EXPLORATORY RESEARCH

Functional requirements and specifications for the ATM performance assessment framework

Deliverable D3.2

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 framework to assess European ATM (air traffic management) 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 presents the software requirements for the APACHE System. The APACHE System is the platform, build up with different software components (existing and to be developed) implementing a wide set of performance indicators across several key performance areas (KPA). Moreover, the APACHE System can be configured to synthetize aircraft trajectories and airspace sectorisation for future scenarios, in line with the SESAR 2020 scope, where input data is not available (and also for hypothetical scenarios based in the current concept of operations).

The software requirements presented in the current document are classified as functional requirements, non-functional requirements and domain requirements. These requirements relate to the first phase of the software development cycle, depicted as *Requirements Analysis*. This is the base for the following phases: *Design*, *Development*, *Testing* and *Implementation*.

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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 *D3.2 – Functional requirements and specifications for the ATM performance assessment framework*, as part of the work package (WP) 3: *WP3 – KPI review and definition of novel KPIs*, presents the baseline for the software development cycle of the APACHE System to be followed in the *WP4 – Development of the APACHE framework*. The APACHE System is the software platform to be developed with the objective of capturing ATM performance either in current or future operational contexts.

The common software development cycle consists of a set of sequential and cyclic phases depicted as: *Software requirements analysis*, *design*, *development*, *testing*, *implementation* and *maintenance*. This document represents the results of the first phase, i.e., *software requirements analysis,* and, as it is shown in Figure 1-1, takes as main input the outcome of previous deliverables *D2.1 – Scope and definition of the Concept of operations for the project* (APACHE Consortium, 2017a) and *D3.1 – Review of current KPIs and proposal for new ones* (APACHE Consortium, 2017b).

In Deliverable D2.1, the high-level requirements of the APACHE System were identified and outlined, while in Deliverable D3.1 a wide set of new (or enhanced) performance indicators to be computed by the APACHE System were proposed. As explained in Deliverable D2.1, the APACHE System will be able to simulate a reduced set of SESAR 2020 solutions, representative enough of the future Performance Based Operations (PBO) paradigm, **taking into account several assumptions and limitations** due to the reduced scope and low maturity level intrinsic to this SESAR Exploratory Research Project. The high-level requirements for the simulation of these SESAR 2020 solutions within the APACHE System are identified in D2.1, which were taken directly from the SESAR 2020 Transition ConOps (SESAR Joint Undertaking, 2016). This ensures that the requirements that are further elaborated here, in this Deliverable D3.2, are in-line with the solutions currently implemented in the SESAR 2020 program.

At the end of WP4 it will be reported how the different SESAR2020 Solutions have been finally modelled and implemented in the APACHE System, along with the final implementation details on the performance indicators and performance assessment tools that are also part of the APACHE System (Deliverable D4.1). Further on, in WP5, the Operational Service and Environment Definition (OSED) developed by SESAR for the considered SESAR 2020 solutions will be traced and compared with the

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final modelling performed in this Project, highlighting the assumptions done and differences found from the related OSEDs. This will be reported in Deliverable D5.1 (see Figure 1-1).

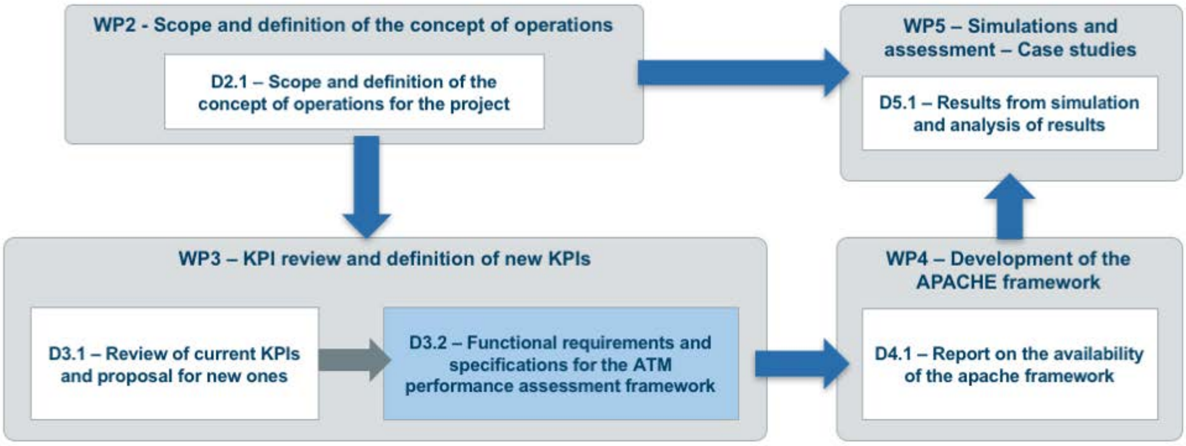

Figure 1-1. Context of deliverable D3.2

1.2 Document structure

The document is structured as follows:

- **Section 1:** Introductory section that outlines the context and purpose of this deliverable, followed by some background information of the common software development cycle ideas and types of requirements that will be used in this Project and containing a glossary of terms and concept definitions.
- **Section 2:** This section summarises the functionalities that are expected for the APACHE System, as derived from the conclusions of deliverables D2.1 and D3.1, which are the precursor deliverables to D3.2 in the workflow of the APACHE Project.
- **Section 3:** The software architecture of the APACHE System is presented in this section. This includes a brief description of each of the software components and its integration and workflow.
- **Section 4:** Devoted to identify and explain the software requirements of the APACHE System.
- **Section 5:** Gives precise details on the set of performance indicators that will be computed by the APACHE System and how these will be computed, mapping this computation with the software requirements identified in section 4.

1.3 Software development cycle

The software development cycle consists of a set of phases devised to follow a logical approach into developing a scalable software solution that satisfies a set of desired requirements. In the context of the APACHE project, the software development team is the APACHE Consortium composed by ALG (Advanced Logistics Group) from Barcelona, Spain, ENAC (*École Nationale de l'Aviation Civile*) from Toulouse, France, UB-FTTE (University of Belgrade – Faculty of Transport and Traffic Engineering) from Belgrade, Serbia and UPC (Universitat Politècnica de Catalunya) from Barcelona, Spain.

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There are several existing approaches regarding how to handle the transition between one phase and the next, which can be generally classified as linear (one after the other) or cyclic. The cyclic approach can be managed in several ways, for example following linear development and then coming back to a previous phase (even the first one) if it is required, and it is generally accepted as the best approach. With this in mind, the APACHE System will be developed in a cyclic approach.

These phases are summarised in Table 1-1.

PHASE	Description	Output
Requirements analysis	This phase aims at detecting and describing all the features desired by the final user to be satisfied by the software. In this sense, the developer discusses via questionnaires, meetings, interviews, etc., with the user and presents a document summarizing all the software requirements. The requirements also include hardware necessities, etc.	Software requirements document (APACHE Deliverable D3.2)
Design	This phase consists of devising the overall system architecture (components and integration) and the user cases. The user cases are the ways in which the user interacts with the software to satisfy the software requirements provided by the previous phase.	User cases and Unified Modelling Language (UML) diagrams (Internal document within WP4 activities)
Development	Software coding. This phase inputs are the user cases and the UML diagrams provided by the previous phase.	Software (main activity of WP4)
Testing	This phase consists of testing the user cases and evaluating the satisfaction of the software requirements by the client.	Software testing document (Internal document within WP4 activities)
Deployment	Once the software has been tested and the results are satisfying, the software is deployed over the selected final hardware and is put in operation.	Final documentation (APACHE Deliverable D4.1)
Maintenance	During normal operation, bugs and contraventions are expected to occur. In this sense, the software is maintained in order to continue and improve its operation.	Maintenance documentation (bug tracking, etc.)

Table 1-1. Software development cycle phases

1.4 Types of software requirements

The software requirements are classified as follows (see Table 1-2).

Type of software requirement	Description
Functional requirements	This type of requirements relates to the function of the software. In other words: 'What' the software will do.
Non-functional requirements	This type of requirements relates to resources required for the software to work and specific constraints. In other words: 'How' the software will do it.
Domain requirements	This type of requirements relates to the software application domain. In this case, the domain is related to aviation, air transportation and air traffic management. It also considers official data sources for input files, etc.

Table 1-2. Software requirements classification

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1.5 Definitions

Thorough this document several concepts, needed for the development of the APACHE System, are used. Most of them belong to the ATM field, but might adapted to the context of the APACHE System. Other concepts, however, are introduced here, such as Air traffic pattern. Table 1-3 lists all these concepts and provides a definition.

Concept	Definition
4D point	4 dimensional (4D) aircraft trajectory point including, for a given *Timestamp,* a *Latitude*, *Longitude* and *Altitude*.
4D trajectory	Similar to a radar track log for a single flight in a given timeframe and/or area. It contains: *4D point set + Aircraft type + Callsign + O/D airports + ground speed*
Aircraft type	Unique identifier indicating the aircraft type for a given flight.
Airspace block	It is a section of the airspace that delineate typical demand (hot spots, crossing, merging) but are too small individually for controlling purpose.
Airspace configuration	It is a combination of collapsed and elementary sectors used in the operations that doesn't overlap and covers whole airspace.
Airspace structure	It includes airspace blocks, sectors, sector opening scheme, and airspace configurations. In current ConOps it will also include airspace charges and declared sector capacity.
Air traffic pattern	It contains a set of 4D trajectories a given airspace structure. This is the input of the APACHE system's Risk Assessment (RA) component.
AU data	Specific Airspace User data concerning a given flight including the *Cost Index* and *Payload*.
Callsign	Unique identifier indicating the airspace user and a flight number and/or registration number for a given flight
Collapsed sector	It is the union of two or more elementary sectors that is used to adapt airspace capacity to the demand by grouping/ungrouping elementary sectors depending on the traffic.
Conflict	Is the situation in which either horizontal or vertical separation minima are violated between a pair of aircraft
Conflict severity	Presents the level of aircraft proximity and is defined either for the violation of separation in the horizontal or the vertical plane, or both.
Elementary sector	It is a smallest controllable volume of the airspace, that can't be split further.
ETD/ETA	Estimated time of departure (and arrival) at origin (and destination) airports for a given flight.
Flight	It contains origin, destination airport and ETD
Flights set	Input of the APACHE System, specifically of the APACHE system's Trajectory Planner (TP) component.
Fuel model	Performance tables/formulae to calculate the fuel consumption during a flight
Functional Airspace Block	It is defined in the SESAR as a block of airspace based on operational requirements and established regardless of State boundaries.
Hotspot	Airspace sector or group of sectors where forecast demand is higher than nominal capacity for that sector or group of sectors.
O/D airports	Origin and destination airports for a given flight.
P2P trajectory demand	Point to point demand of flights in a given timeframe and/or area. It contains: O/D airports + ETD/ETA + Aircraft type + Callsign + AU data
Regulation	Affected area, duration and capacity reduction
Regulations set	List of regulations
Risk of conflict	For a pair of flights is assessed using duration and severity of conflict situation in the observed airspace under given circumstances.
Sharable Airspace Module	It is an airspace component, defined in the SESAR, with smallest level of granularity that can be re-allocated laterally and vertically to the neighbouring sector to adapt to changes of the traffic pattern in DAC process.
Sector opening scheme	It is a schedule of configurations i.e. active sectors during a course of the day.

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Concept	Definition
Trajectories set	A set of trajectories. In this case, per each flight in a flights set, a trajectory is calculated by TP. This is the input of the APACHE system's Traffic and capacity planner (TCP) component.
Weather data	Wind force, wind heading and air temperature per 3D cell
Airline Cost Index	ratio between the cost of fuel versus the cost of flying time).
Payload weight	weight of carried passengers, luggage and cargo)

Table 1-3. Definitions used in the APACHE System

1.6 Glossary

Term	Explanation
ADCB	Advanced demand and capacity balance
ASP	Airspace Planner (APACHE system component)
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATFM	Air traffic flow management
ATM	Air traffic management
AU	Airspace User
CASA	Computer Assisted Slot Allocation
ConOps	Concept of operations
CONF	Sector configuration
CS	Collapsed sector
CTA	Control Time of Arrival
DAC	Dynamic Airspace Configuration
DCB	Demand and Capacity Balance
ECAC	European Civil Aviation Conference
ES	Elementary sector
ETD	Estimated Time of Departure
FAB	Functional Airspace Block
FL	Flight Level
FRA	Free Route Area
ICAO	International Civil Aviation Organisation
KPA	Key Performance Area
LI	Loop iteration (TP-TCP)
PA	Performance Analyser (APACHE system module)
RA	Risk Assessment (APACHE system component)
RBT	Reference Business Trajectory
SAM	Sharable Airspace Module
SBB	Sectors Building Blocks
SBT	Shared Business Trajectory
SESAR	Single European Sky ATM Research
SJU	SESAR Joint Undertaking
TAP	Trajectory and airspace planner module (main component of the APACHE system)
TCP	Traffic and Capacity Planner (APACHE system component)
TP	Trajectory Planner (APACHE system component)
UML	Unified Modelling Language

Table 1-4. Glossary

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2 Functionalities of the APACHE System

The main objectives of the **APACHE Project** can be summarised as follows:

- to assess ATM performance with a novel (or enhanced) set of performance indicators (PIs), which were identified in APACHE Deliverable D3.1 (APACHE Consortium, 2017b);
- to capture the complex interdependencies across several ATM key performance areas (KPA), assessing in this way the Pareto front of ATM performance; and
- to perform an initial impact assessment of some SESAR 2020 Solutions, along different KPAs, which were identified in APACHE Deliverable D2.1 (APACHE Consortium, 2017a).

