.g. receipt of an offer, selection of a suitable sector exit level etc.). Conflict resolution in planning terms may involve the identification of alternative co-ordination conditions (level, route, etc.) at either the entry and/or exit boundaries of the sector (inter-sector coordination). Alternatively, it may involve a trajectory revision by modifying either the lateral (route) or the vertical (altitude) flight profile.

Following a conflict resolution implementation at the planning separation management level, the PC will inform the EC to improve his/her situational awareness. Often the PC can consider more appropriate that the EC takes some tactical action to resolve/monitor a detected conflict (Skybrary, 2016).

Conflicts between aircraft are detected by comparing the predicted evolution of trajectories (simple linear prediction) in order to identify potential losses of separation. Conflict resolution may involve the identification of different solutions, e.g. by modifying the trajectory laterally, vertically or in terms of speed adjustments. Both the PC and EC monitor the progress of the aircraft with respect to the given clearance to ensure that the conflict resolution has been appropriately implemented.

If the above two layers fail in providing due separation to traffic, then a set of tools called safety nets can still avoid a mid-air collision (e.g., TCAS, when available).

Safety is paramount in ATM and ATC. Therefore, the goal of separation and conflict management is to keep actual level of safety bellow or equal to given safety target levels no matter how this will influence AUs performances (flight efficiency and delay) and ATM throughput.

ATCOs also aim at facilitating and optimising the flight trajectories within a sector (when safety is not compromised), and due to that it is usual to find ATCOs clearing 'direct to' instructions to shorten the flight tracks, thus impacting positively to the flight efficiency of the flights and making a better use of the capacity available at the sector (i.e., increasing throughput).

Efficiency of the de-conflicting methods and tools depends on the selected look-ahead time periods, and on the quality of trajectory information available. If the predictions are not accurate, the detection of conflicts can produce false alarms, thus generating extra cost to the flight efficiency and false clearances, thus increasing the workload of the ATCOs, the actual level of risk and the predictability of the flights crossing a sector.

Summarising, in separation and conflict management the main performance targets are the avoidance of separation losses, to preserve safety, and the path optimisation for the flights crossing a sector and during conflict resolution amendments, to preserve flight efficiency and predictability. A complex trade-off exists among safety (represented by number of accidents and incidents), capacity (workload of the ATCOs and throughput), flight efficiency (extra time and fuel burnt) and environment KPAs (emissions), which are all affected by this concept. Also, predictability of the flights delivered to other sectors is affected by the tactical amendments of the ATCOs, yet applied to separate the traffic or to optimise the flight trajectories crossing the sector.

3.2.4.2 APACHE system high-level requirements and scope

Separation of traffic for current ATM operations modelling will involve several modules of the APACHE system. A set of trajectories generated during the planning phase by Trajectory Planning module, following the pre-designed airways available, and refined by Traffic and Capacity Planning module, taking into account the sector configurations and capacities given by the Airspace Planning module, will reduce the density and complexity of traffic and indeed provide some degree of separation. For the execution phase, the traffic planned in such a way will be simulated through all the sectors present in the ECAC airspace.

The tactical conflict detection and separation provision done by ATC will be modelled in the APACHE system by using and adapting some algorithms that were already used in previous SESAR research projects, in particular in the SESAR WP-E project called STREAM (Strategic Trajectory de-confliction to Enable Aircraft separation Management). Further details about this technology are available in (Ruiz S. , 2013). The tool implementing such conflict detection and resolution algorithms is called TPAS (Test-bed Platform for ATM Studies).

The conflict detection module will use the trajectories from the trajectory planner to detect conflicts among them. The algorithm is based on a technology known as Spatial Data Structures (SDSs), present excellent scalabilities to process all the traffic at ECAC level in a few seconds.

The conflict resolution algorithm will be based on the Geometric Optimisation Approach (GOA) developed by NASA (Bilimoria K. , 2000) and already implemented in TPAS. Figure 3-7 shows an example of two trajectories in conflict and four different resolutions amendments found by the GOA algorithm.

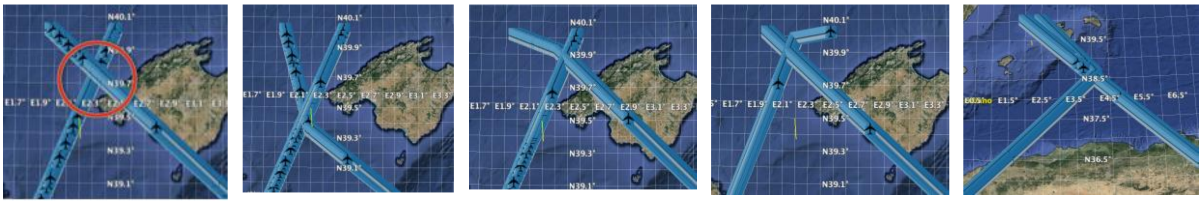

Figure 3-7. Two trajectories in conflict (red circle) and four different trajectory amendments found by GOA

The algorithm will be adapted to apply several types of manoeuvres (heading angle change, flight altitude change, speed variation, or a combination of them). For the application of tactical trajectory de-confliction tasks, the amendment will be fully decided by the ATC (as nowadays). To model the ATC actions, the prioritisation shown in Table 3-2 taken from EUROCONTROL's ACR2000 project will be implemented. The amended trajectories will be verified for compatibility with other surrounding traffic before being accepted/cleared.

Other simplified rules to model the ATC decision-making include: a) the look-ahead time for amending a trajectory will five minutes before the first instant of separation predicted; b) the conflicts will be solved sequentially (first-come first-served order); and c) the trajectory farthest from its TOD or destination will be amendment first.

	Choice of manoeuvre	Scale
En-route phase of flight	Heading change	Increase route segment (max. +5%)
	Climb	If >= 150 NM from TOD
	Speed reduction	Not <= 95% of cruising MAC/CAS
	Descent	Not < -4 flight levels
	Speed increase	Not > +3% of cruising MAC/CAS

Table 3-2. Hierarchy of tactical trajectory resolutions

3.3 Target Operations (SESAR 2020 ATM model)

SESAR 2020 target ATM introduces new concepts of operations to move from an airspace-centric ATM, in which the demand is dynamically adapted and regulated to fit to the available capacity, to a trajectory-centric ATM in which the flight trajectories are allocated following the AUs preferences as much as possible. Under this paradigm, the ATM resources and airspace capacities are allocated in such a way that the ATM services can be provided to the actual demand with the higher quality of service possible. Such paradigm shift will require the modernisation of ATM technologies and the amalgamation of the flight planning and execution processes based on flight trajectory management, i.e., the so-called Trajectory Based Operations (TBO), in which the flight planning processes and ATM hazard mitigation layers are well-synchronised by continuously exchanging precise 4D information about the current state and future intentions of the traffic.

The final goal of the ATM target foreseen by SESAR 2020 and beyond is a trajectory-based ATM system, where the different stakeholders can optimise and allocate "business and mission trajectories" through common 4D trajectory information, user defined priorities and precise definition of ATM constraints (SESAR Joint Undertaking, 2016c). Taking advantage of the TBO concept, the SESAR envisioned ConOps aims at managing the overall system to conform with all the high-level and network-centric performance objectives at the same time and in a holistic way, i.e., taking into account safety and capacity as priorities, and reaching a good trade-off between flexibility, efficiency and robustness, among other KPAs. In the context of SESAR, such holistic and performance-driven approach is known as Performance Based Operations (PBO).

The purpose of this section is to present the current understanding of the SESAR ATM target, and how it will be modelled in the context of APACHE to assess the expected potential impact in the ATM performance after enabling some SESAR solutions.

In brief, the TBO/PBO concept of operations envisions that the early information sharing and continuous updates will enable the early identification of potential problems (demand-capacity imbalances and/or potential trajectory separation infringements). This shall enhance safety and capacity performances. In turn, the network and traffic planning processes would be invoked through collaborative decision-making processes. Exchange of trajectory information through SWIM (System Wide Information Management) to all relevant actors optimises the planning, management and utilisation of the ATM network capacities (thus improving cost-effectiveness) as well as enhances the situational awareness and predictability of the operations. Within TBO/PBO, user preferred routeing through multiple Functional Airspace Blocks (FABs) can be introduced increasing in this way flight efficiency while reducing the environmental impact of the aviation.

Figure 3-8 shows how the ATM layers are expected to evolve in the context of SESAR 2020, i.e., with the activation of the SESAR Solutions (see Appendix A). Note that at present, traffic is strategically organized by airspace design to minimize conflicts and reduce traffic complexity for ATCOs. Such ordering is achieved via arrival and departure procedures (including altitude limitations to strategically separate different traffic flows), en-route airways, flight level allocation and orientation schemes, etc. The introduction of SESAR Solutions such as Free Route and User-Preferred Route operations will imply the relaxation of structured routing constraints for flights, potentially further evolving in the future to allow Airspace Users to plan their trajectories freely, and eventually in the vertical domain (i.e., continuous operations).

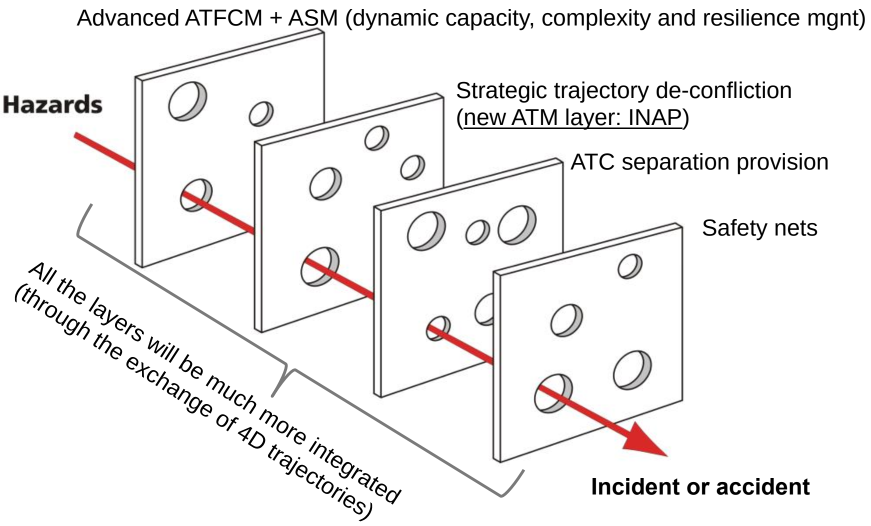

Figure 3-8. Swiss Cheese Model representing the main safety layers of SESAR 2020 target ATM

In the new operational context, traffic managers will count with a greater degree of flexibility in dynamically reconfiguring airspace to adapt to changing operational conditions and to user-preferred routing (i.e., 'advanced airspace management' in SESAR). For that purpose, the new ATM concept of Dynamic Airspace Configuration is inextricably linked and fully integrated to Advanced Demand and Capacity Balancing processes (referred in this document as dDCB, from 'dynamic DCB'). In particular, availability of precise trajectory predictions (i.e., 4D trajectories with high confidence index) in dDCB will allow an increase in the look-ahead time to anticipate the traffic separation tasks, and the complexity and ATCOs’ workload management, at network level.