In order to fulfil these objectives, the **APACHE System** will be implemented in this Project. This system is intended to be a novel tool capable to generate optimal trajectories at microscopic level, with the consideration of the business models of the airspace users (AU); integrate them into an air traffic flow and management (ATFM) scheme, aiming to simulate advanced demand and capacity balance (ADCB) mechanisms; and at the same time, assess airspace complexity. See APACHE Deliverable D2.1 (APACHE Consortium, 2017a) for more details.

The activities of the APACHE Project could be summarised in Fig. 2-1. Firstly, several scenarios (Project validation scenarios) will be defined, setting up different options regarding the demand of traffic, airspace capacities and eventual restrictions; the SESAR solution(s) to be enabled; and the level of uncertainty to be considered.

The APACHE-TAP (trajectory and airspace planner) is the main part of the APACHE System and could be seen as a small prototype of an ATM simulator. It has a double functionality in this Project:

- to synthesize traffic and airspace scenarios representative enough of current operations; or emulating future operational concepts in line with the SESAR 2020 ConOps (i.e. enabling one or more SESAR solutions), aiming at an initial assessment of their impact in ATM performance (validation case studies of the APACHE Project); and
- to support the implementation of novel ATM PIs, which require from some advanced functionalities (such as optimal fuel trajectories considering real weather conditions, optimal airspace opening schemes, large-scale conflict detection, etc.).

The performance analyser (PA) module is the other main part of the APACHE System and it is in charge of implementing all the PIs of the APACHE performance framework, including as well a few set of indicators from the current performance scheme for benchmarking purposes.

This chapter summarises the **functionalities** that are expected for the **APACHE System**, taking into account the conclusions and high-level requirements of the APACHE Deliverables D2.1 and D3.1. First, the types of performance assessments are explained; followed by the initial list of simulation scenarios proposed for WP5; and finally, the set of PIs that will be computed by the software are enumerated. In Chapter 3 the general software **architecture** for the **APACHE System** is detailed.

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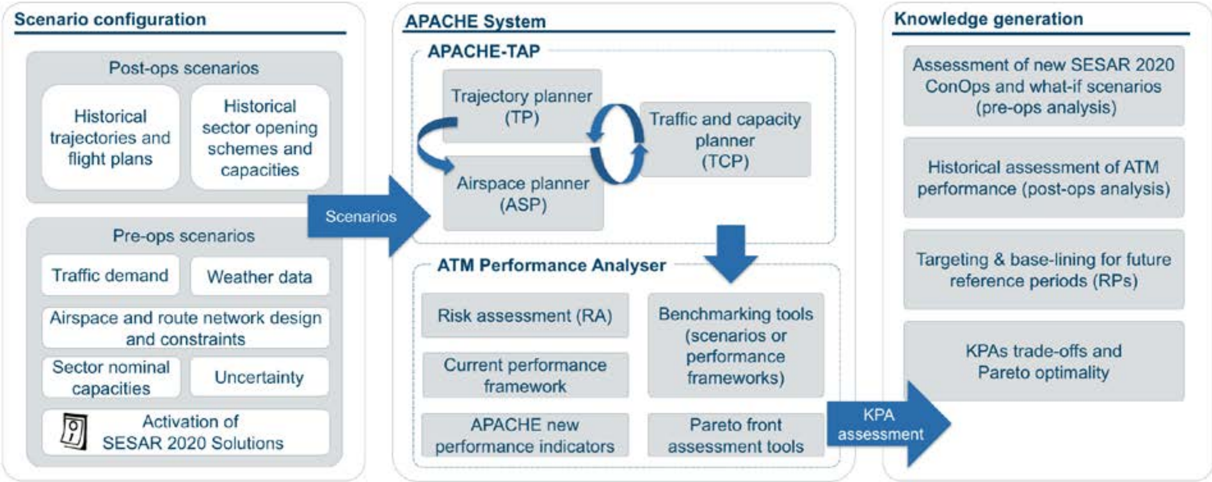

Figure 2-1. Context of the APACHE system within the APACHE Project

2.1 Types of performance assessment in the APACHE Project

The APACHE Project deals mainly with 'Pre-ops' ATM performance assessment (i.e. assessing ATM performance for planned operations), and will focus its validation and demonstration exercises on the initial evaluation of a small set of SESAR 2020 Solutions. Nevertheless, **the APACHE System could also be used against real (historical) data** for 'Post-ops' ATM monitoring purposes.

Figure 2-2 shows the scope of the research that is foreseen in the **APACHE Project**, in terms of ATM performance assessment.

- **For 'Post-ops' (monitoring) analysis**, the APACHE System will be able to compute a set of PIs (currenty used or new/enhanced as proposed in D3.1) for current historical data. Ideally, this historical data should come from the Network Manager and/or the different ANSPs. If such data is not available in the timeframe of the APACHE project, Eurocontrol DDR2 data repository (Eurocontrol, 2016) will be used instead, which will provide data realistic enough to demonstrate the usefulness of the APACHE System as an ATM performance monitoring tool. Thus, DDR2 M1 trajectory data will be taken to reconstruct the 'last filled trajectory', M2 trajectory data to reconstruct the 'regulated trajectory' and M3 trajectory data to reconstruct the 'actual trajectory' (Eurocontrol, 2016).
- **For 'Pre-ops' (planning) analisys**, the APACHE System will be used with a two-fold objective, as explained above: Firstly, to generate (or synthesise) the scenarios (trajectories and airspace sectorisations) to be studied. Secondly, to support the computation of some PIs. **Simulating the tactical layer of ATM is out of the scope of the APACHE Project**. Therefore, the APACHE System will bring synthesized shared business trajectories (SBT), by modelling the behaviour of the AUs; and reference business trajectories (RBT), by modelling the negotiation process via the Network manager to balance demand and capacity.

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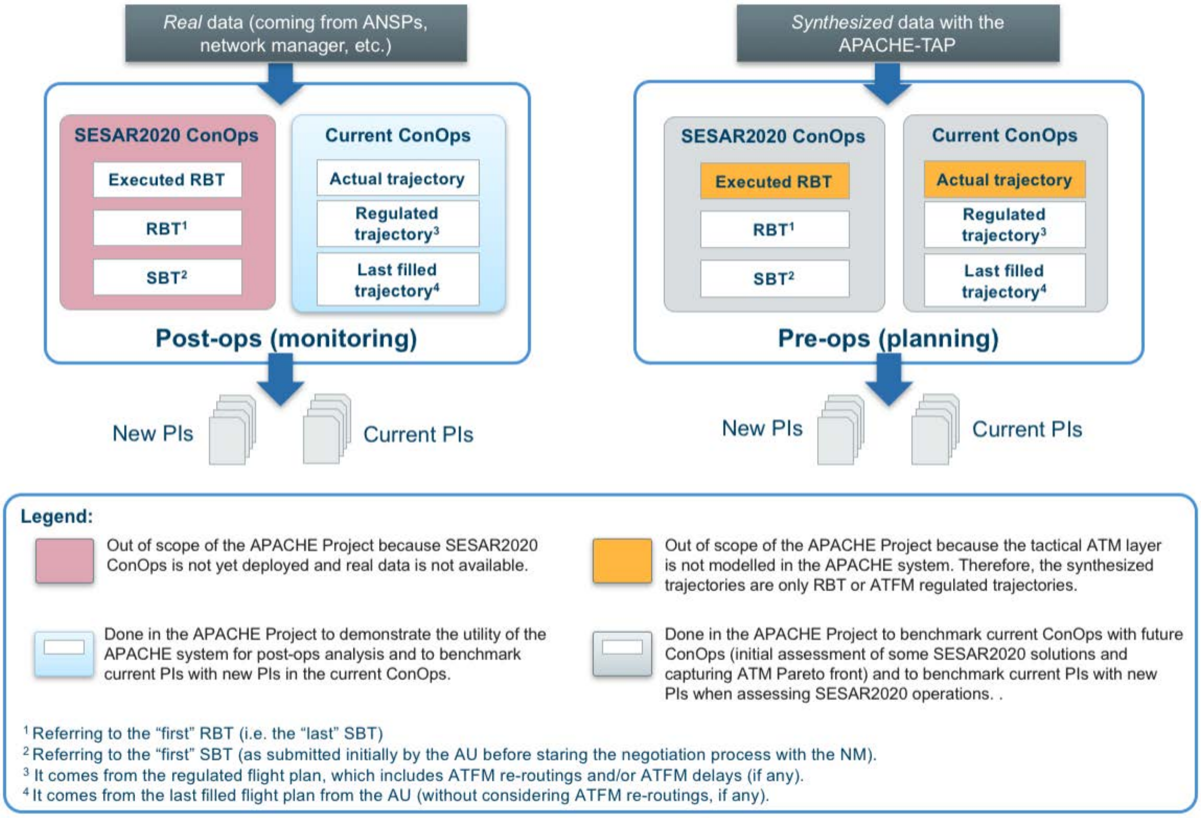

Figure 2-2. Scope of the APACHE System and types of performance assessment

2.2 Simulation scenarios

In order to show the usefulness of the new (or enhanced) PIs proposed in APACHE and also to capture interdependencies among KPAs when assessing ATM performance, a wide set of simulation scenarios will be studied in the APACHE Project. These scenarios were initially identified in Deliverable D2.1 and refined during the activities of WP3. An initial list of scenarios is summarised in Table 2-1 below. The final list of scenarios will be specified in WP5.

The scenarios are designed to answer the research questions of the Project and to fulfil the project high-level objectives. In particular, they aim to initially assess the performance of a reduced set of SESAR 2020 Solutions not yet implemented, or not fully implemented, in current operations ('Pre-ops' assessment). Moreover, as commented before, the APACHE System could be used against historical data, for monitoring purposes (or 'Post-ops' assessment).

The different modules that compose the APACHE-TAP will be configured either to simulate operations in the current ATM paradigm **("baseline operations"** or **"current ConOps"**), or to simulate (i.e. synthetize) operations with some SESAR solutions enabled (**"target/future operations"** or **"SESAR 2020 ConOps"**), in line with the available information on the SESAR 2020 Transition ConOps (SESAR Joint Undertaking, 2016). All this will be configured at scenario level in the Project validation exercises (see Fig 2-1).

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Scenario	Trajectory planner modes		Airspace Planner mode	Traffic and capacity planner mode
		"Post-ops" assessment		
S0	-	-	-	-
		"Pre-ops" assessment		
S1	Current route network and FRA	Current FL allocation/orientation scheme	Static sectorisation	CASA
S2	**Full free route**	Current FL allocation/orientation scheme	Static sectorisation	CASA
S3	Current route network and FRA	***Continuous Cruise Climbs***	Static sectorisation	CASA
S4	Current route network and FRA	Current FL allocation/orientation scheme	**Dynamic sectoristion**	CASA
S5	Current route network and FRA	Current FL allocation/orientation scheme	Static sectorisation	**ADCB**
S6	**Full free route**	Current FL allocation/orientation scheme	**Dynamic sectoristion**	**ADCB**
S7	**Full free route**	***Continuous Cruise Climbs***	**Dynamic sectoristion**	**ADCB**

Table 2-1. Preliminary set of scenarios for research

Consequently, each APACHE-TAP module will be able to enable/disable some functionalities in line, or inspired, with these selected SESAR solutions:

- **Trajectory planner module:**
  - *Current Operations*: the module is configured to use currently published airways (structured routes) and free route areas (FRA). In the vertical domain, current flight level allocation and orientation schemes are used. Thus, Airspace Users (AUs) will optimise their trajectories taking into account these ATM constraints.
  - *SESAR 2020 ConOps:* taking SESAR 2020 solutions **PJ06** (trajectory based free routing) and **PJ07-01** (AU processes for trajectory definition) to their theoretical limit, this mode of operation will assume that airspace users can freely optimise their trajectories from the origin airport to the destination airport, in order to best consider their own operational requirements while fulfilling the requirements of the other ATM stakeholders expressed with ATM constraints.
  - *Continuous Cruise Climbs:* Additionally, simulation of hypothetical operations where flight level allocation and orientation schemes are removed, allowing continuous climb cruise operations en-route. This is not a SESAR solution *per se*, but can be a useful baseline for maximum fuel efficiency flights.

- **Airspace planner module:**
  - *Current operations:* configuration of the module according to current ConOps, where for each period and for each Air Traffic Control Centre (ACC) one airspace configuration is selected, from a set of predefined airsapce configurations, consisting of one or more elementary/collapsed sectors. Sector grouping/ungrouping principles are respected by constraints on the airspace configurations that are selected in two consecutive periods.