Within the new TBO/PBO paradigm, ATC will be able to coordinate better with dDCB (and vice-versa) through the Integrated Network Management and ATC Planning (INAP) function, which together with improved trajectory predictions will enabled a seamless management of the traffic complexity and a reduction in the number of potentially conflicting trajectories to be handled by tactical ATC. In this manner, Airspace Users will be able to fly closer to their business needs, while offering the best possible performance at network level.

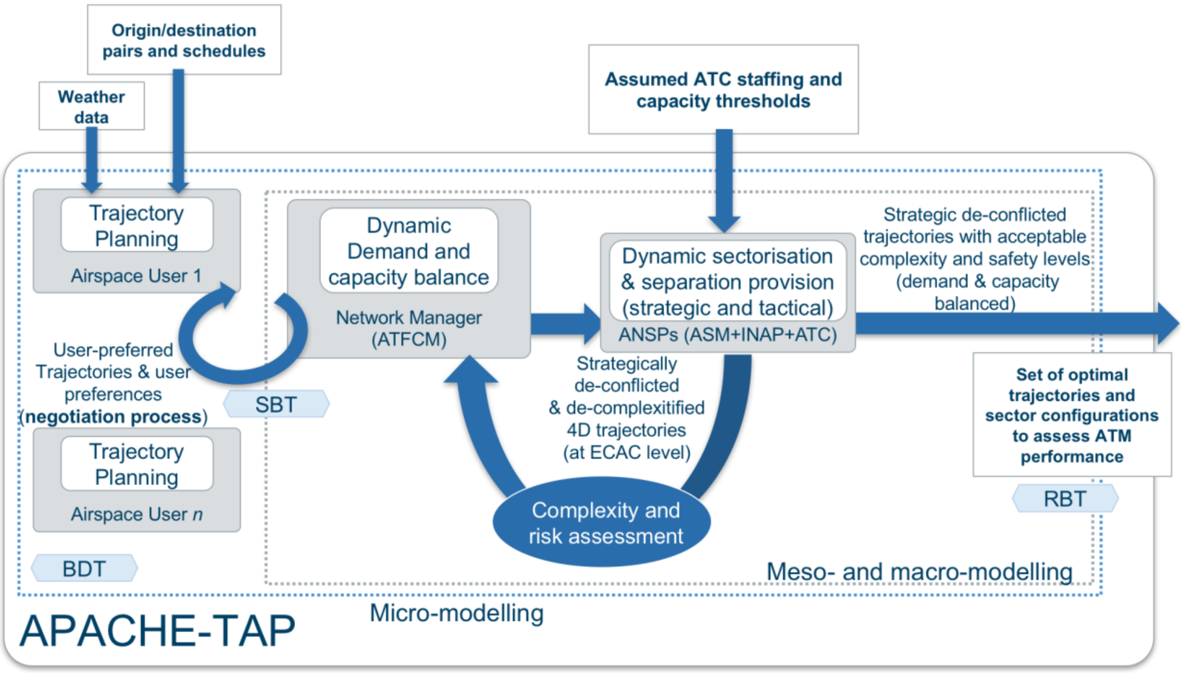

Figure 3-9. APACHE Framework configuration to model SESAR 2020 target ATM operations

On the other hand, Airspace Users will be still able, subject to ATC clearance, to re-plan in real time to adapt to the changing environment (e.g., weather, delay recovery, or other reasons) in order to maximise their flight cost efficiency and meet their business goals. Therefore, the coordination among all the ATM layers shall be agile enough to provide with the required flexibility to adapt the ATM resources to the AUs changing needs as quick as possible, in a continuous and seamless dynamic 4D trajectory and airspace planning.

Figure 3-9 shows the configuration of the APACHE system to model the above four ATM actors for the future SESAR 2020 operations. Note that now the airspace constraints for the AUs are no longer in place and only origin/destination pairs and schedules are needed to (ideally) compute the trajectory for each AU. Similarly, note that sector configurations will be calculated and optimised dynamically according to the traffic dynamics in the ECAC airspace, but assuming some input ATC staffing and/or capacity constraints (thresholds). All this is congruent with the fact that SESAR aims at utilising the airspace as a continuum, with the minimum constraints as possible for the airspace users.

While the AUs will optimise their operations from origin to destination airports (flight schedules in APACHE will be based on historical demand), the NM will perform the Advanced Demand and Capacity Balance activity to protect the potential overloading of sectors. The hotspot identification and mitigation will be addressed using new advanced concepts for traffic complexity management and taking advantage of the 4D trajectory information as an element for precise coordination; these new advanced complexity management models will take into account the non-trivial relationships between safety and capacity of the ATM, which is paramount to explore and understand the performance limits of the system (purpose of this project).

The ATC tactical separation provision will be modelled and complemented with a new INAP role, i.e., the Extended ATC Planner (EAP), that will be in charge of anticipating the separation of trajectories through strategic de-confliction mechanisms. Such separation tasks will be performed with enough anticipation to allow a collaborative flight and network planning process among all the stakeholders, in order to enhance the overall ATM performance in a holistic way.

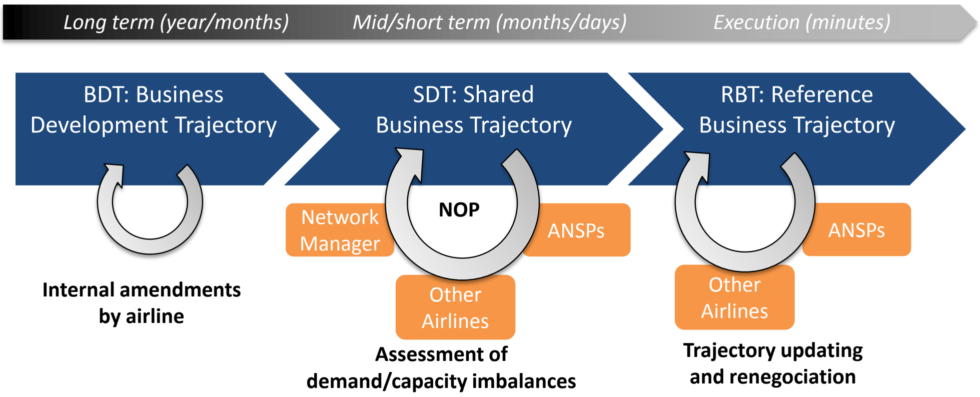

Figure 3-10. Development of the Business Trajectory under SESAR TBO/PBO concept of operations

3.3.1 Flight Planning and Trajectory Management

3.3.1.1 Description of the concept, actors, performance drivers and trade-offs

Figure 3-10 shows the lifecycle foreseen for the planning of a user-preferred 4D trajectory, a.k.a. 'business trajectory', in parallel with three ATM network planning temporal layers: strategic (long term), pre-tactical (mid/short term), and tactical (execution). In the strategic design/planning of the ATM network, the airlines plan their preferred trajectories resulting in the business development trajectory (BDT). Eventually, the BDT will become the shared business trajectory (SBT) and will be available to other stakeholders via the network operations plan (NOP), which will be coordinated by the network manager (NM) and the ANSPs. Using these SBTs, the ANSP can assess airspace configurations, route catalogues, and their allocation of resources. The NM, having visibility of all SBTs and ANSPs' resources can identify possible capacity and demand imbalances and act accordingly by proposing trajectory changes and/or negotiating different configurations with the ANSPs (leading to different capacity distributions).

This iterative and collaborative process of negotiations will end when an acceptable solution for all the stakeholders is found. At this point, the SBT becomes the reference business trajectory (RBT), which the airline agrees to fly and the ANSPs agree to facilitate. Yet, during the trajectory execution, RBT might be impacted, e.g., by de-conflicting, real-time queuing, or due to weather hazards. Therefore, the RBT might be revised, negotiated, and updated in response to the changing conditions of the ATM. This process will be iteratively repeated until an agreement is reached among all the agents (i.e., a good-enough feasible trajectory is found), except in time-critical situations in which the ANSPs or the Network Manager (NM) may impose their trajectories.

In SESAR concept the planning at each point in time will be represented in the Network Operations Plan (NOP), which facilitates the processes needed to reach agreement on airspace demand and capacity. It is supported by a set of collaborative applications that provide access to traffic demand, to airspace and airport capacities and to the activated ATM constraints. The airspace stakeholders, enabled by the modern CNS technologies and SWIM platform, will use the NOP as a single portal access to ATM information (e.g., demand and capacity situation).

The enhanced coordination of all stakeholders through agile collaborative negotiation processes (subject to final approval of the NM and ANSPs), is expected to bring an increase of the ATM flexibility to adapt better to changing conditions, an improved cost-effectiveness per flight, and as a better utilization of the airspace capacity.

At the moment of flight execution, the pilots must follow the RBT, with the help of the proper advanced airborne navigation systems. Due manoeuvre amendments will be applied to not come outside certain tolerances defined by the Trajectory Management Requirements (TMR) for each flight. If at any time an unforeseen event comes up, for example bad weather at the destination airport that decreases its capacity and thus, requires a change in the optimal trajectory; the RBT can also be used as a reference to minimize such tactical changes with respect to the optimal RBT.

Any new trajectory proposition, revision or update will be made in due consideration of the **complete trajectory** still to be flown and not only at sector or local level, taking due account of the wider impact on other flights' concerned trajectories, as well as on the network operations, i.e., domino effects and emergent dynamics must be considered. Note that since RBT express the user preferences and network restrictions, and it is considered 'optimal' (from a system-wide point of view). Unsolicited ATC proposals (e.g., direct routings) may not in fact be beneficial for the airspace users, whereas destabilizing network effects may additionally occur downstream.

The Business Trajectory will be considered entirely (i.e., gate to gate) during the phases of development, negotiation and acceptance, but it will be cleared/authorized during the execution phase for time-windows of order of 20-30 minutes (i.e., tactical look-ahead). See Figure 3-11.

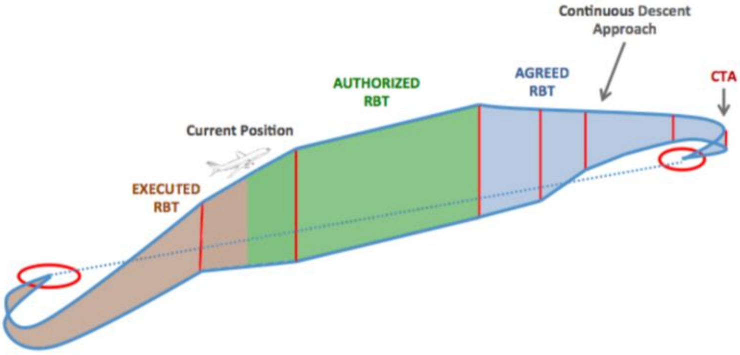

Figure 3-11. Different phases of a 4D trajectory

Each AU is focused in maximising their business needs and utilities. Thus, the AU will plan, negotiate and execute their trajectories accordingly. Fuel costs take an important share on direct flight operating costs and therefore, in trajectory planning, but they are not unique. Delay recovery strategies might for instance encourage AUs to plan trajectories flying faster than expected, different route charges in Europe might result from longer flights, where the extra fuel burnt is compensated by lower fees, etc. As a consequence, a trade-off will exist between environmentally friendly trajectories (i.e. minimising fuel) and operationally flight efficient trajectories (understanding them as the trajectories an AUs would like to fly).

In order to enhance flight punctuality and operational predictability, AUs might also be prone to plan trajectories avoiding typically congested airspaces (before knowing if there is actually a congestion or not). In this way, the extra cost for the flight is compensated for a more stable schedule and less reactionary delays in their network.

The integration of AUs in the ATM planning processes will increase the situational awareness and predictability of the operations, therefore allowing more proactive and robust traffic and network plans at the same time than the AUs preferences and needs can be better served, all of them conditions that are required to move towards a Performance Based Operations ATM.

In this context, it is important to point out that AUs are not expected, in general, to cooperate among them (even if they are expected to participate in a collaborative ATM planning process). Thus, the equilibrium solutions of future collaborative demand and capacity imbalance mechanisms might often result on a zero-sum game, in which the gains for one AU might likely result in losses for another AUs. Thus, trade-offs will exist between equity, flexibility and flight efficiency.

3.3.1.2 APACHE system high-level requirements and scope

For the modelling of target operation (SESAR 2020 ATM model) in the APACHE system, SESAR solution PJ18 (4D Trajectory Management) will be assumed as implemented and fully functional for all the AUs. With this assumption, **PJ06 (trajectory based free routing) and PJ07 (Optimised AUs Operations) will be assessed in APACHE**, taking into account the following high-level requirements taken from (SESAR Joint Undertaking, 2016c):

- Seamless Free routing shall allow Airspace Users to significantly optimise flight trajectories over a large-scale area of interest (e.g. multiple FIR AORs or FABs);
- Trajectory definition processes shall allow civil Airspace User to plan optimised trajectories that best consider their own operational requirements while fulfilling the requirements of the other ATM stakeholders expressed with ATM constraints.
- The SBTs and RBTs can include the user preferences associated to the most updated meteo information.
- AUs can re-plan and re-prioritise their flight trajectories whenever seen necessary.
- All types of civil Airspace User shall be able to participate to DCB processes throughout the whole lifecycle of a flight by influencing the allocation of ATM constraint.
- Provided detailed ATM constraint information, the AUs can plan an alternative new trajectory. These alternative trajectories can be shared to assess what-if scenarios in the context of a CDM process with the other ATM stakeholders (each flight may have at any moment several potential trajectories for planning and coordination purposes, although only one will be executed).

Considering the above items, the APACHE system will embed a trajectory optimisation framework developed by UPC (i.e., DYNAMO tool, already presented in previous Section 3.2.3), which is capable to compute optimal 4D trajectories for flights in different contexts. In particular, free-route scenarios can be configured at any scale (configuring entry/exit points to hypothetical free route areas or leaving complete lateral freedom from origin/destination airports).

Dynamo will generate optimal trajectories that minimise a given objective function, which can be configured by the user. In this way, each AU (or group of AUs) can be modelled with different business needs, producing in this way trajectories that best consider their operational requirements, in terms of direct operating costs (taking into account fuel, time and route charges optimisation).

It must be pointed out that the principal limitation of the trajectories obtained in APACHE is the impossibility to model exactly all AUs behaviours, interests and reactive actions in the presence of uncertain events and disruptions. In this context some standard operations, plus some (random) variability, will be assumed to model some parameters, like for instance, the Cost Index[2] for each flight. Furthermore, tactical trajectory management will be also simplified in APACHE, since weather uncertainty, weather hazards, network disruptions and human behaviour are all out of the scope of the APACHE project. These assumptions can be tackled in further research and development activities conducted in the context of higher levels of concept maturity. Nonetheless, it is expected that for the current level of maturity, APACHE can provide with acceptable order of magnitudes regarding the operational efficiency metrics and AUs representation.

Regarding its interaction with other system components, Dynamo will be integrated with the TPAS tool (the module representing dDCB and INAP in APACHE) to simulate the negotiation of the shared business trajectory. In this context, Dynamo will be able to compute alternative (sub-optimal) flight trajectories and rank them with distinct priorities, to facilitate the collaborative flight and network planning process in the dDCB/INAP functionality. Tactical ATC interventions, when required, will be assumed as not-negotiable (due to short look-ahead) and therefore can be modelled in a similar way as illustrated in the flight planning models used for current ATM (section 3.2.3).

3.3.2 Advanced Demand and Capacity Balancing (Advanced DCB, or dDCB)

3.3.2.1 Description of the concept, actors, performance drivers and trade-offs

Advanced DCB solutions (simplistically referred in this document as dDCB, from 'dynamic demand and capacity balancing') are enhanced ATFCM processes that will ensure that Flow and Capacity Management operations, from planning through to execution at local, sub-regional, and regional levels, are conducted on a holistic, seamless, continuous, and fully collaborative basis. This includes activities in the long term and medium to short term planning phases establishing an optimised and stable Network Operations Plan, and enabling all partners concerned to fine-tune the planning of their resources according to the latest known information.

The primary objective of the SESAR dDCB concept is to improve ATM safety and capacity by keeping traffic complexity and air traffic controller workload under acceptable levels, thus preserving robustness and resilience in sectors, as a part of the safety management activities.

The dDCB solutions will include dynamic airspace configurations combined with 2D, 3D or 4D constraints to adapt the available capacity to the traffic demand at the maximum extent, with minimal demand adjustments. Local traffic managers, flow managers and NM will be involved via collaborative decision-making processes to integrate airspace and coordinated ATM constraints (2D, 3D or 4D constraints, as necessary) that will be selectively applied to individual flight trajectories, from planning

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[2] The Cost Index (CI) is the ratio between the cost of time and the cost of fuel for a given flight. The value of this parameter has an important impact when optimising trajectories, since higher CIs will lead to faster trajectories, with shallower climbs and lower cruise altitudes; wile lower CIs will lead to trajectories flying closer to maximum range speeds, climbing faster and flying higher. Computing the CI for each flight is a task done by the AUs according to their business needs and/or reactions to disruptions or uncertainty events.

through to execution phases. Coordinated 4D constraints are expected to replace current slot allocation (i.e., regulation).

New decision support tools and methods will be introduced and fully integrated with the dDCB processes in a seamless way, among others:

- **Dynamic airspace management (ASM)**, e.g. sector boundaries, adaptable route structures, in order to meet capacity or efficiency needs;
- **Advanced complexity management** by fully exploiting 4D Trajectories data in order to identify and resolve local complex situations, by de-conflicting or synchronizing flight trajectories;
- **Integrated ATFM and ATC Planner (INAP)**, a new ATM mitigation layer enabling a seamless management of the traffic complexity and a reduction in the number of potentially conflicting trajectories to be handled by tactical ATC.
- **Collaborative traffic planning and holistic planning management** through CDM processes including every level of Network Management function (NMF regional, sub-regional, local and airport), ANSPs and AUs for the negotiation of the 4D trajectories in the planning phase (up to 20-30 minutes before execution), in particular for the publication of ad hoc DCB constraints.

Following, the above dDCB processes are further detailed.

Dynamic airspace management (ASM)

The efficient and flexible management of capacity will be paramount in high-density airspace. Therefore, SESAR contemplates the Dynamic Capacity Management concept, which aims to vary capacity to match forecasted demand by grouping and de-grouping sectors and managing the staff resources. Dynamic Capacity Management, and in particular Dynamic Airspace Configuration, is further explained in section 3.3.3.

Advanced complexity management

The identification and management of complexity, as a fundamental contributor to workload, represents key capabilities in the DCB process. The main feature of the complexity management process is the assessment of the complexity, in both quantitative and qualitative aspects, taking into account the uncertainty of the trajectory prediction over time horizon. The complexity assessment encapsulates the relationship between workload and traffic. Consequently, the new advanced airspace environments (i.e., dynamic modular airspace and free routing trajectories) necessitate either new or evolved complementary algorithms associated to a good complexity metric to allow the accurate identification of feasible and efficient dDCB solutions to indicated areas of excessive workload in which safety could be compromised.

The diagnosis of a DCB imbalance as a hotspot will be more accurate and credible in the future ATM due to enhanced processing based on advanced complexity and workload assessment provided by automated tools. These automated tools will continuously process and monitor predicted workload and traffic complexity, alerting to the dDCB operators when appropriate. These tools are therefore expected to provide those responsible actors with an accurate and timely prediction of imbalance as well as providing input into those tools used to manage hotspots and complexity resolution with the most operationally efficient and cost-effective measures**.**

Integrated ATFM and ATC Planner (INAP),

In SESAR ATM, the Integrated ATFCM and ATC Planning Function (INAP) is a new key ATM mitigation layer (see Figure 3-8). The scope of INAP is to bridge the traditional gap between ATFCM and ATC activities, and to address the overlapping period where the Network Management function runs DCB and dDCB processes at all geographical levels, while ATC planning starts preparing early strategic conflict detection and deconfliction of 4D trajectories within the appropriate look ahead time horizon and within its defined local area of responsibility. The objective is to enable a seamless ATM layered planning process, taking into account two targets: a) provide optimum solutions (airspace configuration and trajectory/flow management) to solve workload imbalances with resolution assessment from local level to the network level; and b) ensure that those solutions are compatible and efficient with traffic synchronisation activities and strategic conflict management under the responsibility of the ATC planning function.

INAP actors are expected to be provided with the capability to identify and resolve local hotspots (i.e., airspace regions with too much complexity) in a fully integrated way, encompassing trajectory de-confliction, synchronisation and sequencing tasks.

Note that the introduction of INAP functionality in the ATM is directly related with the main strategy followed by the SESAR concept to achieve the targets of increasing capacity and safety in the ATM, while reducing costs. Such strategy consists in moving from current short-term tactical instructions to more strategic 2D, 3D and 4D clearances to de-conflict traffic, and providing with the proper automation support though different advanced and coordinated decision support tools to aid and reduce a portion of the ATCOs workload while increasing their productivity. The air-ground harmonization of the 4D trajectory predictions, supported by robust meteorological forecast (wind, temperature, etc.), all shared via data link, improves significantly the accuracy and reliability of trajectory data used for decision making and effective traffic separation, thus enabling longer usable prediction horizons and permitting the issue of longer duration clearances.

Collaborative traffic planning and holistic planning management

The main strategy followed by SESAR to improve flight efficiency, thus reducing operational costs and pollution, is to allow the direct involvement of AUs into the ATM planning process, by means of a collaborative traffic planning, in which airlines are able to optimize their business trajectories while ANSPs can update the actual available airspace/ATM capacity in real-time. The Network Manager will be in charge of coordinating and arbitrating (in a transparent and equitable manner) those collaborative traffic planning processes to ensure the proper levels of safety during the planning and execution of all network operations.

In particular, the consideration of AUs’ priorities and preferences allows the NM to take them into account in the dDCB processes used to solve remaining complexity/hotspots. Preferences will be used when choosing between different trajectory adjustments alternatives for dDCB purposes (e.g. time based or lateral/vertical constraint). This provides opportunities for AUs to choose how they best reconcile their business needs with a dDCB initiative, i.e., respect the 4D constraints through trajectory refinement/revision, through speed/time and/or alternative route/vertical profile. Since safety and capacity are the main performance drivers in this process, the NM must find the best trade-off between AUs’ flexibility and the planning stability necessary for effective management of ATM resources.