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  - *SESAR 2020 ConOps*: simplified simulation of SESAR solution **PJ08** (Management of dynamic airspace configurations) allowing airspace to be managed as a continuum in order to make optimum use of available airspace resource. In this mode of the ASP, existing elementary sectors are taken as SBB and grouped into controlled sectors not previously defined and not taking into account ACC borders.

- **Traffic and capacity planner module:**
  - *Current operations:* configuration of the module according to current ConOps, where the computer assisted slot allocation (CASA) algorithm is used to balance demand and capacity by delaying aircraft on ground following a ration-by-schedule principle.
  - *SESAR 2020 ConOps*: inspired by SESAR solution **PJ09**, Advanced DCB (demand and capacity balancing). Enabling some degree of collaborative trajectory planning close to the execution phase, integrating the AUs and network planning processes in a holistic network planning management. In this mode, the TCP will also consider alternative routes, previously proposed by the AUs (ATFM re-routing), and/or flight level capping, and/or linear holding strategies; as alternatives to ground holding for DCB purposes.

Bold text in Table 2-1 depicts those configurations that enable the SESAR 2020 solution considered for that particular APACHE-TAP module. As seen in the table, only scenarios **S0** and **S1,** correspond to **the "current ConOps"** as identified in Deliverable D2.1. Conversely**,** scenario **S6,** correspond to the **"SESAR 2020 ConOps"** as identified in D2.1. Scenarios S2, S4 and S5, only enable one SESAR solution and are designed for benchmarking purposes and also to help assessing the Pareto front of ATM performance and to find the theoretical performance limits of some KPA. Finally, **S3** will simulate CCC in current concept of operations, while **S7** will simulate all SESAR solutions plus CCC, in order to serve as an indication of the theoretical upper bound for fuel efficiency.

For each scenario, several case studies will be defined in WP5 of the APACHE Project. A case study is a variant of the scenario were some input parameters may change (such as traffic demand, weather conditions, etc.) or where the scope of the simulation may change (simulated timeframe, simulated geographical area, etc.).

2.3 Performance indicators (PIs)

In Deliverable D3.1, a comprehensive list of new or enhanced PIs was produced for a wide set of KPAs. Some of these PIs, however, cannot be implemented in the APACHE System because of its technical limitations; considering the timeframe of the APACHE project; or because it might require additional data or models not available to the APACHE Consortium.

Moreover, and for benchmarking purposes, some performance indicators of current Performance Framework (PF) used by SES/PRU, and reported regularly in their annual Performance Review Reports (PRRs), will be also computed by the APACHE System. Taking into account the scope of the APACHE Project and the limitations of the APACHE System, among all SES/PRU indicators, those ones that can be calculated by the APACHE System are summarised in Table 2-2 (details on these PIs are given in section 5.1 of this document). Table 2-3 lists all PIs that were proposed in D3.1 that will be finally implemented in the APACHE System (details on each PI are given in Section 5.2 of this document).

The PIs presented in Tables 2-2 and 2-3 can be used for 'Pre-ops' assessment, 'Post-ops' assessment or both (details of their applicability are given in Section 5 of this document). It is important to note that

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those new/enhanced PIs initially proposed in APACHE Deliverable D3.1 that aimed to capture tactical ATM performance, will not be used for Pre-ops analysis, since the tactical layer of ATM is not modelled by the APACHE system.

ID	KPA	Performance Indicator
C-CAP-1	Capacity	Average en-route ATFM delay per flight attributable to ANS
C-EFF-1	Efficiency	The share of regulated flights
C-ENV-1	Environment	Average horizontal en-route flight efficiency for the filed flight plan trajectory
C-ENV-2	Environment	Average horizontal en-route flight efficiency of the actual trajectory
C-SAF-1	Safety	Number of separation minima infringements.

Table 2-2. SES/PRU Performance indicators computed by the APACHE System

ID	Performance Indicator	ID	Performance Indicator
AEQ-1	Percentage of RBTs which are equal to the first submitted SBTs per AU	**ENV-2.4**	Strategic ATM vertical trajectory inefficiency on trip fuel (or emissions)
AEQ-2	Worst penalty cost	**ENV-2.5**	Strategic ATM horizontal trajectory inefficiency on trip fuel (or emissions)
AEQ-3	Total ATM Delay relative to Reference ATM delay	**ENV-2.6**	Tactical ATM inefficiency on trip fuel (or emissions)
AEQ-4	Percentage of Flights Advantaged and/or Disadvantaged	**ENV-2.7**	Tactical ATM vertical trajectory inefficiency on trip fuel (or emissions)
AEQ-5	AU cost per Flight relative to Reference AU cost	**ENV-2.8**	Tactical ATM horizontal trajectory inefficiency on trip fuel (or emissions)
CAP-1	Robust maximum en-route ATFM delay	**FLEX-1**	Percentage of RBTs equal to first submitted SBTs
CAP-2	Average flow management arrival delay	**FLEX-2**	Spare capacity
CAP-3	Capacity shortfalls	**FLEX-3**	Sector changes relative to time/distance
CE-1	En-route unit economic costs for the AU	**FLEX-4**	Flexibility of DCB solutions
CE-1.1	En-route unit economic costs for the AU – strategic	**SAF-1**	Number of Traffic Alerts warnings
CE-1.2	En-route unit economic costs for the AU – tactical	**SAF-1.1**	Traffic Alerts warnings
CE-1.3	En-route ATM charges cost for the Airspace User	**SAF-2**	Number of Resolution Advisories issued
CE-2	Sectorisation cost	**SAF-2.1**	Resolution advisories issued
CE-3	Flights per ATCO hour on duty	**SAF-3**	Number of Near Mid Air Collisions – NMACs
ENV-1	ATM inefficiency on the horizontal track	**SAF-3.1**	Near Mid Air Collisions - NMACs
ENV-1.1	Strategic ATM inefficiency on the horizontal track	**SAF-4**	Number of separation violations
ENV-1.2	Tactical ATM inefficiency on the horizontal track	**SAF-4.1**	Separation violations
ENV-2	ATM inefficiency on trip fuel (or emissions)	**SAF-5**	Severity of separation violations
ENV-2.1	ATM vertical trajectory inefficiency on trip fuel (or emissions)	**SAF-6**	Duration of separation violations
ENV-2.2	ATM horizontal trajectory inefficiency on trip fuel (or emissions)	**SAF-7**	Risk of conflicts/accidents
ENV-2.3	Strategic ATM inefficiency on trip fuel (or emissions)	**PAR-1**	Collaborative SBT updates
KPAs: AEQ (access and equity); CAP (capacity); CE (Cost-efficiency); ENV (Environment); FLEX (Flexibility); SAF (Safety); PAR (Participation).			

Table 2-3. New (or enhanced) Performance indicators computed by the APACHE System

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3 The APACHE System software architecture

This section presents the general software architecture for the **APACHE System**, which is composed by the integration of a set of existing independent software modules developed, or to be further developed, by the partners forming the APACHE consortium. In this context, each of the existing software applications will be modified/improved to satisfy the software requirements identified in this document.

As seen in Fig. 2-1, the **APACHE System** consists of the integration of the following software modules:

- The **APACHE-TAP** (Trajectory and Airspace Planner), in turn composed by:
    - Trajectory planner component (TP).
    - Traffic and capacity planner component (TCP).
    - Airspace planner component (ASP).
- The **Performance analyser (PA)** module, which includes a Risk assessment component (RA).

3.1 The APACHE-TAP

The APACHE-TAP, as part of the APACHE System, is the module in charge of simulating and synthetizing air traffic scenarios, from which PIs will be calculated by the Performance Analyser module. As explained in Section 2, each APACHE-TAP module can be configured either to reproduce current ATM concept of operations or to simulate a futuristic concept (based on some SESAR 2020 Solutions) and can also be used to support the computation of some PIs requiring advanced functionalities, such as optimisation.

Fig. 3-1, shows a high-level functional view of the APACHE-TAP. It should be noted that if current operations are simulated, regarding demand and capacity balance, the SBT negotiation loop depicted in the figure is disabled and flights are regulated according to current ration-by-schedule CASA algorithm.

3.1.1 Trajectory planner component

The Trajectory Planner (TP) component (Figure 3-2) generates and simulates traffic scenario (4D trajectories) based on real or future traffic demand (flight plans) and weather data. This one uses information and data from Traffic Databases (WPs, routes, STARs, SIDs), schedules or radar tracks in order to provide, as output, realistic 4D trajectories that will feed the Traffic and Capacity Planner component. The trajectories are assumed to be optimal for the airspace user.

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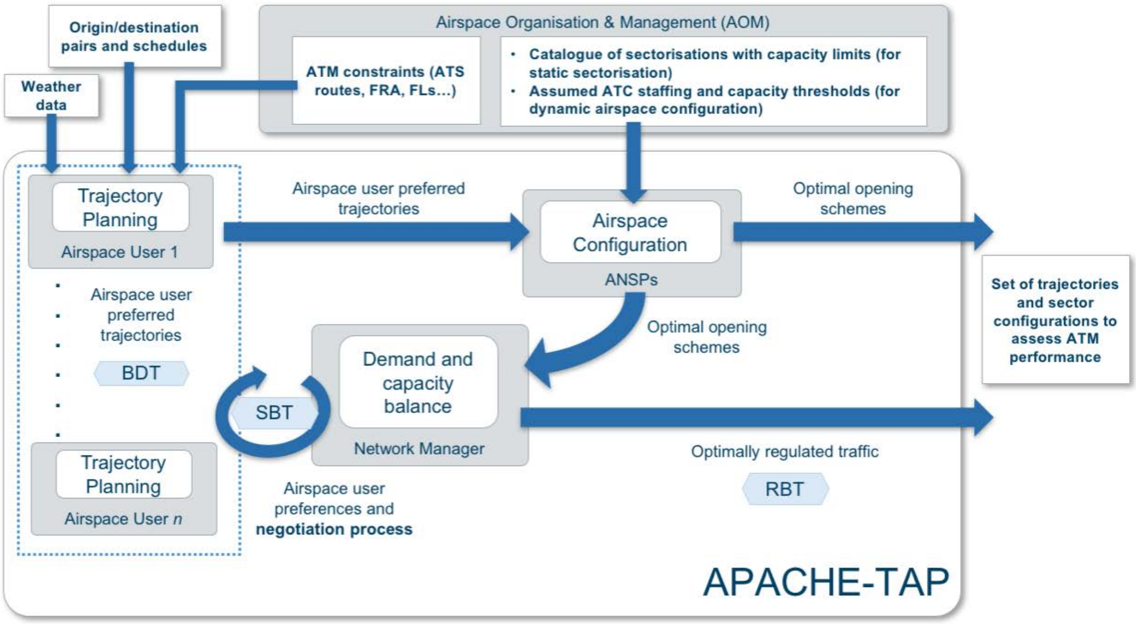

Figure 3-1. High level functional view of the APACHE-TAP

The software developed at UPC and named as DYNAMO (Dynamic Optimiser) will be adapted and enhanced to serve the role of the TP component. The overall DYNAMO architecture is broken in four modules with different functionalities, whose interactions are depicted in Figure 3-2. 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 profile and implements a module to model aircraft performance (such as fuel flow and aerodynamic drag magnitudes) and a module to process and model weather data.

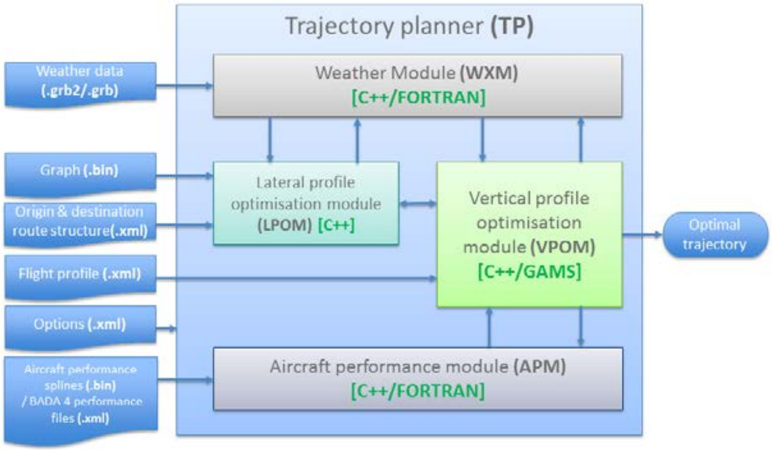

Figure 3-2. Trajectory planner software architecture

This component will be able to simulate current operations (structured routes and flight level allocation/orientation schemes) and SESAR solutions PJ06 and PJ07. Moreover, this component could be also configured to optimise the vertical profile of the trajectory by producing continuous cruise climbs. More details on this component and the associated high-level requirements are given in sections 3.2.3.2 and 3.1.2 of Deliverable D2.1 of the APACHE Project.

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3.1.2 Airspace planner component

Figure 3-3 shows general architecture of the AirSpace Planner (ASP) component that is simulating Airspace management service of the current and future ATM environments. Airspace management services aim to improve airspace design and utilisation in order to ensure delivery of the performance targets for the ATM system.