In the context of PBO, the planning phase of the flights is dynamically and flexibly updated until 20-30 minutes before execution, and involves all the stakeholders’ views and needs, including AUs, NM, ANSPs and Airport Operators. Therefore, it is during the dDCB period, and enabled by the INAP function that allows shifting from and airspace- and flow-centric DCB process to a collaborative trajectory-centric dDCB, that the concept Holistic Planning Management (HPM) arises. This concept allows each stakeholder, and in particular the Airspace Users, to get an exhaustive view of all constraints by sharing trajectory information and intentions through NOP. This thorough view of all constraints provides a real opportunity to find the global optimum among the various stakeholders' requirements, including Airspace Users' preferred trajectories and costs associated to deviations, as well as ATM Planning constraints issued from Airport sequencing, Airspace Management and Demand Capacity Balancing or ATC flow optimisation. Holistic Planning Management can be seen as a toolbox evolving along the timeline, from Planning to Execution, where the tools (including 'what-if' capabilities) can be used by the different actors, at different moments, for different problems but always considering the network view of constraints. Such HPM is a novel and challenging key ATM concept introduced by SESAR that must be understood, modelled and assessed in APACHE to anticipate the future performance of the proposed ATM 2020+ target concept.

3.3.2.2 APACHE system high-level requirements and scope

TPAS (Test-Bed Platform for ATM Studies) is a **traffic simulation tool with global optimization capabilities** developed by UPC that will be used for generating and providing mitigation measures to model the future SESAR ATM target concept, more specifically the dDCB functionalities specified above, except the ASM (Dynamic Airspace Configuration and Advanced Airspace Management is tackled in section 3.3.3). The concept of INAP in which 4D trajectories are collaboratively negotiated and planned among all the stakeholders from 2-3 hours in advance up to 30 minutes will be enabled by TPAS. Advanced complexity management will be also considered during the trajectory negotiations.

Among the functionalities of TPAS, it can be found an innovative and computationally efficient Conflict Detection and Resolution (CD&R) system for the strategic de-confliction of 4D trajectories at ECAC-wide scale, including some degree of collaborative 4D trajectory planning carried from several hours up to minutes close to the execution phase. Similar algorithms were seen working successfully under the WP-E project called STREAM (Strategic TRajectory de-confliction to Enable seamless Aircraft conflict Management), executed between 2011 and 2013 (Ruiz S., 2014).

The TPAS sub-module will perform the following functionalities:

- Conflict detection (with a global perspective and detecting potential domino effects of any trajectory amendment).
- Conflict resolution to apply due separation between aircraft to protect against potential mid-air collisions and against potential WVEs. To model the SESAR ATM model, the de-confliction of trajectories will be issued at strategic level, i.e., from 2 hours up to 20 minutes before any potential traffic separation, and at multi-sector level (a simplified concept of Extended ATC Planner and tactical ATC will be modelled). Tactical conflicts, i.e., those predicted to occur in a look-ahead time of 20 minutes or less, will be modelled as current ATC (see Section 3.2.4).

- Collaborative traffic/trajectory planning process in which the AUs, the NM and the Extended ATC Planner can negotiate 4D trajectories and optimise the network traffic plan with different performance criteria (a simplified CDM model to enable Performance Based Operations as expected in the SESAR ATM target concept)

Note that in APACHE the SESAR solution that enables the SWIM infrastructure (PJ17) to exchange all the ATM information for required for collaborative flight planning, and the one that enables 4D trajectory management (PJ18) are assumed as implemented and fully functional for all the AUs. Also, the required CNS capabilities (PJ13) and safety nets (PJ11) are assumed active and fully functional.

Regarding the TPAS models used in APACHE, they aim at representing the SESAR solution of **Advanced Demand and Capacity Balancing (PJ09)** during the simulations. Hence, at least the following high-level requirements defined in the SESAR transition ConOps (SESAR Joint Undertaking, 2016c) will be taken into account:

- Dynamic Demand and Capacity balancing (dDCB) shall expand the continuous integration of operational data for improving tailored real time performance assessment and allow continuous monitoring of Network Performance. This requirement is fundamental part of the PBO concept and primary driver of the APACHE project.
- dDCB shall ensure from planning up to execution at local, sub-regional and regional levels seamless and fully collaborative Flow & Capacity Management operations. For that purpose, ECAC-wide scenarios will be managed in APACHE, with the purpose to provide full global network performance optimisation.
- dDCB shall integrate Airspace Users (including UDPP), Airport (including A-CDM), ATC and Network planning processes in a holistic network planning management through the Network Operations Plan (NOP). In APACHE, airports will not be considered, but AUs, ANSPs and the NM will be modelled to find an agreed traffic solution to implement, taking into consideration the best ATM performance levels for each KPA and their trade-offs.
- Dynamic Airspace Configuration shall be fully integrated in dDCB processes. In APACHE, this will be included as part of the network planning and advanced airspace management. See Section 3.3.3 for more details about how the available ATC resources will be allocated through a sector configuration optimisation process to give maximum quality of service to the AUs with minimum demand amendments.
- New metrics to characterise, predict and assess complexity shall be developed and included into the hotspot detection and resolution processes. In APACHE, a new way to assess both risk of conflict and traffic complexity will be developed to understand better the relationships and trade-offs between safety and capacity. This shall enable a better management of safety and capacity at microscopic/trajectory level, therefore allowing a better exploration of the ATM limits to enhance other KPAs.
- Collaborative management of ATM constraints. This will be also included in APACHE, as part of the collaborative flight and network planning processes enabled by TPAS algorithms.
- Incorporation of enhanced meteorological data. In the APACHE project, a first step towards full implementation of meteorological data will be addressed, in particular considering realistic wind maps and temperature gradients during the flight planning phases. No-go regions due to severe convective weather are not being modelled at this early stage of the APACHE concept.
- Automated tool supporting the INAP actors in a multi-sector/unit environment to manage traffic complexity in order to alleviate traffic complexity, density and traffic flow problems by planning individual trajectories using advanced planning tools. In APACHE, this INAP

functionality will be modelled with the strategic de-confliction and de-complexification provided by TPAS.

The principles of Holistic Planning Management will be driving the mechanisms used to model the INAP functionality in APACHE. It is worth noting that the planning of conflict-free 4D trajectories with a global and holistic optimization scope represents a highly combinatorial problem that has been considered to be untreatable (i.e., non-polynomial). Therefore, the use of classical optimization techniques, analytical methods or exhaustive combinatorial exploration of the solution space do not constitute practical methods for identifying conflict-free optimal solutions (Durand, 2004). See for instance the Figure 3-12, in which a simple scenario with 3 trajectories and one single conflict is developed and quickly reaches a relatively high number of new scenarios (some of them conflict-free and other not). Furthermore, the order in which the conflicts are processed may vary the solutions finally obtained, thus making the variability of the solutions highly untreatable.

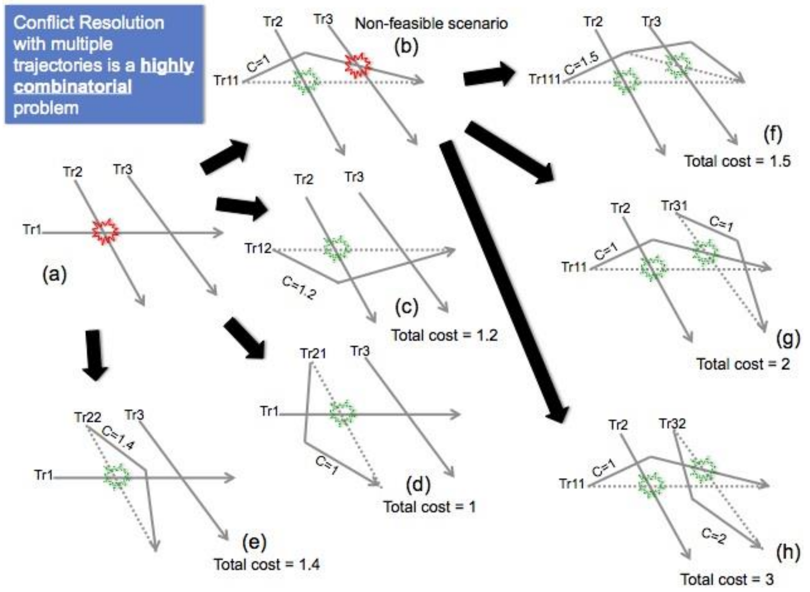

Figure 3-12. Global conflict resolution is a highly combinatorial problem

For the conflict resolution manoeuvres to be effective, the complex interactions and emergent dynamics among the trajectories must be taken into account in a global scope because the resolution of one conflict may imply the reactive creation of a new conflict in the network (i.e., domino effects) (Bilimoria K., 2001). Delivering conflict-free scenarios to the ATC services can contribute to increase operational capacity at sectors while the anticipation of traffic separation tasks allows enhancing safety and efficiency through a collaborative optimization approach in which the AUs preferences and network constraints can be all taken into account.

This efficient CD&R system also enables air traffic to be de-conflicted over wide airspace regions and permits large look-ahead times on the order of hours (e.g., 2–3 h). Figure 3-13 shows realistic traffic demand under a free-route ConOps simulated in previous research at European airspace (ECAC).

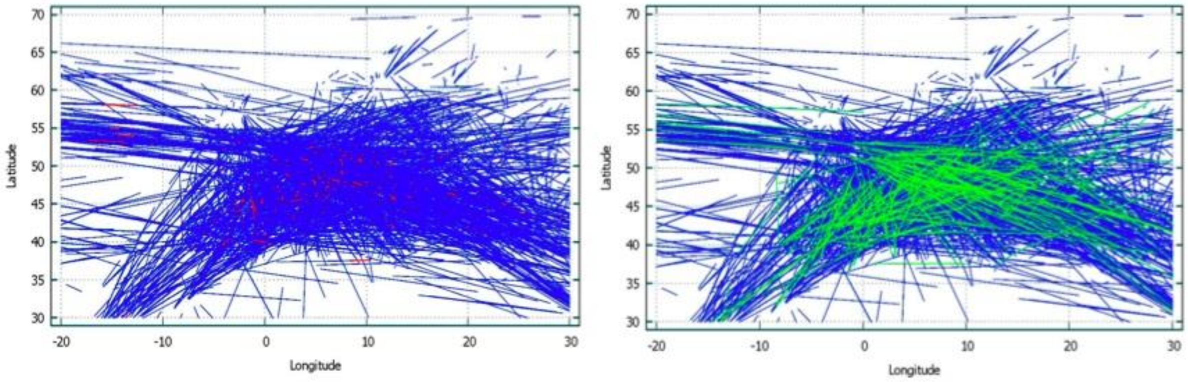

Figure 3-13. Scenario of ECAC as a single sector with 4010 and more than 300 conflict (left) and globally de-conflicted scenario with 283 flight routes modified (right)

Due to the high degree of connectivity in the European ATM Network, it is expected that only with consideration of the entire European airspace (i.e., global scope) at the micro-level it will be possible to ensure that all potential interactions are identified and that any flight route finally allocated is globally de-conflicted at the strategic/planning phase under a collaborative optimization approach. The left figure shows the non-deconflicted nominal scenario, whereas the right figure shows the conflict-free scenario after the process of thousands of trajectories within a few seconds or minutes and by taking into consideration the AUs preferences and network constraints.

During the APACHE project, the TPAS algorithms will be enhanced by adding new functionalities for demand and capacity balance, so the system will be adapted to detect en-route hotspots and some Short Term ATFCM Measures (STAM) will be implemented to deliver Pareto-efficient conflict-free scenarios that will respect the maximum capacities at all the sectors. Therefore, the developed algorithms can contribute to the achievement of the NM's goals by suggesting deconflicted trajectories and balanced flows that closely match the AUs preferences and the ATM performance requirements in free-route with eventually continuous cruise climb operations.