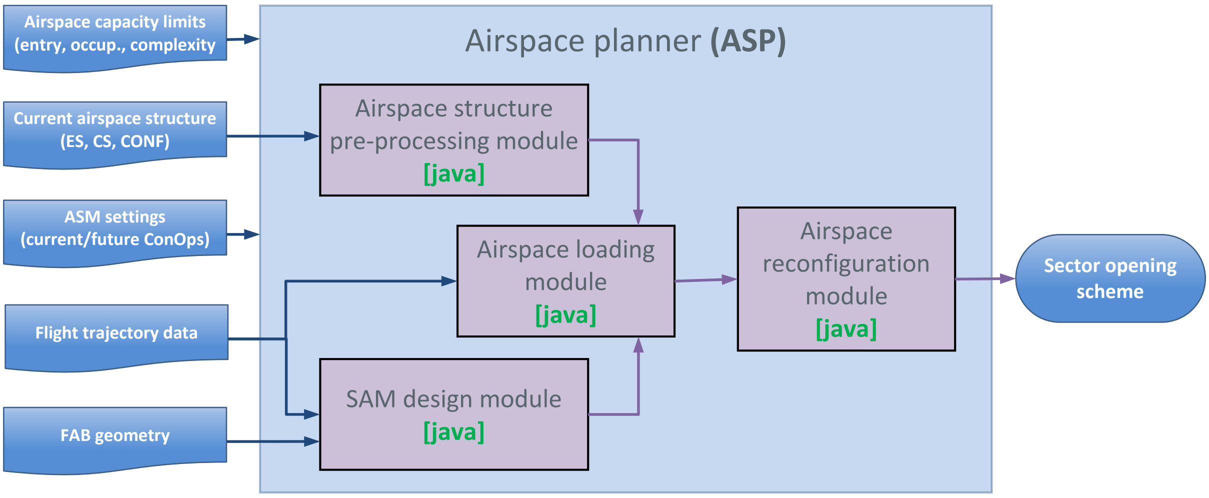

Figure 3-3. Airspace planner software architecture

For a given traffic sample and airspace structure with operational limitations, the ASP component finds an optimal sector opening scheme, i.e. an optimal list of airspace configurations or optimal grouping of the SAM (sharable airspace modules) for each period of time, depending on ATM environment. The ASP component consists of the several modules shown as purple rectangles in Figure 3-3. Some of the modules are specific to simulate the current/future ATM system, while others are configured to work in both environments. These modules and their main functionalities are explained as follows:

- Airspace structure pre-processing module – it is a module used for the simulation of the current ATM system with the purpose of data editing of pre-defined (existing) airspace structure elements into digital form: airspace blocks, elementary/collapsed sectors (ES/CS), configurations (CONF), etc. The process is done manually, with the assistance of a computer or a combination of both, depending on the data source and format.
- SAM design module – it is a module inherent to the simulation of the future ATM system and Dynamic airspace configuration (DAC), which aims to design SAMs, an airspace component that is constituent of a sector.
- Airspace loading module – aims at loading airspace structure elements with traffic, associating each elementary sector/SAM (as a smallest level of granularity of the airspace) with a traffic load metric: entry rates, occupancy counts, complexity, etc.).
- Airspace reconfiguration module – it is the main module that based on the airspace elements, loaded with the traffic, and operational limitations of the ATM system (capacity/max. complexity) outputs the optimal sector opening scheme.

This component will be able to simulate current operations (static sectors) and SESAR solution PJ08. More details on this component and the associated high-level requirements are given in sections 3.2.1.2 and 3.3.3.2 of Deliverable D2.1 of the APACHE Project.

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3.1.3 Traffic and capacity planner component

The Traffic and Capacity Planner (TCP) component (Figure 3-4), as the name suggests, is in charge of traffic planning and network optimisation. This module will model the current ATM and the future SESAR ATM target concept, regarding demand and capacity balance measures.

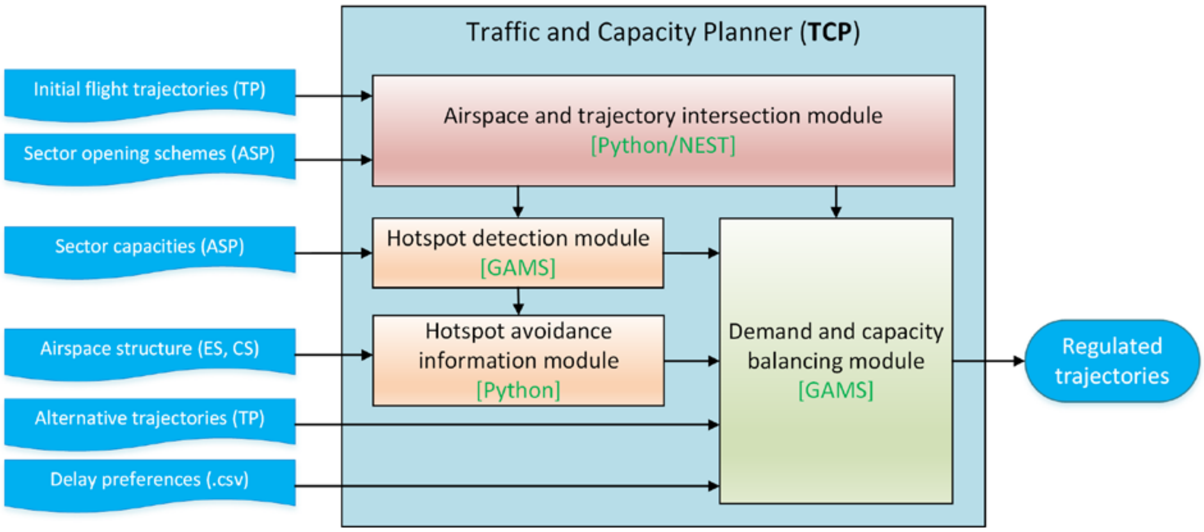

Figure 3-4. Traffic and capacity planner software architecture

The current ATM will be modelled using current ATFM practices: a computer assisted slot allocation (CASA) algorithm will be implemented.

Regarding the future SESAR ConOps, they will be modelled y introducing an advanced demand and capacity balance algorithm, including some degree of collaborative trajectory planning with the airspace users and in line with SESAR Solution PJ09 (advanced demand and capacity balancing). In this mode of operation, the TCP module will perform the following functionalities:

- detection of time-varying hotspots (i.e. airspace volumes with demand greater than capacity);
- generation of hotspot avoidance information, for each affected flight, for trajectory negotiation with the TP; and
- advanced demand and capacity balancing (through optimising trajectory alternative selections and delay assignments).

These functionalities of the TCP component are activated in interactions with the TP component (see details in Section 3.3.3), but the TCP component can be also used independently, in which only (optimal) delay assignments will remain the only applicable measure to regulate demand.

This component uses a linear optimisation model to incorporate a series of options to manage the traffic flow in a high flexible way. The possible measures consist of (alternative) trajectory options (given by the TP once the hotspots are detected) and different delay strategies (including ground holding, airborne holding, linear holding and delay recovery after the regulated airspace). The objective is to minimise the overall deviation to the initial status which is composed of all the user-preferred trajectories, whilst maintaining the traffic demand not higher than the capacity provision across all the considered airspace sectors.

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3.2 Performance analyser module

The Performance Analyser (PA) module (Figure 3-5) is in charge of: a) assessing the outputs generated by the APACHE-TAP (i.e. optimal baselines of traffic and sectors) and according to the different metrics implemented - new KPIs proposed in the APACHE project and/or current KPIs, as well as b) performing risk assessments of traffic and sectorisations coming from the APACHE-TAP.

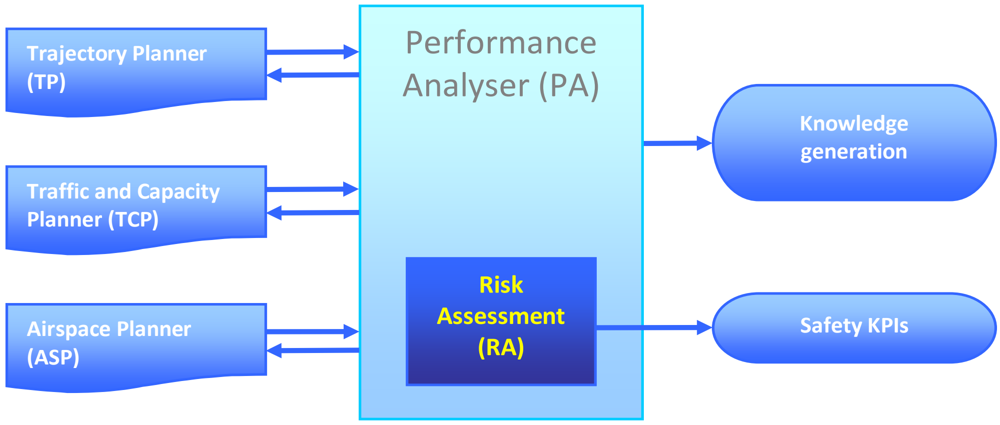

Figure 3-5. Performance analyser module software architecture

3.2.1 Risk assessment component

The Risk Assessment (RA) component (Figure 3-6) is intended for simulation of air traffic consisting of optimal flights trajectories (outputs from TCP component) through a given airspace sectorisation (output from ASP component) with aim to assess air traffic safety and to provide outputs in form of Safety KPIs as well as safety feedback which could be considered by TCP and ASP components in case that proposed flight trajectories and sector boundaries are not suitable from the safety point of view.

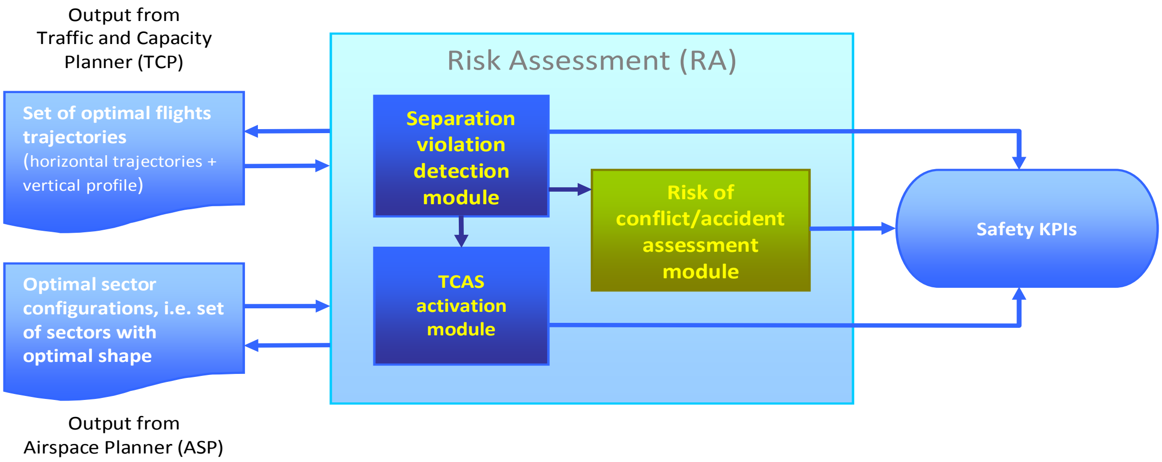

Figure 3-6. Risk assessment software architecture

The RA component is consisting of three modules: 1) separation violation detection module, 2) TCAS activation module and 3) risk of conflict/accident assessment module. The RA component is based on the assumption that conflict between pair of aircraft exists when either horizontal and/or vertical separation minima are violated.

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The separation violation detection module compares actual separation of aircraft (both in horizontal and vertical plane) with given separation minima in order to detect potential conflict. Once conflict is detected this module calculates duration and severity of conflict situation in the observed airspace under given circumstances. If the situation worsens the TCAS activation module is activated. It counts Traffic Alerts, Resolution Advisories as well as Clear of Conflict warnings.

The risk of conflict/accident assessment module is based on calculation of 'elementary risk' which is defined as the area between the surface limited by the minimum separation line and the function representing the change of aircraft separation. The risk of conflict/accident is then defined as the ratio between the 'elementary risk' and the observed period of time. Apart from the risk between specific aircraft pairs, an assessment of the total risk in a given sector is also considered.

The conflict/accident risk between aircraft pairs and the total conflict/accident risk depends on airspace geometry, traffic demand, aircraft velocities, spatial and temporal distribution of air traffic in the airspace as well as the applied separation minima. As such, the risk value taken as a safety feedback could suggest changes in flight trajectories and/or changes in sector boundaries, i.e. sector geometry.

More details on this component and the associated high-level requirements are given in section 3.4.2 of Deliverable D2.1 of the APACHE Project.

3.2.2 PI computation

The PA will contain a set of analytical formulas with which APACHE-TAP output metrics will be transformed into meaningful performance indicators. Apart from those formulas the PA will also contain logically the Risk Assessment (RA) component, whose role is twofold: to provide safety feedback on traffic patterns and sectorisations provided by APACHE-TAP as well as for the determination of safety performance indicators. The physical location of each component, even in the cases of the logical integration of PA and RA, will be depicted in section 3.3 of this document.

More details on this component and the associated high-level requirements are given in section 3.4 of Deliverable D2.1 of the APACHE Project.

3.3 Components workflow

As explained before, the three main components composing the APACHE-TAP can be either configured to simulate the “current ConOps” or a simplification of a SESAR 2020 solution. While, for both operation modes, all components will be active, its interaction and internal configuration will depend on the particular SESAR solution enabled in each particular Case Study (see Figure 3-1). For example, the TP will be set to execute with profiles related to structured routes, free route, continuous operations, etc. Also, the ASP will use profiles for static (pre-defined airspace configurations) or dynamic airspace sectors.

As commented in section 2, in “Pre-ops” operation (see Figure 2-2) the APACHE-TAP is used to synthesise trajectories and airspace sectors to re-create the different scenarios of the Table 2-1 (using the same set of input data that define a scenario, such as origin-destination pairs, schedules, etc.). Moreover, in “Pre-ops” and “Post-ops” the APACHE-TAP is needed to compute some PIs too (baseline optimal trajectories and/or sectorisations).

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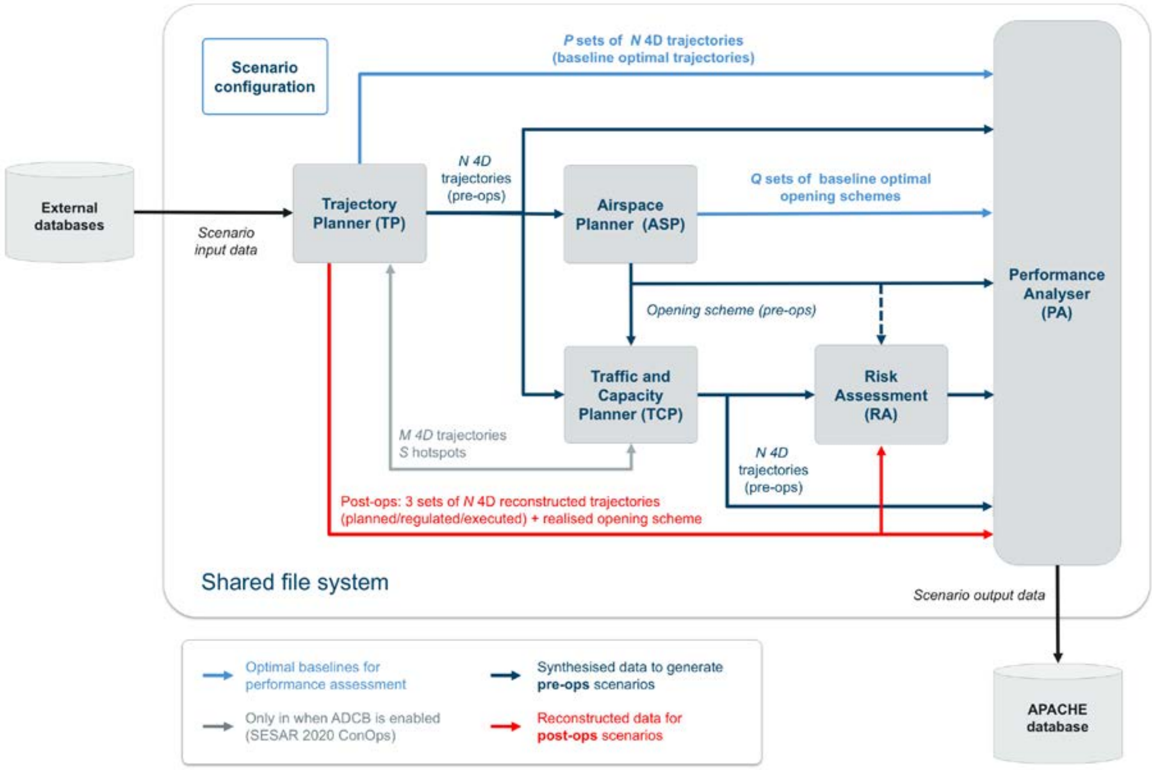

Figure 3-7. APACHE System general software architecture / Workflow

Figure 3-7 shows the general (i.e. for both operation modes and all possible scenarios) software architecture or workflow of the APACHE System, as the integration of all the software components of the APACHE System (TP, TCP, ASP, RA and PA). The TP and TCP will be physically located at UPC, the ASP at ENAC, the RA at UB-FTTE and the PA at UPC. Input and output data for all components will be stored in a shared file system, physically located at UPC.

Some aspects, to be considered before entering the description of the workflow, are:

- The scenario configuration (top left box in Figure 3-7) represents options for all components in order to set up a specific scenario (i.e. TP for structured routes, TCP with CASA algorithm, ASP with static sectors, etc.)
- In order to execute all scenarios (Table 2-1), Figure 3-7 integrates all expected interactions among components. Some of those interactions will occur for current, future or both ConOps operation modes. Details of such interactions will be presented in the following subsections (3.3.1 – 3.3.7).
- In all scenarios, the final results of all components will flow into the PA, where the values of the PIs are calculated and stored into a final database.
- A key feature of the APACHE System is that it will not be run completely automatic. This means, that at each partner site, a software component operator will exist in charge of their specific modules during the simulations.
- Due to the stochastic nature of uncertainties of flight trajectories, several iterations for each scenario (and test case) will be performed in the RA component, aiming at providing reliable safety assessment. These iterations will be agreed among project partners and will include uncertainties of sector entry times and/or uncertainties in flight speeds.

The workflow between components is described in the following sections.

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3.3.1 Trajectory planner component

Scenario input data will be delivered to the TP component, which is the starting point of the whole workflow. This data will contain the basic information to reproduce *N* flights (flight set). The input data for each flight is summarised in Table 3-1. It should be noted that by setting properly the trajectory constraints input, the free route or the continuous climb concepts will be enabled or disabled. For those case studies with an increased demand, Eurocontrol's statistics and forecasts (STAFOR) data might be considered.

In pre-ops mode, and for each of the *N* flights, an optimal trajectory will be calculated, such that minimum operational costs are minimised while fulfilling all trajectory constraints. These *N* optimal trajectories (trajectories set) will be formatted as inputs for the ASP and TCP. Conversely, in post-ops mode, the TP will use the input data to reconstruct 4D trajectories belonging to three different sets: actual trajectories flown, regulated trajectories and planned trajectories.

As explained above, the TP will also be used to compute optimal/baseline trajectories needed by the PA to build some advanced indicators (such as those accounting for fuel inefficiencies for instance). Thus, *P* different sets of *N* optimal/baseline trajectories will also be generated by the TP. All these sets of trajectories are also delivered to the PA, as shown in Figure 3-7.

Input	Source
Origin/Destination airports	Eurocontrol's Demand Data Repository 2 (DDR2)
ETD/ETA	Eurocontrol's Demand Data Repository 2 (DDR2)
Aircraft type and Callsign	Eurocontrol's Demand Data Repository 2 (DDR2)
Aircraft performance data	Eurocontrol's Base of Aircraft Data (BADA) version 4.x
Airline Cost Index	Assumed or estimated
Payload weight	Assumed or estimated
Trajectory Constraints (altitude, speed, take-off time, route, etc.).	From DDR2 for airspace organisation and management constraints (ATS routes, for instance) or from TCP component for ADCB (TP-TCP interactions to compute alternative trajectories avoiding hotspots)
Weather data (wind, pressure and temperature)	National Oceanic and Atmospheric Administration (NOAA) or European Centre for Medium-Range Weather Forecasts (ECMWF).

Table 3-1. Source for the external inputs of the TP

3.3.2 Traffic and capacity planner component

The Traffic and capacity planner component (TCP) receives inputs from the TP (*N* trajectories) and ASP (opening scheme) and regulates the demand. In current ConOps mode the CASA algorithm is applied and the output of the TCP is another set of *N* 4D trajectories with delays in some flights (regulated demand). In SESAR 2020 ConOps, however, some interaction with the TP is needed, as explained in next section, but the output is also a set of *N* 4D regulated trajectories with delays and/or trajectory re-routings or level cappings.

The output trajectories are discretized in a one-second time interval as main input for the RA component.

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3.3.3 Trajectory planner component and Traffic and capacity planner component loop interactions

Given the initial set of *N* trajectories (from the TP) and the sector capacities (from the ASP) as input, time-varying hotspot areas are first detected by the Hotspot Detector of the TCP, who then generates the hotspot-avoidance information for the affected flights.

This information is shared, on basis of individual flight, to the relevant AUs (i.e. the TP in the APACHE System), enabling them to precisely schedule alternative trajectories to avoid entering those sectors, with as few as possible extra costs incurred. Such avoidance can be performed by lateral or vertical manoeuvres, or simply by adjusting the arrival time. AUs assess their costs and eventually submit the alternative trajectories and timeline setting preferences that they believe are most beneficial.

Incorporating all these potential options, the ADCB model computes the best trajectory selections and the optimal distribution of delay assignments, which are the final output of the TCP component. See Figure 3-8 for a detailed workflow between the TP and TCP components when implementing this ADCB functionality (TCP in "SESAR2020 ConOps" mode).

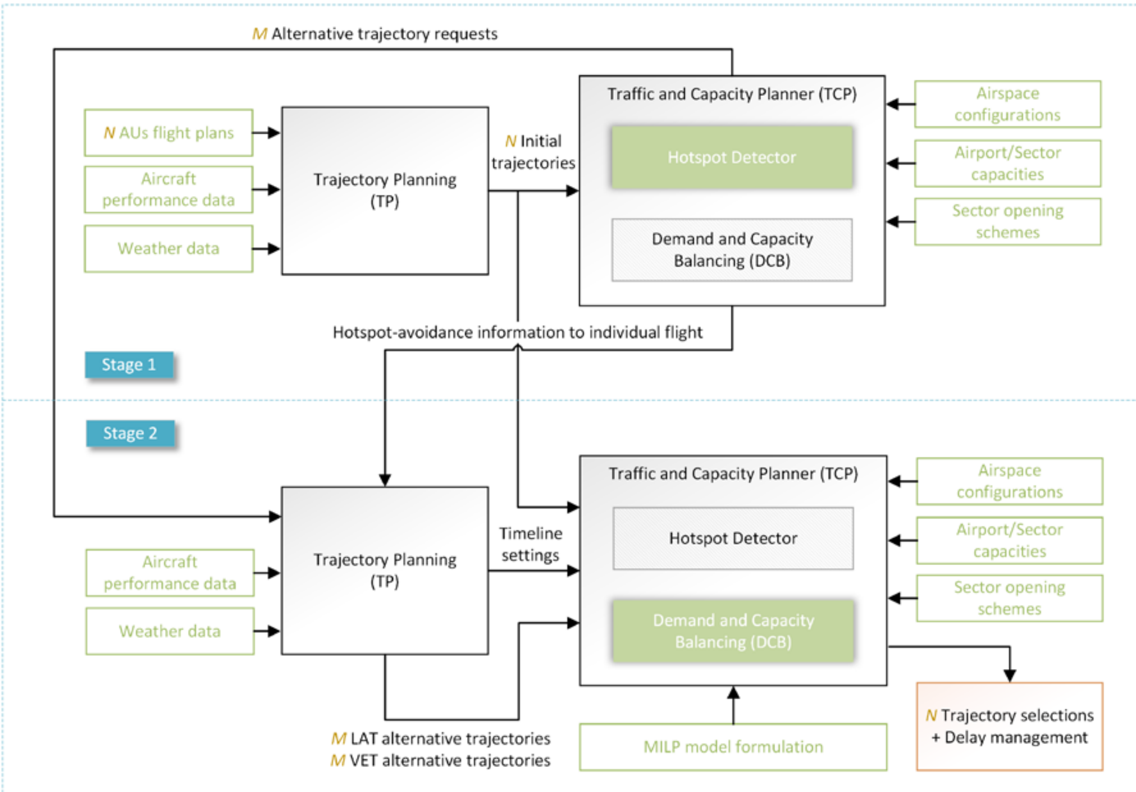

Figure 3-8. Interactions between the TCP and the TP components when using the TCP in ADCB (future ConOps)

3.3.4 Airspace planner component

The ASP will receive one set of *N* trajectories from the TP. Each trajectory will include position and velocity vector, discretized in one or five-second time interval. In pre-ops, the trajectories will be synthesised by the TP, while in post-ops the ASP will take the regulated trajectories found in the input external database.

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The ASP will also use an external set of input data (stored in the shared file system), containing the airspace structure elements detailed in Table 3-2.

Depending on the simulated scenario, ASM settings will be properly set that will configure ASP modules to the required ATM environment.

As a result, the ASP component will deliver and format as inputs for:

- PA component: one optimal sector opening scheme (only in pre-ops mode) plus Q sets of baseline optimal sectorisations to build some of the PA performance indicators.
- TCP component: one optimal sector opening scheme (only in pre-ops mode).