In addition, recent research by Ruiz & Soler (2015) has shown that the de-confliction of thousands of trajectories flying in a free route environment with continuous cruise climbs require new enhancements and strategies will be implemented to simulate and benchmark all these scenarios in the context of APACHE project.

To include the hotspot detection and resolution capabilities, the notion of traffic complexity (typically understood as geometrical complexity), will be enhanced and extended with detailed analysis of the risk of separation and used during the collaborative negotiation of the traffic trajectories to maintain the controllability (i.e., capacity) of ATC at any region of the airspace. Note that the word 'region' is used here instead of 'sector' due to the fact that in the APACHE approach the traffic planning will be delivered before the sector planning, i.e., capacity will be adapted to demand afterwards by means of optimisation methods for dynamic sector configuration.

The traffic demand will be planned, in a first instance, with no reference to any sector (i.e., treating the airspace as a continuum) but trying to avoid too much complexity at any region to facilitate the finding of solutions during the sector configuration process (and the acceptability by the risk assessment module). If no solutions are found during the dynamic sector configuration process (e.g., due to too high complexity), a new iteration of traffic-sector planning will start (the number of iterations will be limited to avoid infinite loops), and if no solution could not be still found, then classical DCB techniques (i.e., regulations) might still be applied to find a traffic solution that meet the safety and capacity requirements in any case.

3.3.3 Dynamic Airspace Configuration and Advanced Airspace Management

3.3.3.1 Description of the concept, actors, performance drivers and trade-offs

An Airspace Configuration refers to "the pre-defined and co-ordinated organisation of ATS Routes and/or Terminal Routes, FRA (free route airspace) and their associated airspace structures, airspace reservations, and ATC sectorisation" (EUROCONTROL - Network Manager, 2015b) incorporating all airspace elements, designed to be managed and coordinated through a continuous, seamless and iterative CDM process. Within SESAR operations it is expected that Airspace configurations will be dynamically managed (Dynamic Airspace Configuration - DAC) adapting to civil/military users demand, to respond flexibly to different performance objectives which vary in time and place (SESAR Joint Undertaking, 2016c).

DAC in the context of Advance Airspace Management (AAM) is realised by sector design and sector configuration based on traffic complexity. This paradigm shift enables the dynamic adjustment of airspace characteristics capable of adapting optimally to users' demand with minimal implication to the Business/Mission Trajectories with enough flexibility to meet changing constraints of weather, congestion/complexity and expected diverse aircraft fleets while maintaining the safety targets. Based on continuously assessment of traffic load metrics (traffic load/complexity, ATC workload) DAC provides automated support to dynamic change of sector boundaries, in terms of sector shape and volume, and aiming to balance the ATC workload over adjacent sectors or across an ACC or FAB.

Overall context of airspace planning and management in the SESAR environment is shown in Figure 3-14.

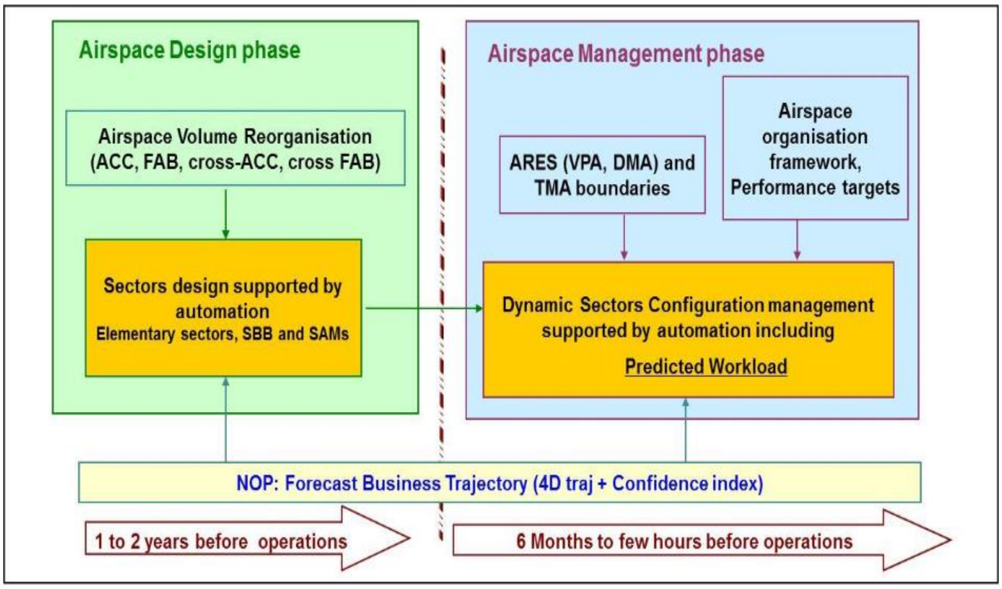

Figure 3-14. Airspace management in SESAR environment overview (EUROCONTROL, 2013)

In the SESAR framework ASM function is tightly integrated with other ATM function and therefore DAC falls under responsibility of the NM that enables optimal use of airspace and allows airspace users maximum access to ANS. NM function is based on CDM processes and is performed at all levels (regional, sub-regional FAB and local ACC).

In the DAC airspace is considered as a continuum and the ATC sectors are formed as the most suitable combination of the airspace component modules to meet the demand-capacity balance at a certain moment. The concept uses reliable planning methods and provides adaptive approach. It offers an efficient way to meet capacity, demand and staffing problems at the same time. Because of the huge number of possible sectors configurations, enabled by higher modularity of the sector design, finding optimal sector opening schemes will require the use of automated support tools.

SESAR foresees several levels of modularity and flexibility that allow for customised application of the DAC concept, driven by the local operational environment, requirements, constraints, etc. Depending on the required level of dynamicity future sectors will be composed of two airspace blocks types allowing lateral and/or vertical modularity between them:

- **Sectors Building Blocks (SBB) -** an airspace volume with permanently high traffic volume delineated by recurring traffic patterns.
- **Sharable Airspace Module (SAM) -** the smallest level of granularity of an airspace volume that is less busy with temporary high traffic loads.

These airspace blocks are combined into non-predefined airspaces configurations starting from Level I using solely SBB (todays Elementary Sectors), through airspace sectorisation with limited variability to vertical and lateral sector boundaries, up to full dynamic Level IV based on SAM.

The main objective of DAC is to optimally adapt capacity to the traffic demand with minimal implication to the Business/Mission Trajectories. In addition, DAC solution shall optimise workload distribution with more equally share of the load peaks for ATCOs. This is expected to be enabled by the introduction of TBO in the SESAR context, which is expected to improve the operational predictability, thus leading to improved performance of ATCO support tools and reduced task-load per flight. The capacity gains enabled by the reduction in controller workload can be realised in a number of ways: e.g. reduction in delay, increased flexibility for sectorisation and ANSP staff utilisation (sector team organizations), etc. All this leads to ATCOs being less reliant on sector knowledge and experience (contrary to the current state) allowing more dynamic change of the sector boundaries, in terms of sector shape and volume.

In the DAC concept, airspace is configured dynamically to accommodate the user preferred trajectories (SBT/RBT) as far as possible in the trade-off between trajectory efficiency and overall network effectiveness, subject to the available resources (e.g., ATC officers).

3.3.3.2 APACHE system high-level requirements and scope

In the APACHE project a fully dynamic approach – DAC Level IV will be considered, to explore the operational limits of the DAC in terms of ATM performance. As previously defined, DAC represent a classification problem and graph formalism is used to model and solve it in the APACHE project. The fundamentals of the approach that will be used in APACHE can be found in (Sergeeva, Delahaye, Zerrouki, & Schede, 2015), which has been successfully able to solve realistic instances on the scale of a country such as France.

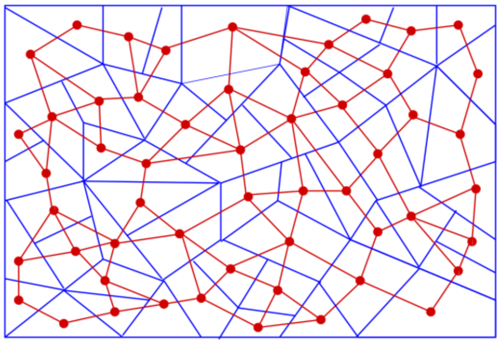

Figure 3-15: Airspace blocks - SAMs building process

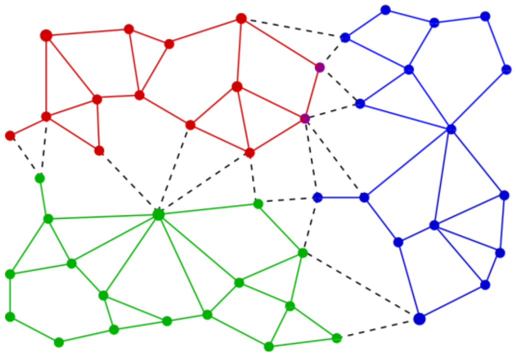

Figure 3-16: Example of the graph partitioning

Based on the set of shared business trajectories closely representing airspace user intention and provided by TP/TCP modules, in the pre-processing step, the airspace volume considered (FAB or ECAC) is first divided into airspace blocks, notably SAMs. The SAMs are synthesized by means of Voronoi diagrams producing convex blocks, whereas the associated Delaunay triangulation is used to create connected planar graph (Delahaye & Puechmorel, 2013) as shown in the Figure 3-15. Initial graph of SAMs is extended in time dimension associating every SAM with traffic load metric, corresponding to the given traffic sample, for each period of time. In APACHE, traffic complexity will be used as a metric that is associated with the relative difficulty that an ATCO may experience during the monitoring, detection and resolution of possible conflict situations.

Based on designed SAMs and graph formalism, the optimisation problem consists on finding an optimal multi-period geometric graph partitioning. For each time period, one graph partition (as shown in Figure 3-16) is defined representing airspace configuration for the considered airspace (FAB/ECAC) as whole, where each node (SAM) is associated with one single ATC sector (colour) and all nodes belonging to the same sector are interconnected.

Similar to ASM in the current operation, DAC is a multi-criteria optimization problem with main objectives to minimize number of ATC sectors (required ATCOs) for the given traffic demand respecting operational constraints such as maximal traffic complexity per sector. The assessment of workload associated with complexity is potentially the most challenging task, to which special attention will be given in the WP4. Other optimisation criteria of DAC problem include workload balance, traffic transfers minimization, and others.

A set of Pareto-optimal solutions will be given by the dDCB functionality to the ASP module, all of them taking into account a pre-reduction of traffic complexity. In this way the optimal sectorisation process will find with high probability (the system will be fine-tuned for that) a set of optimised sectors that can fulfil the capacity requirements. In the situations when traffic complexity in the given zones exceed established limit preventing good airspace configuration and fair workload balance, these solutions will be rejected (i.e., considered not feasible). If there still are feasible solutions available (i.e., strategically de-conflicted and capacity-balanced traffic trajectories), these will be assessed by the Performance Analyser to further filter or prioritise them, otherwise the TCP module will be launched again imposing extra traffic restrictions that reduce the complexity at regions in which sector solutions could not be found. This iterative process is the APACHE interpretation of dDCB in the future SESAR system.

Regarding the high-level requirements that the SESAR transition ConOps identifies for the Advanced **Airspace Management solution (PJ08),** the following ones will be explicitly incorporated in the APACHE models:

- Dynamic configuration of airspace shall enhance support to sector design and configurations allowing airspace to be managed as a continuum (i.e., coordinated single sky) in order to make optimum use of airspace resource and staffing versus AUs demand at any given time.
- The optimisation of sector design, configuration and opening schemes shall be fully integrated with the ASM, dDCB and ATC layered processes, and optimise airspace configuration based on workload and complexity.
- Sector design and configurations should be unconstrained by predetermined boundaries, and must assess and conciliate local level airspace configurations to build optimal configurations at ECAC network level.

Since military operations are out of the scope of APACHE project, Dynamic Mobile Areas (DMAs), Airspace Reservations/Restrictions (ARES), Advance Flexible User of Airspace (A-FUA) are not considered in the ASP-DAC module. This limitation must be considered during the assessment of scenarios and interpretation of simulation results.

Main input for the ASP module represents flight trajectories provided by the TP/TCP modules. Due to the higher integration of all ATM function in the SESAR framework, interaction with TCP module is not unidirectional but represents iterative process of demand-capacity balancing.

3.3.4 Separation and Conflict Management

3.3.4.1 Description of the concept, actors, performance drivers and trade-offs

Separation provision and conflict management are both ATM functions typically provided by ATC that aims at mitigating the risk of mid-air collisions or the risk of any other hazard, so that the risk levels are limited to an acceptable level (the Target Level of Safety). Separation provision must be done if two aircraft have lost their separation minima, but this concept can be extended through conflict management if the separation is anticipated by predicting potential losses of separation before they occur.

Since conflict management at tactical ATC layer is one of the most safety and time critical processes, the current ATM paradigm is focused on restricting the level of traffic simultaneously flying within a same sector. Capacity of the ATM and flight throughput in en-route sectors is limited by the workload capability of the ATCOs to manage the traffic under control in a safe way. For current levels of traffic, some ANSPs are often operating at the saturation limit of their operational capacity (e.g., MUAC). Therefore, although safety performance is preserved, this situation limits the opportunities to enhance other KPAs such as AUs operational efficiency, predictability or the environmental impact.

In the SESAR scope the conflict management is expected to be substantially improved by increasing the predictability of the 4D flight trajectories and by introducing higher levels of data sharing, automation and decision support tools to aid the controller’s tasks.

The anticipation of conflict detection and resolution tasks as well as the assessment of the impact on the downstream sectors is paramount to enhance the overall performance of the ATM, and therefore new de-confliction tools supported by SESAR solutions suitable to the ATCOs needs are necessary to improve ATM performance.

In order to improve the quality of the trajectory information and to enhance the predictability and efficiency of the operations, the involvement of the AUs through a collaborative traffic planning process is required. In addition, a more strategic management of the conflicts will allow a collaborative planning and de-confliction of the traffic. The tactical ATC layer will be still supervising the expected execution of the flights and will apply amendments if required (with enhanced tools and procedures). However, the tactical ATC is expected to adopt a role lesser reactive than nowadays and focus more in refining and adjusting the 4D trajectories already planned and negotiated in a more proactive strategic layer, i.e., from 2-3 hours up to 20-30 minutes in advance.

Strategic trajectory de-confliction will be provided at multi-sector level and typically by means of a collaborative decision making process in which AUs, NM and ATC will participate (airports also, but they are out of the scope of APACHE). The gap between tactical ATC and DCB will be bridged through the INAP (Integrated Network Manager and ATC Planning) function, which leads to a seamless management of the traffic and a reduction of the number of potentially conflicting trajectories to be handled by tactical ATC. The latter can then benefit from a simplified traffic situation and act to refine the traffic situation (i.e., applying extra tactical separation if required or adjusting the trajectories for efficiency and throughput purposes).

The INAP function can be handled by several roles from Network Operations and ATC Operations, possibly including the Local Traffic Manager role from the Network Management Function and appropriate ATC operational role such as the new figure of Extended ATC Planner (EAP). Within the ATM layered planning, the EAP role stands between the Local Traffic Manager Role and the Planning Controller Role. The Extended ATC Planner role has planning responsibilities for a Sector Family and will allow a sector configuration where the Planning and Executive Controllers are assisted by an EAP to reduce the complexity of the traffic situation with a look-ahead time of 30 minutes or more (possibly up to 120 minutes). Within Extended ATC planning time horizon, thanks to advanced planning tools, any measure on flights to manage complexity is naturally assessed in the ATC environment, taking into account multi-sectors strategic de-confliction view and traffic synchronisation plans, so that the measure can be aligned with ATC perspective.

Further investigation is needed in relation to task distribution and sharing of responsibilities among different ATC roles, however it is expected that a seamless coordination between the EAP and Planning controller will lead to a more efficient management of the traffic and a reduction in the number of potentially conflicting trajectories to be handled by tactical ATC. Note that the basic responsibilities given to the controller in this new concept of operations remain untouched, i.e., she or he has to ensure a conflict-free flight as well as safety and optimization of traffic flows, but now controllers may be able to concentrate their effort in higher added value activities as well as to increase their productivity.

Resolutions in INAP should be automated, based on large number of resolution scenarios with different levels of granularity, synchronized and applicable at different levels in the ATM layered planning. The INAP actors, thanks to its extended situation awareness encompassing both the ATFCM perspective and the ATC expertise, are able to better plan flights through sectors (typically at Sector Family level), and to perform punctual actions on flows or individual flights chosen when necessary. Advanced strategic conflict detection and resolution tools will indicate potential conflicts/ interactions (associated to relevant time horizon and parameters, which are different from the ‘tactical’ conflicts) and propose associated resolutions or constraints across a number of sectors. Airspace Users’ preferred trajectories and declared priorities are taken in consideration, thus facilitating CDM with better anticipation and reducing needs for tactical coordination during the execution phase. This provides opportunities for AUs to choose how they best reconcile their business needs with a DCB initiative and at the same time reduces the workload of the tactical ATC officers.

Additionally, the en-route tactical ATC controllers will be also provided with advanced conflict detection and resolution tools, to provide enhanced resolution support. In case of conflicting traffic and when appropriate, the ATC controller will initiate a RBT/RMT revision process, preferably through CDM, while preserving the Network strategy as much as possible. Open loop clearances via data-link or R/T may be provided by the ATCO for time critical situations (typically by exception).

In any case, the assessment of the resolutions will not only concentrate on the operational ATC aspects of their execution but it will also systematically consider AU needs and preferences, making sure that RBT/SBT revisions are used when duly needed and when their cost/benefit ratio is clear and undeniable. In addition, in case of an opportunity to improve the trajectory for the AU (for example removal of a constraint), the RBT/RMT revision process can also be initiated by ATC through coordination with NMF actors and AU and if time permits. Any coordinated decision among any concerned actor will dynamically update the NOP, and through SWIM all the ATM actors will kept informed about the NOP updates, thus increasing predictability in all regions of the network.

The integrated process between NMF and ATC planning will enable the consideration of the overall impact of their potential actions, both at the level of flows and sectors, and at the level of individual trajectories, in order to produce the optimum solution without mutual interference for positive network performance.

The expected increase of ATCOs productivity due to the introduction of advanced support tools and anticipation of traffic separation and de-complexification is expected to improve the capacity and ATM cost-effectiveness KPAs. The AUs participation in the traffic planning and trajectory de-confliction processes is expected to enhance the flight efficiency and environmental impact and together with higher trajectory prediction and data sharing, also the predictability.

3.3.4.2 APACHE system high-level requirements and scope

In APACHE, the INAP function will be in charge of the strategic de-confliction of trajectories, de-complexification of the airspace regions and collaborative traffic planning. Thus, it is part of the models presented in section 3.2.2 about dDCB. The tactical ATC, in those cases that may still be necessary (i.e., in the presence of uncertainty), will be modelled in APACHE a similar way as explained in section 3.2.4 about the separation provision and conflict management in current ATM. The most important difference will be the adaptation of the trajectory amendments into a closed-loop feedback in which the tactical amendments will be evaluated considering their downstream impact and adjusted to respect the strategic planning and resulting RBTs at the maximum extent.

In both cases, the following top and high level requirements of SESAR for the future separation management techniques will be modelled or considered in the context of APACHE:

- New functionalities for detection, resolution and coordination task will be present.
- More accurate trajectory prediction.

- New separation tools for ATC and automated support to reduce the ATCO workload and increase the productivity.
- Information will be shared with all concerned stakeholders.
- De-confliction decisions (specially the strategic ones) will be evaluated against their potential domino effects and performance impact, and negotiated among the stakeholders.
- Validation of the resolution including with respect third party aircraft.
- Collaborative control, based on new responsibilities and roles to reduce the ATC workload and remove strategic airspace and procedural constraints.
- Achieving more efficient flight profiles by anticipating the amendments and considering the AUs preferences and priorities.
- Checking compatibility with DCB processes and Minimising ATFCM constraints.
- Support for coordination between ATCOs.
- More flexible ATCo regime, allowing a controller to operate in any airspace.
- Compatibility with safety nets and adapted procedures in case of multiple complex conflicts configuration.

3.4 Performance Analyser

The Performance Analyser (PA) module is a part of APACHE system and it is closely related with APACHE-TAP. This relationship, illustrated in Figure 3-17 below, is bi-directional: the PA is receiving outputs from APACHE TAP for the computation of metrics and indicators, and the APACHE-TAP is receiving from the PA module safety feedback (computed in the Risk Assessment – RA – module) concerning aircraft conflicts and possible collisions of computed trajectories. The performance indicators assessed in the PA will serve as input for knowledge generation within the APACHE project.

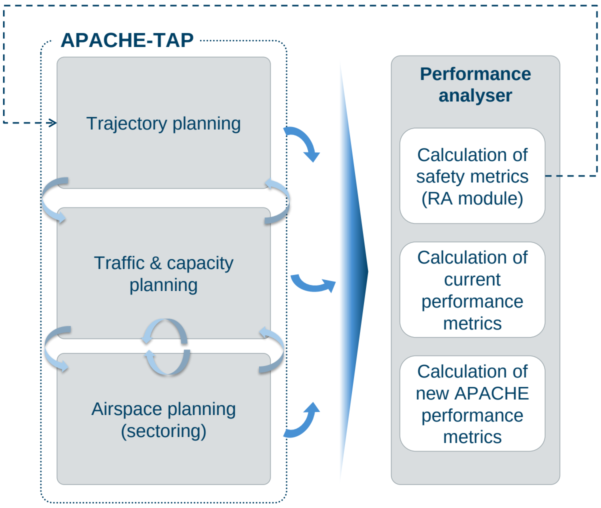

Figure 3-17. Interaction between APACHE-TAP and Performance Analyser

Further information on the computation of performance indicators and on the risk assessment module are given in the next sub-sections.

3.4.1 Computation of Performance Indicators (PIs)

The PA module will be in charge of assessing the outputs (i.e. optimal baselines of traffic and sectors) generated by the APACHE-TAP according to the different metrics or indicators implemented – either new ones proposed in the APACHE project and/or current PIs. The definition of PIs to be measured by the APACHE PA is out of the scope of the present deliverable, and thus the description of the computations within this module is kept brief (please refer to APACHE deliverable D3.1 - *Review of current KPIs and proposal for new ones* for more information).