Each optimal/baseline sector opening scheme will contain a list of active sectors for each period of time. It should be noted that for some sets of trajectories, the ASP may find the same sector opening schemes. Similarly, some sets of trajectories might not have a feasible solution. Nevertheless, “non-valid solutions” will be flagged and will still be provided to the RA component for the further evaluation of such cases. All, will be stored in the final database for future reference (out of the scope of the APACHE project), such as training a machine learning algorithm to exploit eventually these results.

Input	Source
Functional Airspace Blocks (FABs)	Eurocontrol’s Demand Data Repository 2 (DDR2) Eurocontrol’s European AIS Database (EAD)
Airspace blocks	Eurocontrol’s Demand Data Repository 2 (DDR2) Eurocontrol’s European AIS Database (EAD)
Elementary Sectors (ESs)	Eurocontrol’s Demand Data Repository 2 (DDR2) Eurocontrol’s European AIS Database (EAD)
Collapsed Sectors (CSs)	Eurocontrol’s Demand Data Repository 2 (DDR2) Eurocontrol’s European AIS Database (EAD)
Airspace Configurations (CONFs)	Estimated from sector opening schemes published in Eurocontrol’s Demand Data Repository 2 (DDR2) ACC internal documentation
Airspace sector capacities	ACC internal documentation

Table 3-2. Source for the external inputs of the ASP

A sector opening scheme, for each period of time, is composed of:

- number of active controllers and list of active sectors accompanied with a geometrical definition of the sectors; and
- traffic load metric per active sector.

The internal workflow between ASP modules, presented in Figure 3-3, is summarised as follows:

- Airspace structure pre-processing module – uses as input pre-defined (existing) airspace element, such as: Airspace blocks, ESs, CSs and CONFs given in different formats (paper copies, electronic documents, text, graphs, tables) depending on the source; and it outputs digital data: list of ESs with their geometrical definition, list of CSs with set of ESs that forms each CS, and finally, list of CONFs with set of CSs included in each CONF.

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- SAM design module – receives FABs geometry and traffic samples, and it outputs designed SAMs with their geometrical form and associated neighbouring graph.
- Airspace loading module – uses as input airspace structure elements and traffic sample, and outputs for each element and period of time associated load metric: number of entries, occupancy, complexity, etc.
- Airspace reconfiguration module – receives loaded airspace elements and it outputs the optimal sector opening scheme.

3.3.5 Risk assessment component

The RA, as logical part of the PA, will output safety PIs. One set of *N* trajectories will be used as inputs for the Risk Assessment component. Optionally, this module could also take as input the opening scheme produced by the ASP. The joint set of trajectories together with the airspace sectors configuration, is referred as an air traffic pattern, for the rest of the document.

In pre-ops mode, the *N* trajectories will come from the TCP (synthesised trajectories), while in post-ops the RA will take directly the reconstructed trajectories from the TP (red arrow in Figure 3-7).

According to the type of scenario to be carried out, the air traffic pattern will be simulated under a specific configuration described by ConOps, e.g. structured route, free route, flight level orientation scheme, etc. Uncertainty of aircraft velocities and flight entry time into given airspace will be introduced using Monte Carlo simulation technique. Certain number of simulation iterations (exact numbers of iterations have to be decided in WP5) will be performed in order to evaluate PIs and risk of conflict/accident.

3.3.6 Performance analyser module

While the Risk Assessment component is pictographically separated in the APACHE System software architecture (see Figure 3-7), it is logically integrated in the Performance analyser module (PA).

After the APACHE-TAP is executed with a specific scenario and test case, the PA will be used to analyse the output of all components. Interfaces between the APACHE-TAP components (TP, TSP, ASP, RA) and PA are foreseen for this purpose.

Moreover, the PA is the only software element interacting directly with the APACHE database by summarizing output from each component according to specific scenarios and test cases (scenario output data).

The entity/relationship model for the APACHE database will be developed during the software development phase within the WP4 of the Project.

Specifically, the PA is the module in charge of:

- Calculation of some Performance Indicators of the current PF (for benchmarking purposes), as listed in table 2-2.
- Calculation of novel (or enhanced) Performance indicators proposed in the context of the APACHE project, as listed in table 2-3.

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- Benchmarking between current and novel (or enhanced performance indicators). Comparisons between current and novel PIs will be done via the PA according to specific scenarios and test cases.
- (Initial) assessment and benchmarking of SESAR solutions (comparison between current ConOps and SESAR 2020 simulated ConOps). Comparisons will be done via the PA according to specific scenarios and test cases.
- Estimation of the ATM Pareto frontier by performing simulations of different scenarios and test cases and comparing results via the PA.

3.3.7 Shared file system

In order to facilitate distributed access to input and output files, required and generated by all the software components, a shared file system is proposed. The physical location will be at UPC premises and the specific hardware and software to be used for its deploying will be decided during WP4 execution.

The shared file system is composed of the APACHE database, official repositories (e.g. data downloaded from DDR2, BADA, etc.) and a folder specifically devised to store all inputs/outputs for each of the scenario simulations carried out via the distributed software components. Figure 3-9 shows a depiction of the shared file system.

Software components located internally at UPC or externally at ENAC or UB-FTTE premises will access the shared file system via a network protocol such as Network File System (NFS).

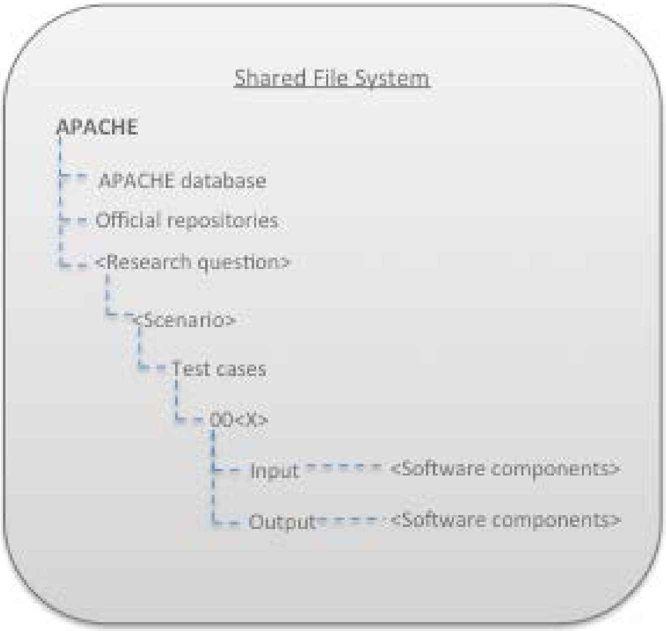

Figure 3-9. APACHE Shared File System

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4 Software requirements

This section presents the software requirements for the APACHE System. The software requirements include features existing and non-existing in each of the software components. In this sense, some of the requirements might be achieved already.

The requirements are listed and described in Tables 4-1, 4-2 and 4-3. The columns of the tables are:

- Unique identifier for the software requirement.
- Description of the software requirement
- Depends on: the software requirement needs other requirements to be satisfied.
- Relates with: there is a relationship between the software requirements that is not of dependency. This means that to satisfy one, there is no need of satisfying the other, but the two are related somehow. For example, the official source of input data (non-functional requirement) relates with the functional requirement of such input data.
- Priority: requirements are ranked and those with high priority (H) should be developed first, following requirements with medium (M) priority and low (L) priority.

4.1 Functional requirements

Software Requirement ID	Description	Depends on	Relates with	Priority
Trajectory planner component (TP)				
TP-FR-001	The TP will receive a set of *P2P flight demand* per simulation scenario (flights set), weather data and trajectory constraints (if any) as input to which optimal trajectories will be calculated.	TP-FR-002 to TP-FR-011	TP-NFR-001, TP-NFR-002, PA-FR-001, PA-FR-005, PA-DR-005, PA-DR-006, PA-DR-009	H
TP-FR-002	The information of each *P2P flight* will include origin airport and destination airport described by their geographic coordinates (longitude, latitude) and elevation.		TP-DR-001	H
TP-FR-003	The information of each *P2P flight* will include *estimated time of departure* (ETD) and if flight time is fixed and not subject to optimisation (trying to reproduce historical data, for instance) it will also include the *estimated time of arrival* (ETA).		TP-DR-002	H
TP-FR-004	The information of each *P2P flight* will include the aircraft type and callsign.		TP-DR-003	H
TP-FR-005	The TP will use specific aircraft performance models according to the aircraft type.		TP-DR-004	H

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TP-FR-006	The TP will use specific *cost indexes* according to the airline to which each flight belongs, and eventually also depending on the O/D pair. Since this information is not publicly available, these cost indexes will be assumed/estimated according to assumptions regarding the type of airline (e.g., low-cost) and the ETA if available.			M
TP-FR-007	The TP will compute a *4D trajectory* for each flight.			H
TP-FR-008	The TP will simulate a set of flights under specific ConOps: structured route or free route and flight level allocation/orientation schemes or continuous cruise climb procedures.			M
TP-FR-009	The TP will use weather information to be considered in the calculation of optimal trajectories per flight.		TP-DR-005	M
TP-FR-010	The TP will use specific *Payload weights* according to the airline to which each flight belongs, and eventually also depending on the O/D pair. Since this information is not publicly available, these weights will be assumed/estimated according to assumptions regarding the type of airline (e.g. low-cost) and historical trajectory data (if available).			M
TP-FR-011	The TP will also consider other trajectory constraints in the form of controlled times of arrival/departure, speed/altitude constraints, control time of arrivals (CTAs), etc.			H
TP-FR-012	The TP shall be able to produce alternative trajectories to avoid one or several hotspots. Alternative trajectories should account for i) lateral avoidance and ii) vertical avoidance of the concerned sector(s).		LI-FR-002	M
TP-FR-013	The TP shall be able to compute the best vertical profile (altitude and speed profiles) given an input route.			H
	Traffic and capacity planner component (TCP)			
TCP-FR-001	The TCP will receive a set of 4D trajectories per simulation scenario (trajectories set computed by the TP) and an opening scheme (list of active sectors as a function of the time, provided by the ASP).			H
TCP-FR-002	The TCP will implement an ATFM slot allocation mechanism based on the CFMU CASA algorithm. The demand will be given by the TP, while the sectorisation and nominal capacities per sector will be given by the ASP module.	TCP-FR-001		H
TCP-FR-003	The TCP will detect hotspots (sectors with demand above capacity) and those flights crossing these hotspots.		TCP-NFR-001	M
TCP-FR-004	The TCP will implement an advanced demand and capacity balance (ADCB) algorithm which will take into account not only delay as possible measure to shift demand, but also lateral and vertical re-routings (i.e. alternative trajectories avoiding the list of hotspots). This ADCB algorithm will compute a system-wide optimal solution minimising the total cost for the airspace user of the ADCB regulations.	TCP-FR-001, TCP-FR-003	LI-FR-001 to LI-FR-003, PA-FR-002, PA-FR-005	H
TCP-FR-005	The TCP will return a trajectory set with the regulated demand (only delay in current ConOps or delay and/or re-routings in future ConOps).	TCP-FR-002, TCP-FR-004		M
	TP-TCP loop interactions			
LI-FR-001	The TCP will query the TP with the list of flights traversing one or several hotspots.			H
LI-FR-002	The different alternatives to avoid a hotspot will be feed back to the TCP in a standardised format.		TP-FR-012	H
	Airspace planner component (ASP)			

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ASP-FR-001	The ASP will receive a 4D trajectories set and the available sector configurations and capacities and it will compute an optimal sector opening scheme following the current ConOps. The sector opening scheme will include for each period of time list of active sectors, including: number of active controllers and traffic load metric per sector. The module will seek for the minimum number of controllers (active sectors) that satisfies the workload limits.		ASP-DR-001 to ASP-DR-006, PA-FR-003, PA-FR-005, PA-DR-010	H
ASP-FR-002	The ASP will provide a functionality for simulating severe weather events on the airspace. For a given Airspace structure, the ASP will introduce the necessary capacity limitations in form of regulations or SAM parametrization. The weather events will have a limited duration.		ASP-DR-001 to ASP-DR-006, PA-FR-003, PA-FR-005, PA-DR-010	L
ASP-FR-003	The ASP will receive a 4D trajectories set and will design a dynamic sectorisation of the airspace, in line with SESAR2020 ConOps (future) based on the complexity of the received traffic. The airspace dynamic configuration will be provided in terms of SAM groupings for each period of time. This includes a list of active sectors, called Controlled Airspace Block (CAB), not previously defined and built as re-grouping of SAMs (which are defined before the grouping process). The output also contains the traffic load per CAB.		ASP-DR-001 to ASP-DR-006, PA-FR-003, PA-FR-005, PA-DR-010	H
	Risk assessment component (RA)			
RA-FR-001	The RA is considered functionally part of the Performance analyser module, though is separated in the software architecture.			L
RA-FR-002	The RA will receive a set of trajectories to which it will estimate safety PIs and risk of conflict. This set of trajectories could come from the TCP (regulated traffic), TP (planned traffic) or in post-ops assessment from actual trajectories (realised traffic).	RA-FR-003 to RA-FR-005	RA-NFR-001, PA-FR-004, PA-FR-005	H
RA-FR-003	The RA will detect separation violation between pairwise aircraft.			M
RA-FR-004	The RA will compute the minimum separation between pair of aircraft and based on that, conflict severity.			M
RA-FR-005	The RA will compute the duration of separation violations between pairs of aircraft.			M
RA-FR-006	The RA will count traffic alerts, resolution advisories and near mid-air collisions depending on the duration of pairwise separation violations.			M
RA-FR-007	The RA will calculate conflict/accident risks between pairs of aircraft.			M
	Performance analyser module (PA)			
PA-FR-001	The PA will interface with the TP to process 4D trajectories and summarize information regarding individual flights within scenarios and test cases simulations.		TP-FR-001	H
PA-FR-002	The PA will interface with the TCP to process its outputs and summarize information regarding sets of individual trajectories within scenarios and test cases simulations.		TCP-FR-004	H
PA-FR-003	The PA will interface with the ASP to process airspace sectors outputs and summarize information regarding individual sectorisation configurations within scenarios and test cases simulations.		ASP-FR-001 to ASP-FR-003	H