Due to the holistic nature of the APACHE framework, the kind of results and analysis applied to the APACHE-TAP outputs will vary according to the nature of the scenarios and case studies configured.

The analysis of baseline scenarios will serve to identify the baseline values on all performance metrics. These values will be used to benchmark metrics of different scenarios in order to identify and quantify changes in performance with the introduction of new business models for the NM, the ANSPs and the AUs (see Figure 3-18 below).

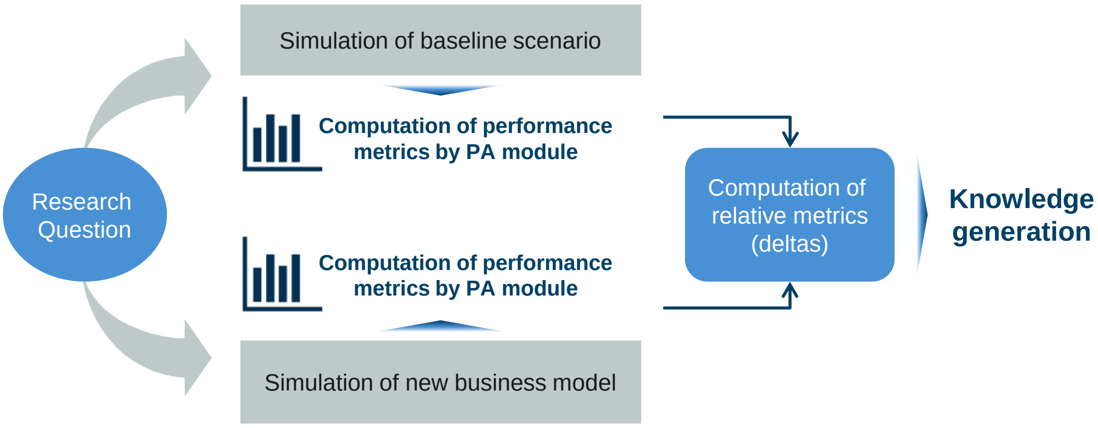

Figure 3-18. APACHE PA module and knowledge generation

On the other hand, some of the analysis of results will be oriented to quantify/approximate the theoretical limits of each of the KPAs. Note that the APACHE system could also be set up to monitor and target performance in real-time, or at different time-frames regarding the different traffic and airspace planning phases. These real-time capabilities could contribute to the effective implementation of Performance Based Operations (PBO) in a future ATM in which air traffic and airspace will be planned collaboratively and dynamically in order to adapt the KPA performances of the operations to the uncertain changing conditions of the ATM and weather.

The outputs after the analysis of results in PA shall generate new knowledge for a better understanding of the performance drivers and the interactions between KPAs at the Pareto-frontier. A preliminary approximation of the ideal values for long-term targeting and base-lining will be also reported. Apart from that, the PA will also enable the (initial) assessment of the impact of some SESAR solutions, or historical assessments of ATM performance. A special feature of the PA will be the visualisation of results.

Knowledge generated with the PA might be useful for benchmarking against different historical scenarios, against the theoretical optimal reference and/or against the targeted performances to assess the level of consecution of such targets.

Since safety is a 'must-have' in the ATM, the rest of the KPAs will be bounded and conditioned by the safety requirements (except in those simulations run to find the 'theoretical' limits of each KPA). Consequently, PA will pay special attention to safety and will build as a main component a powerful module to assess the risk of mid-air collision in several levels, i.e., risk of conflict (prediction of a future separation), risk of separation, and risk of collision itself. The Risk Assessment will include a robustness analysis based on adding uncertainties to the network traffic plans.

Next sub-section presents the foundations of the Risk Assessment module, whose role is twofold: to provide safety feedback (potentially in real-time) on traffic pattern and sectorisation provided by APACHE TAP, as well as determination of safety performance indicators.

3.4.2 Risk Assessment module

Risk Assessment (RA) module of PA presents a simulation tool which, as inputs, uses flight trajectories (outputs from Traffic and Capacity Planning module) and sectorisation plans (outputs from Airspace Planning module) and enables conflict risk assessment for the purpose of preventing aircraft conflicts and collisions. It is a part of wider framework for airspace planning and design previously developed (Netjasov, 2012).

This module introduces uncertainty through probability distribution functions of flight entry time into given sectors (simulating in such a way delays due to different causes) and/or aircraft ground speed (simulating in such a way wind influence), those enabling stochastic simulation of independent or dependant impact of flight entry time and aircraft ground speed variations on conflict risk estimations. Many simulation iterations will be performed in order to obtain a distribution of safety performance indicators.

The RA module enables the determination of a conflict risk between two aircraft in both horizontal and vertical plane as a main output. On Figure 3-19 a conflict situation between two aircraft was shown (separation is violated both in horizontal and vertical plane, so Δt_c presents a duration of conflict situation). Conflict risk presents an area of shaded surface on Figure 3-19.

Conflict risk that could be understood as a unique safety performance of considered (given) airspace is depending on airspace geometry (airways length and airways crossing angles), traffic flows/traffic demand, average flow speeds/aircraft speed, average aircraft inter-arrival times, spatial and temporal distribution of aircraft in the airspace, as well as applied separation minima. Conflict risk is sensitive to traffic demand as well as to airspace volume changes.

Additionally, a set of safety critical KPIs could be also assessed as well as geographically most safety jeopardized location (“hot spot”) determined.

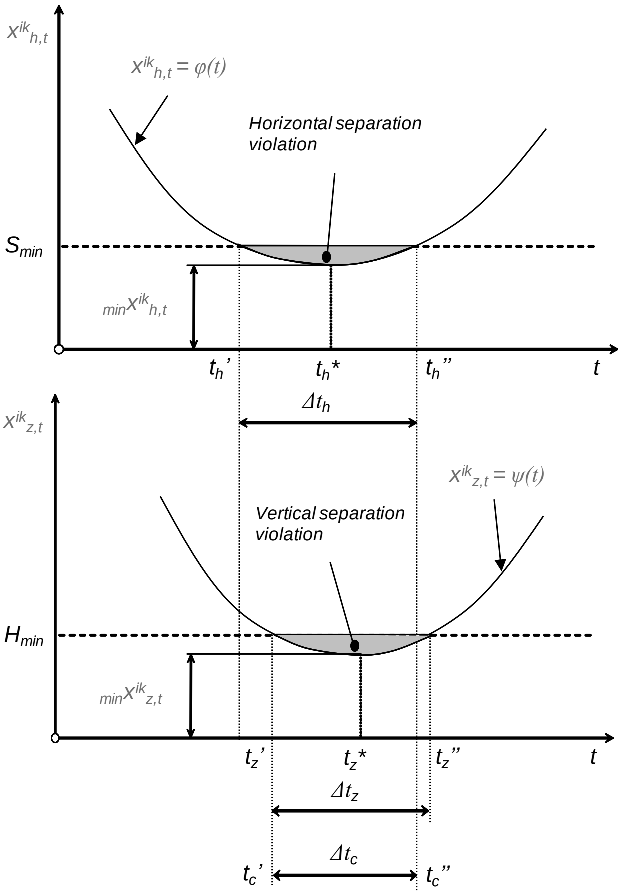

Figure 3-19. Situation in which conflict between two aircraft exist (Netjasov, 2012)

Finally, as a feedback to APACHE TAP, RA can provide a set of flights which are creating conflicts and which trajectory modification could be considered again in Traffic and Capacity Planning and Airspace Planning modules. Safety feedback is given in a form of conflict/accident risk values as well as counts on certain safety events, as well as pairs of aircraft candidates for trajectory modifications and sectors which presents a safety “hot spots” candidate for boundary modifications.

Moreover, this module will be extended to consider traffic complexity as a proxy of ATC workload and therefore as a proxy of ATM capacity. Such extension can be seen as a wider safety approach in which resilience is partly considered (i.e., considering capacity as the ATC potential to recover the system given potential trajectory conflicts and de-synchronisations).

4 Conclusions

Both the SESAR ATM concept and the European ATM Master Plan have succeeded in the high-level envisioning of a new ATM paradigm that shall bring benefits on all of the currently four main ATM Key Performance Areas, i.e. safety, capacity, cost-efficiency, and flight efficiency. However, the opportunities and limits of these KPAs, as well as their complex interdependencies, are not yet well understood by the ATM scientific community.

The APACHE Project brings the opportunity to study (through simulation and optimization mechanisms) the theoretical limits for each KPA as well as assessing how they may actually reduce the performance of the other KPAs (and in which proportion). The System proposed can contribute to reproduce the future ATM concepts envisioned by SESAR in order to anticipate and support the activities of targeting, monitoring, measuring, baselining and benchmarking for the holistic enhancement of the overall ATM performance.

Performance indicators used in the current Performance Scheme are not sufficient to describe with an accurate and holistic perspective the performance of future ATM concepts, in which the management of trajectories and the relaxation of airspace constraints will allow introducing user-preferred 4D trajectories, while at the same time the separation of flights will be anticipated and carried out in a more strategic phase. This is why the APACHE project will try to enhance current performance indicators, or even define new ones, which are expected to capture the benefits and performance trade-offs of such new operational concepts.

Deliverable 3.1 of the APACHE Project will provide compressive review of performance indicators used nowadays by different institutions while, at the same time, will provide a new set of enhanced or new performance indicators supported by the computing capabilities of the APACHE System presented in this document. APACHE system description provided in this document will also serve as an input for identification of the APACHE framework functional requirements in Deliverable 3.2. Finally all three deliverables will serve as inputs for *WP4 - Development of the APACHE framework.*

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Appendix A Complete SESAR Solutions list

Solution ID	SESAR Solution Name	Time frame
#01	Runway Status Lights	SESAR1
#02	Airport Safety Nets for controllers: conformance monitoring alerts and detection of conflicting ATC clearances	SESAR1
#04	Enhanced Traffic Situational Awareness and Airport Safety Nets for the vehicle drivers	SESAR1
#05	Extended Arrival Management (AMAN) horizon	SESAR1
#06	Controlled Time of Arrival (CTA) in Medium density / medium complexity environment	SESAR1
#08	Arrival Management into Multiple Airports	SESAR1
#09	Enhanced terminal operations with automatic RNP transition to ILS/GLS	SESAR1
#10	Optimised Route Network using Advanced RNP	SESAR1
#11	Continuous Descent Operations (CDO) and Continuous Climb Operations (CCO)	SESAR1
#12	Single Remote Tower operations for medium traffic volumes	SESAR1
#13	Remotely Provided Air Traffic Service for Contingency Situations at Aerodromes	SESAR1
#14	Departure Management integrating Surface Management constraints	SESAR1
#15	Integrated and throughput-optimised sequence of arrivals and departures	SESAR1
#16	ASAS Spacing applications Remain behind and Merge behind	SESAR1
#17	Advanced Short ATFCM Measures (STAM)	SESAR1
#18	CTOT and TTA	SESAR1
#19	Automated support for Traffic Complexity Detection and Resolution	SESAR1
#20	Collaborative NOP for Step 1	SESAR1
#21	Airport Operations Plan and AOP-NOP Seamless Integration	SESAR1
#22	Automated Assistance to Controller for Surface Movement Planning and Routing	SESAR1
#23	D-TAXI service for CPDLC application	SESAR1
#24	Improved vehicle guidance	SESAR1
#26	Manual taxi routing function	SESAR1
#27	MTCD and conformance monitoring tools	SESAR1
#28	Initial ground-ground interoperability	SESAR1
#31	Variable profile military reserved areas and enhanced (further automated) civil-military collaboration	SESAR1
#32	Free Route through the use of Direct Routing	SESAR1
#33	Free Route through Free Routing for Flights both in cruise and vertically evolving above a specified Flight Level	SESAR1
#34	Digital Integrated Briefing	SESAR1
#35	MET Information Exchange	SESAR1
#37	Extended Flight Plan	SESAR1
#46	Initial SWIM technology solution	SESAR1
#47	Guidance Assistance through Airfield Ground Lighting	SESAR1
#48	Virtual Block Control in LVPs	SESAR1
#51	Enhanced terminal operations with LPV procedures	SESAR1
#52	Remote Tower for multiple low density aerodromes	SESAR1