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PA-FR-004	The PA will interface with RA to process safety and risk outputs and summarize information regarding individual air traffic patterns within scenarios and test cases simulations.		RA-FR-002	H
PA-FR-005	The PA will interface with the APACHE database in order to record summarized information related to TP, TCP, ASP and RA.		TP-FR-001, TCP-FR-004, ASP-FR-001 to ASP-FR-003, RA-FR-002	H
PA-FR-006	The PA will compute the variable denominated *DelayPerFlight*. This variable is the time deviation in arrival of two sets of trajectories with the same flights. It will produce as output a vector of arrival delays, where each vector element represents a flight delay. A vector with cancelled flights and a vector of diverted flights will be also produced.	TP-FR-001, TCP-FR-004		H
PA-FR-007	The PA will compute the variable denominated *SectorOccupancyPerHour*. This variable contains three occupancy metrics detailed per airspace sector and per hour. The PA requires as input one 4D trajectory set and an airspace sectorisation scheme. It will produce as output a data structure consisting of number of aircraft, the time spent and the nautical miles flown in each sector per hour.	TP-FR-001, ASP-FR-001 to ASP-FR-003		H
PA-FR-008	The PA will compute the variable denominated *EnRouteCharges*. The PA requires as input the list of 4D trajectory sets and the airspace structure (including unit cost charges). The PA will produce as output a vector where each position consists of the ANSP costs (in Euros) per flight.	TP-FR-001, ASP-FR-001 to ASP-FR-003		H
PA-FR-009	The PA will compute the variable denominated *OpeningSchemeEvaluation*. The PA requires the airspace structure (in term of opening scheme for current ConOps or in terms of SAMs for SESAR2020 ConOps) and a 4D trajectory set. It will output a vector of sector activations and a matrix of sector occupancy. The vector of sector activations contains the number of minutes of each activated sector. The matrix of sector occupancy contains the number of aircraft per active sector and per hour.	TP-FR-001, ASP-FR-001 to ASP-FR-003		H
PA-FR-010	The PA will have a functionality to estimated burnt fuel for a given flight. The PA will receive a 4D trajectory and the information of the weather. The output of the PA will be the burned fuel in Kg. This functionality can also be depicted as the variable *FuelCalculation*, which will be computed via the PA-TP interface.	TP-FR-001	PA-DR-003, PA-DR-007	H
PA-FR-011	The PA will compute the variable denominated *Transfers*. The PA will receive a 4D trajectory set and an airspace structure. The output will consist on a vector that provides the number of active sectors crossed per flight.	TP-FR-001, ASP-FR-001 to ASP-FR-003		H
PA-FR-012	The PA will compute the metrics related to an individual flight. The PA will receive a 4D trajectory and will calculate the total distance flown, the total flight time, the Available Seat Mile (ASM) and the number of flight level changes. The ASM will be computed using a standard number of seats of each aircraft type. This functionality can also be depicted as the variable *EvaluateFlight*, which will be computed via the PA-TP interface.	TP-FR-001	PA-DR-004	H

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PA-FR-013	The PA will compute the variable denominated *CutTrajectorySet_xAU*. This variable has the set of trajectories grouped by airspace user. The PA requires as input one 4D trajectory set. As output the PA will produce a dictionary like structure indexed by airspace user to hold for each one the trajectory set of the flights of the airspace user.	TP-FR-001		H
PA-FR-014	The PA will produce graphs for the PIs visualisation. The technology considered in this moment is JavaScript Data-Driven documents. However, the specific technology and the specific graphs to be considered will be selected in a future phase of the software development cycle.			M
PA-FR-015	The PA will calculate the Great Circle Distance between two points in a sphere (given in latitude/longitude coordinates).			M
	Software components integration			
SCI-FR-001	The TP will format each of the N trajectories, in order to match the input file format of the TCP component. This format consists of longitude, latitude, altitude (meters) and speed (meters per second) per trajectory point discretized in a one-second-time interval.	TP-FR-001	TCP-FR-001	H
SCI-FR-002	The TCP will format flight trajectories in order to match the input file format of the ASP component. This format consists of longitude, latitude, altitude and ground speed per trajectory point, discretized in a one or five -second time interval.	TCP-FR-004	ASP-FR-001	H

Table 4-1. Functional requirements

4.2 Non-functional requirements

Software Requirement ID	Description	Depends on	Relates with	Priority
	Trajectory planner component (TP)			
TP-NFR-001	The TP will be designed to be the most efficient for the simulation of a flights set. For this purpose, a High-Performance Computing (HPC) approach might be implemented. Specifically, a cluster of computers and a parallelisation prototype for TP could be used.		TP-FR-001	L
TP-NFR-002	The TP will be designed to be the most efficient for the simulation of a specific flight. This might include coding optimization techniques for the TP.		TP-FR-001	L
TP-NFR-003	The TP will be physically located at UPC premises.		TP-FR-001	H
	Traffic and capacity planner component (TCP)			
TCP-NFR-001	The TCP will be physically located at UPC premises.		TCP-FR-001	L
	TP-TCP loop interactions			
LI-NFR-001	The loop interactions between TP and TCP will be designed to be the most efficient possible (HPC).		LI-FR-001 to LI-FR-003	L
	Airspace planner component (ASP)			
ASP-NFR-001	The ASP will be physically located at ENAC premises.			L
	Risk assessment component (RA)			
RA-NFR-001	The RA will be designed to be the most efficient for the simulation of an air traffic pattern. For this purpose, an HPC approach might be implemented. Specifically, a cluster of computers and a parallelisation approach.		RA-FR-002	M

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RA-NFR-002	The RA will be physically located at UB-FTTE premises.			L
	Performance analyser module (PA)			
PA-NFR-001	The performance analyser will be physically located at UPC premises.			L
	Software components integration			
SCI-NFR-001	All input and output files will be stored in a shared file system located physically at UPC premises.		ALL	H
SCI-NFR-002	The APACHE database will be stored in a shared file system located physically at UPC premises.		ALL	H
SCI-NFR-003	Each software component will have a human operator in the corresponding partner's premises			H
SCI-NFR-004	The TP and the TCP components will process input files and write output files directly over the shared file system.		ALL TP-FR, ALL TCP-FR	H
SCI-NFR-005	The ASP and the RA component will not process input files and write output files directly over the shared file system. In this sense, inputs file shall be copied to local storage at each partner premises and the output files copied to the shared file system.		ALL ASP-FR, ALL RA-FR	H

Table 4-2. Non-functional requirements

4.3 Domain requirements

Software Requirement ID	Description	Depends on	Relates with	Priority
	Trajectory planner component (TP)			
TP-DR-001	Flight origin and destination airport for simulation test cases will be obtained from DDR2.		TP-FR-002	H
TP-DR-002	Flight ETD and ETA for simulation test cases will be obtained from DDR2.		TP-FR-003	H
TP-DR-003	Flights aircraft type for simulation test cases will be obtained from DDR2.		TP-FR-004	H
TP-DR-004	Aircraft performance models will be obtained from BADA 4.x		TP-FR-005	H
TP-DR-005	Weather information will be obtained via GRIB2 files from NOAA or ECMWF.		TP-FR-009	M
	Airspace planner component (ASP)			
ASP-DR-001	FABs definition will be obtained from DDR2 or FAB dedicated documentations available at official websites.		ASP-FR-001 to ASP-FR-003	H
ASP-DR-002	Airspace blocks definition will be obtained from DDR2 or EAD.		ASP-FR-001 to ASP-FR-003	H
ASP-DR-003	ESs definition will be obtained from DDR2 or EAD.		ASP-FR-001 to ASP-FR-003	H
ASP-DR-004	CSs definition will be obtained from DDR2 or EAD.		ASP-FR-001 to ASP-FR-003	H
ASP-DR-005	CONFs definition will be obtained from DDR2 or ACC internal documentation.		ASP-FR-001 to	M

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			ASP-FR-003	
ASP-DR-006	Airspace sector capacities will be obtained from ACC internal documentation.		ASP-FR-001 to ASP-FR-003	M
	Risk assessment component (RA)			
RA-DR-001	Uncertainties about flights sector entry time and flight velocities (necessary for simulation) in the form of probability density functions will be assumed based on expert judgement.			L
	Performance analyser module (PA)			
PA-DR-001	See TP-DR-005 (Weather).			M
PA-DR-002	Flight arrival delay cost and flight cancelation/diversion costs will be modelled using existing state-of-the-art bibliography. This model is referred as *DelayCostModel.*			M
PA-DR-003	Airline data shall be estimated. This includes cost-indexes and payload weights for each aircraft of the airline.	TP-DR-004		M
PA-DR-004	The Available Seat Mile (ASM) information (number of seats per aircraft type) shall be estimated from a public/private data base			L
PA-DR-005	Radar data for the actual flights (for scenario recreation or historical scenario assessment) will be obtained from ANSPs or using DDR2 M3 files if ANSP data is not available.		TP-FR-001	H
PA-DR-006	Data about the planned flights (for scenario recreation or historical scenario assessment) will be obtained from ANSPs or using DDR2 M1 files if ANSP data is not available.		TP-FR-001	L
PA-DR-007	The PA will convert from kg of fuel to euros using some external source (to be identified) or assuming an input value.			L
PA-DR-008	The PA will convert from kg of fuel to kg of CO_2 or other emissions using some external source (to be identified) or assuming some basic conversions.			L
PA-DR-009	Regulated flight plans (for scenario recreation or historical scenario assessment) will be obtained from ANSPs or using DDR2 M2 files if ANSP data is not available.		TP-FR-001	
PA-DR-010	Current airspace structure including opening scheme and sector capacities will be obtained from DDR2.		ASP-FR-001 to ASP-FR-003	

Table 4-3. Domain requirements

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5 Performance indicators calculation

This section describes the method to calculate all PIs proposed in APACHE: the set of new (or enhanced) PIs proposed in this Project plus the sub-set of PIs corresponding to the current Performance Framework (used by EUROCONTROL PRU and reported regularly in their annual Performance Review Reports) and which will be computed for benchmarking purposes.

For each PI the formula to compute it is recalled and the inputs required are detailed. Inputs of the calculations can have origin in one of the APACHE modules or could be external data. In such case a domain requirement is mentioned in the text. Calculations can be straightforward from the inputs, or might, in some cases, need the creation of intermediate variables. A same intermediate variable can be used for one or more PI calculations.

All PI are in relation with one or more functional requirements of the Performance Analyser (PA), or of the Risk Assessment (RA) module. Moreover, functionalities of other APACHE modules can directly provide inputs to the PI calculations or, in a few number of cases, provide directly the value of the PI.

Two exhaustive lists are provided: the first one addresses the current PIs and the second one the APACHE new/enhanced PIs. Both lists aim to correctly identify all requirements to properly implement the PIs in the PA module.

5.1 Current PF PIs addressed by APACHE

Table 5-1 below describes de details on how the current PF PIs (listed in Table 2-2) will be computed.