Solution ID	SESAR Solution Name	Time frame
#53	Pre-Departure Sequencing supported by Route Planning	SESAR1
#54	Flow based Integration of Arrival and Departure Management	SESAR1
#55	Precision approaches using GBAS CAT II/III based on GPS L1	SESAR1
#56	ATFM Slot Swapping	SESAR1
#57	UDPP Departure	SESAR1
#58	Display and use of ACAS resolution advisory downlink on the controller working position	SESAR1
#60	Enhanced Short Term Conflict Alert (STCA) for Terminal Manoeuvring Areas (TMAs)	SESAR1
#61	CWP Airport - Low Cost and Simple Departure Data Entry Panel	SESAR1
#62	Enhanced Terminal Airspace for RNP-based Operations	SESAR1
#63	Multi Sector Planning	SESAR1
#64	Time Based Separation	SESAR1
#65	User Preferred Routing	SESAR1
#66	Automated Support for Dynamic Sectorisation	SESAR1
#67	AOC Data Increasing Trajectory Prediction Accuracy	SESAR1
#68	Optimised enhanced braking information at a pre-selected runway exit coordinated with Ground ATC by voice	SESAR1
#69	Enhanced STCA with down-linked parameters	SESAR1
#70	Enhanced Ground Controller Situation Awareness in all Weather Conditions	SESAR1
#71	ATC and AFIS service in a single low density aerodrome from a remote CWP	SESAR1
#100	ACAS ground monitoring system	SESAR1
#101	Improved hybrid surveillance	SESAR1
#102	Aeronautical mobile airport communication system (AeroMACS)	SESAR1
#103	Approach procedures with vertical guidance	SESAR1
#104	Sector team operations - en-route air traffic organise	SESAR1
#105	Enhanced airborne collision avoidance system (ACAS)	SESAR1
#106	Departure manager (DMAN) baseline for integrated AMAN DMAN	SESAR1
#107	Point merge in complex terminal airspace	SESAR1
#108	Arrival management (AMAN) and point merge	SESAR1
#109	Air traffic services (ATS) datalink using Iris Precursor	SESAR1
#110	ADS-B surveillance of aircraft in flight and on the surface	SESAR1
#112	Flexible communication avionics	SESAR1
PJ.01-01	Extended Arrival Management with overlapping AMAN operations and interaction with DCB and CTA	SESAR 2020
PJ.01-02	Use of Arrival and Departure Management Information for Traffic Optimisation within the TMA	SESAR 2020
PJ.01-03	Dynamic and Enhanced Routes and Airspace	SESAR 2020
PJ.01-05	Airborne Spacing Flight Deck Interval Management	SESAR 2020
PJ.01-06	Enhanced Rotorcraft and GA operations in the TMA	SESAR 2020
PJ.01-07	Approach Improvement through Assisted Visual Separation	SESAR 2020
PJ.02-01	Wake turbulence separation optimization	SESAR 2020
PJ.02-02	Enhanced arrival procedures	SESAR 2020

Solution ID	SESAR Solution Name	Time frame
PJ.02-03	Minimum-Pair separations based on RSP	SESAR 2020
PJ.02-05	Independent Rotorcraft operations at the Airport	SESAR 2020
PJ.02-06	Improved access into secondary airports in low visibility conditions	SESAR 2020
PJ.02-08	Traffic optimisation on single and multiple runway airports	SESAR 2020
PJ.02-09	Enhanced Runway Condition Awareness	SESAR 2020
PJ.02-11	Enhanced Terminal Area for efficient curved operation	SESAR 2020
PJ.03a-01	Enhanced Guidance Assistance to Aircraft and Vehicles on the Airport Surface Combined with Routing	SESAR 2020
PJ.03a-03	Enhanced navigation and accuracy in low visibility conditions on the airport surface	SESAR 2020
PJ.03a-04	Enhanced Visual Operations	SESAR 2020
PJ.03a-09	Surface operations by RPAS	SESAR 2020
PJ.03b-01	Enhanced Airport Safety Nets for Controllers	SESAR 2020
PJ.03b-03	Conformance monitoring safety net for Pilots	SESAR 2020
PJ.03b-05	Traffic alerts for pilots for airport operations	SESAR 2020
PJ.03b-06	Safety support tools for runway excursions	SESAR 2020
PJ.04-01	Enhanced Collaborative Airport Performance Planning and Monitoring	SESAR 2020
PJ.04-02	Enhanced Collaborative Airport Performance Management	SESAR 2020
PJ.05-02	Remotely Provided Air Traffic Service for Multiple Aerodromes	SESAR 2020
PJ.05-03	Remotely Provided Air Traffic Services from a Remote Tower Centre with a flexible allocation of aerodromes to Remote Tower Modules	SESAR 2020
PJ.06-01	Optimized traffic management to enable Free Routing in high and very high complexity environments.	SESAR 2020
PJ.06-02	Management of Performance Based Free Routing in lower Airspace	SESAR 2020
PJ.07-01	AU Processes for Trajectory Definition	SESAR 2020
PJ.07-02	AU Fleet Prioritization and Preferences (UDPP)	SESAR 2020
PJ.07-03	Mission Trajectory Driven Processes	SESAR 2020
PJ.07-04	AU Trajectory Execution from FOC perspective	SESAR 2020
PJ.08-01	Management of Dynamic Airspace configurations	SESAR 2020
PJ.08-02	Dynamic Airspace Configuration supporting moving areas	SESAR 2020
PJ.09-01	Network Prediction and Performance	SESAR 2020
PJ.09-02	Integrated Local DCB Processes	SESAR 2020
PJ.09-03	Collaborative Network Management Functions	SESAR 2020
PJ.10-01a	High Productivity Controller Team Organisation	SESAR 2020
PJ.10-01b	Flight Centred ATC	SESAR 2020
PJ.10-01c	Collaborative Control	SESAR 2020
PJ.10-02a	Improved Performance in the Provision of Separation	SESAR 2020
PJ.10-02b	Advanced Separation Management	SESAR 2020
PJ.10-04	Ad Hoc Delegation of Separation to Flight Deck	SESAR 2020
PJ.10-05	IFR RPAS Integration	SESAR 2020
PJ.10-06	Generic (non-geographical) Controller Validations	SESAR 2020
PJ.11-A1	Enhanced Airborne Collision Avoidance for Commercial Air Transport normal operations - ACAS Xa	SESAR 2020

Solution ID	SESAR Solution Name	Time frame
PJ.11-A2	Airborne Collision Avoidance for Remotely Piloted Aircraft Systems – ACAS Xu	SESAR 2020
PJ.11-A3	ACAS for Commercial Air Transport specific operations – ACAS Xo	SESAR 2020
PJ.11-A4	Airborne Collision Avoidance for General Aviation and Rotorcraft – ACAS Xp	SESAR 2020
PJ.11-G1	Enhanced Ground-based Safety Nets adapted to future operations	SESAR 2020
PJ.13-01-01	Airborne Detect and Avoid Systems supporting integrated RPAS operations	SESAR 2020
PJ.13-02-01	GA/R Specific Communication Systems	SESAR 2020
PJ.13-02-02	GA/R Specific Navigation Systems	SESAR 2020
PJ.13-02-03	GA/R Specific Surveillance Systems	SESAR 2020
PJ.13-02-04	GA/R Specific Information Management systems	SESAR 2020
PJ.14-01-01	CNS environment evolution	SESAR 2020
PJ.14-01-02	CNS Avionics integration	SESAR 2020
PJ.14-01-03	CNS Ground segment integration	SESAR 2020
PJ.14-02-01	FCI Terrestrial Data Link	SESAR 2020
PJ.14-02-02	Future Satellite Communications Data link	SESAR 2020
PJ.14-02-04	FCI Network Technologies incl. voice solutions and military interfacing	SESAR 2020
PJ.14-02-05	Development of new services similar to FIS-B to support ADS-B solutions for General Aviation	SESAR 2020
PJ.14-02-06	Completion of AeroMACS development	SESAR 2020
PJ.14-03-01	GBAS	SESAR 2020
PJ.14-03-02	Multi Constellation / Multi Frequency (MC/MF) GNSS	SESAR 2020
PJ.14-03-04	Alternative Position, Navigation and Timing (A-PNT)	SESAR 2020
PJ.14-04-01	Surveillance Performance Monitoring	SESAR 2020
PJ.14-04-03	New use and evolution of Cooperative and Non-Cooperative Surveillance	SESAR 2020
PJ.15-01	Sub-regional Demand Capacity Balancing Service	SESAR 2020
PJ.15-02	Delay Sharing Service	SESAR 2020
PJ.15-08	Trajectory Prediction Service	SESAR 2020
PJ.15-09	Data Centre Service for Virtual Centres	SESAR 2020
PJ.15-10	Static Aeronautical Data Service	SESAR 2020
PJ.15-11	Aeronautical Digital Map Service	SESAR 2020
PJ.16-03	Work Station, Service Interface Definition & Virtual Centre Concept	SESAR 2020
PJ.16-04	Workstation, Controller productivity	SESAR 2020
PJ.17-01	SWIM TI Purple Profile for Air/Ground Advisory Information Sharing	SESAR 2020
PJ.17-02	SWIM TI Federated Identity Management	SESAR 2020
PJ.17-03	SWIM TI Green profile for G/G Civil Military Information Sharing	SESAR 2020
PJ.17-07	SWIM TI Purple Profile for Air/Ground Safety-Critical Information Sharing	SESAR 2020
PJ.17-08	SWIM TI Common runtime registry	SESAR 2020
PJ.18-01	Mission Trajectories	SESAR 2020
PJ.18-02	Integration of trajectory management processes in planning and execution	SESAR 2020
PJ.18-04	Management and sharing of data used in trajectory (AIM, METEO)	SESAR 2020
PJ.18-06	Performance Based Trajectory Prediction	SESAR 2020

Table A-1. SESAR Solutions list

Apache

APACHE consortium

UPC
UNIVERSITAT POLITÈCNICA
DE CATALUNYA
BARCELONATECH

ALG
TRANSPORTATION
INFRASTRUCTURE
& LOGISTICS

DIVISION OF AIRPORTS AND AIR TRAFFIC SAFETY
FACULTY OF TRANSPORT AND TRAFFIC ENGINEERING
UNIVERSITY OF BELGRADE

ENAC
ECOLE NATIONALE DE L'AVIATION CIVILE