Indicator	**C-CAP-1:** Average en-route ATFM delay per flight attributable to ANS
Calculation	*[Sum (En-route ATFM delay per flight)] / (number of flights)* Units: Minutes Applicable: “Post-ops” and “Pre-ops”. Where: • Two alternative 4D Trajectory sets will be obtained from actual flights database in “Post-ops” (PA-DR-006 and PA-DR-009) or synthetized with the APACHE system in “Pre-ops” (TP-FR-001 and TCP-FR-005). • For each flight, the PA compares the departure time of the two alternative trajectories (PA-FR-006). A vector of normalized values is obtained comparing the extra time of each flight, variable DelayPerFlight. The average of the vector will be computed for only those flights where delay is greater than a given threshold (input parameter)
Remarks	
Indicator	**C-EFF-1: The share of regulated flights**
Calculation	*[(Number of regulated flights) / (Number of flights)]*100* Units: % Applicable: “Post-ops” and “Pre-ops”. Where:

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	• For "Pre-ops", flight is the 4D Trajectories set obtained from the TP (TP-FR-001) and regulated flight is the TCP final trajectory set (TCP-FR-005). For "Post-ops" flight is, in fact, the last filled flight plan (PA-DR-006) and regulated flight is, in fact, the Regulated Flight Plan (PA-DR-009).
Remarks	
Indicator	**C-ENV-1:** Average horizontal en-route flight efficiency for the filed flight plan trajectory
Calculation	*[Sum(Great Circle route distance per flight) –Sum(Planned route distance per flight)]*100* Units: % Applicable: "Post-ops" and "Pre-ops" Where: • For "Post-ops" the planned route is taken from last filled flight plan (PA-DR-006). • For "Pre-ops" the planned route is taken from the TP (TP-FR-001) • Variable *EvaluateFlight* (PA-FR-012) will be calculated for the planned route to obtain its distance. Alternatively, the flight distance provided with planned route (if provided) could be used (PA-DR-005). • *Great circle route distance:* the shortest distance between two geographical points over the surface of a sphere (PA-FR-015). The vector values are averaged to compute the indicator.
Remarks	-
Indicator	**C-ENV-2:** Average horizontal en-route flight efficiency of the actual trajectory
Calculation	*[Sum(Great Circle route distance per flight) – Sum(Actual route distance per flight)]*100* Units: % Applicable: "Post-ops" (see remarks). Where: • *Actual route* comes from the 4D Trajectory set obtained from a historical database of radar tracks or similar (PA-DR-005). • Variable *EvaluateFlight* (PA-FR-012) will be calculated for the actual route to obtain its distance. Alternatively, the flight distance provided with actual route (if provided) could be used (PA-DR-005). • *Great circle route distance:* is the shortest distance between two geographical points over the surface of a sphere (PA-FR-015). The vector values are averaged to compute the indicator.
Remarks	Since APACHE is not providing simulations of tactical operations, this PI can only be used for "Post-ops" assessment with current ConOps historical data (PA-DR-005). When executing for "Pre-ops" mode, this PI will give the same result as C-ENV-1.
Indicator	**C-SAF-1:** Number of separation minima infringements.
Calculation	*Number of separation violations between pair-wise trajectories* Units: - Applicable: "Post-ops". Where: Given a 4D trajectory set, the RA calculates the number of separation violations (RA-FR-003).
Remarks	C-SAF-1 is chosen because, based on the PRRs (Performance Review Commission, 2016), this PI is relatively frequent (2359 in 2014 vs. 2316 in 2015) in comparison to number of accidents with ANS contribution (2 in 2014 vs. 1 in 2015), which are usually reported after long lasting investigation process. Also, this PI can be simulated in APACHE, while other current safety PIs cannot be simulated due to uncertainty factors that could not be modelled (e.g. ANS-related and with ANS contribution in accidents/serious incidents could not be modelled, and e.g., authorisation in case of unauthorised penetration of airspace).

Table 5-1. Calculation method for current Performance indicators modelled in APACHE

5.2 New or enhanced PIs proposed by APACHE

Tables 5-2 to 5-8 below describe de details, per KPA, on how the novel or enhanced PIs (listed in Table 2-3) will be computed.

Indicator	**AEQ-1:** Percentage of RBTs which are equal to the first submitted SBTs per AU

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Calculation	*[max(Total number of RBTs different to first SBTs submitted) / (Total number of first SBTs submitted)] – [average(Total number of RBTs different to first SBTs submitted) / (Total number of first SBTs submitted)]* *Calculated per AU* Units: % Applicable: “Post-ops” and “Pre-ops”. Where: • For “Pre-ops” the first submitted SBT is the 4D Trajectories set obtained from the TP (TP-FR-001) and the RBT is the regulated trajectory from the TCP (TCP-FR-005). • For “Post-ops” the SBT will be assumed as the last filled flight plan (PA-DR-006) and the RBT the regulated flight plan (PA-DR-009). See remarks. • The SBTs and RBTs are separated by AU into two variables of type *CutTrajectorySet_xAU* of the PA (PA-FR-013). • For each AU a functionality of the PA compares the two alternative 4D trajectory set of the given AU and returns the number of trajectories considered equal and the number of trajectories considered different (PA-FR-013). The PA obtains in this way a vector of normalized values with the percentage of the modified trajectories of each AU. • The PA takes the maximum value and the average value of this vector and builds the final metric.
Remarks	• This indicator will be zero when the percentage of RBTs equal to SBTs are equally distributed among all AUs. • For “post-ops” (if analysing historical data in current ConOps) the last filed flight plan will be used as reference for the AU’s most preferred trajectory, since at present, this is the best information available for performance monitoring. Therefore, **regulated trajectories will differ only with delay (if any)**. See additional remarks on this limitation in D3.1 (APACHE Consortium, 2017).
Indicator	**AEQ-2:** Worst penalty cost
Calculation	*Max(penalty cost among all AUs) – Average (penalty cost for all AUs)* Units: Euros Applicable: “Post-ops” and “Pre-ops”. Where: • For “Pre-ops” the first submitted SBT is the 4D Trajectories set obtained from the TP (TP-FR-001) and the RBT is the regulated trajectory from the TCP (TCP-FR-05). • For “Post-ops” the SBT will be assumed as the last filled flight plan (PA-DR-006) and the RBT the regulated flight plan (PA-DR-009). See remarks. • The SBTs and RBTs are separated by AU into two variables of type *CutTrajectorySet_xAU* of the PA (PA-FR-013). • A cost model is applied to each set of trajectories (PA-DR-002, PA-DR-007, PA-FR-008). The PA obtains in this way a vector of normalized values comparing the extra cost of the modified trajectories for each AU. • *Maximum penalty cost among all AUs:* is the maximum value of this vector • *Average penalty cost for all AUs:* is the average of this vector • *Vector of Penalty Costs:* is a vector that contains, for each AU, the average of the penalty costs due to differences between SBT and RBT for all the trajectories corresponding to that AU.
Remarks	• This indicator will be zero when the penalty costs are equally distributed among all AUs (i.e. the maximum penalty cost among all AUs equals to the average penalty cost for all AUs). • For “post-ops” (if analysing historical data in current ConOps) the last filed flight plan will be used as reference for the AU’s most preferred trajectory, since at present, this is the best information available for performance monitoring. Therefore, **regulated trajectories will differ only with delay (if any)**. See additional remarks on this limitation in D3.1 (APACHE Consortium, 2017).
Indicator	**AEQ-3:** Total ATM Delay relative to Reference ATM delay
Calculation	*(Total Delay in the Solution Scenario) / (Total Delay in the Reference Scenario)* Units: Minutes Applicable: Only “Pre-ops”. Where: • Three 4D Trajectory sets (say A, B, C) represent the planned trajectory or SBT (A), and the regulated trajectories or RBT (B and C) (TP-FR-001 and TCP-FR-005, respectively) when applying or not applying a particular SESAR solution under test.

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	• For each flight the PA compares the arrival time of the two alternative trajectories A versus B and A versus C into the variable *DelayPerFlight* (PA-FR-006). Two vectors of normalized values are obtained comparing the extra time for each flight. • *Total Delay in the Solution Scenario* is the sum of all elements of A versus C delays. • *Total Delay in the Reference Scenario* is the sum of all elements of A versus B delays.
Remarks	-
Indicator	**AEQ-4:** Percentage of flights advantaged/disadvantaged (per AU).
Calculation	*(Total number of RBTs different to first submitted SBTs)/(Total number of SBTs submitted)* *Calculated per AU* Units % Applicable: "Post-ops" and "Pre-ops". Where: • Take values obtained from AEQ-1 to construct this indicator.
Remarks	• Like C-EFF-1, but per AU. • For "post-ops" (if analysing historical data in current ConOps) the last filed flight plan will be used as reference for the AU's most preferred trajectory, since at present, this is the best information available for performance monitoring. Therefore, **regulated trajectories will differ only with delay (if any)**. See additional remarks on this limitation in D3.1 (APACHE Consortium, 2017).
Indicator	**AEQ-5:** AU cost per flight relative to Reference AU cost
Calculation	*(Cost per Flight of AU concerned in the Solution Scenario) / (Cost per Flight of AU concerned in the Reference Scenario)* Units: Euros Applicable: Only "Pre-ops". Where: • Three 4D Trajectory sets (say A, B, C) represent the planned trajectory or SBT (A), and the regulated trajectories or RBT (B and C) (TP-FR-001 and TCP-FR-005, respectively) when applying or not applying a particular SESAR solution under test. • For each flight the PA calculates the flight cost for the AU of the two alternative trajectories A versus B and A versus C (PA-FR-008 and PA-FR-010). Two vectors of normalized values are obtained by comparing the extra cost of each flight. • The numerator is the sum of all elements of A versus C delays. • The denominator is the sum of all elements of A versus B delays.
Remarks	• Very similar to AEQ-3

Table 5-2. Calculation method for APACHE performance indicators on Access and Equity KPA

Indicator	**CAP-1:** Robust maximum en-route delay
Calculation	*Average (en-route ATFM departure delay greater than mean value + Standard deviation of en-route ATFM departure delay)* Units: Minutes Applicable: "Post-ops" and "Pre-ops". Where: • For "<u>Pre-ops</u>" the two 4D Trajectory sets are taken from the first submitted SBT from the TP (TP-FR-001) and the regulated trajectory (RBT) from the TCP (TCP-FR-005). • For <u>"Post-ops"</u> the first submitted SBT will be assumed as the last filled flight plan (PA-DR-006) and the RBT the regulated flight plan (PA-DR-009). • For each flight, the PA compares the **departure** time of the two trajectories in variable type *DelayPerFlight* (PA-FR-006). A vector of normalized values is obtained comparing the extra time of each flight. • Mean and standard deviation of the vector will be computed. • The vector values greater than the mean will be averaged.
Remarks	• Enhancement of current C-CAP-1 indicator.
Indicator	**CAP-2:** Average flow management arrival delay
Calculation	*Average [(RBT arrival time per flight) – (first SBT submitted arrival time per flight)]* Units: Minutes

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	Applicable: "Post-ops" and "Pre-ops". Where: • For "Pre-ops" the two 4D Trajectory sets are taken from the first submitted SBT from the TP (TP-FR-001) and the regulated trajectory (RBT) from the TCP (TCP-FR-005). • For "Post-ops" the first submitted SBT will be assumed as the last filled flight plan (PA-DR-006) and the RBT the regulated flight plan (PA-DR-009). • For each flight the PA compares the arrival time of the two trajectories of the same flight. Vector variable *DelayPerFlight* is obtained comparing the extra time of each flight (PA-FR-006).
Remarks	• Very similar to AEQ-3 but this one is also applicable to "Post-ops". • Very similar to C-CAP-1, but focusing in arrival delay instead of departure delay.
Indicator	**CAP-3:** Capacity shortfalls
Calculation	*(Number of flights that received a change of their initial flight plan) / (Total number of flights), calculated per sector.* Units: % Applicable: "Post-ops" and "Pre-ops". Where: • The changes in the flight plan are computed as in AEQ-1 (RBTs different than SBTs), but accounting also for flight cancelations (see remarks). • A functionality of the PA compares the two alternative 4D trajectory set and returns the number of trajectories considered equal and the number of trajectories considered different (PA-FR-013). The PA obtains in this way a vector of normalized values with the percentage of the modified trajectories.
Remarks	• It is out of the scope to simulate cancellations in the APACHE System. Thus, flight cancellations would only be taken into account for "Post-ops" analysis. • For "post-ops" (if analysing historical data in current ConOps) the last filed flight plan will be used as reference for the AU's most preferred trajectory, since at present, this is the best information available for performance monitoring. Therefore, **regulated trajectories will differ only with delay (if any)**. See additional remarks on this limitation in D3.1 (APACHE Consortium, 2017).

Table 5-3. Calculation method for APACHE performance indicators on Capacity KPA

Indicator	**CE-1:** En-route unit economic costs for the Airspace User
Calculation	*(Actual trajectory cost) – (first submitted SBT cost)* Units: Euros (per flight) Applicable: "Post-ops" (see remarks). Where: • For "Post-ops" the first submitted SBT will be assumed as the last filled flight plan (PA-DR-006), while the *Actual trajectory* is the 4D Trajectory set obtained from a historical database of radar tracks or similar (PA-DR-005). See remarks. • The PA calculates the variable *EnRouteCharges* (PA-FR-008) for each 4D trajectory set (one vector with the costs of all flights for the SBT and another for the actual trajectory). • The PA calculates variable *FuelCalculation* (PA-FR-010) for each flight of each 4D trajectory set and builds one vector with the costs of all flights for the SBT and another for the actual trajectory. • The two SBT cost vectors are added into a total number to obtain *SBT cost.* • The two actual trajectory costs vectors are added into a total number to obtain *Actual trajectory cost.* • And the variable DelayCostModel (PA-DR-002) will be computed and added to the Actual costs. • Calculate the difference of the two vectors of costs.
Remarks	• Since APACHE is not providing simulations of tactical operations, this PI can only be used for "Post-ops" assessment with current ConOps historical data (PA-DR-005). When executing for "Pre-ops" mode, this PI will give the same result as CE-1.1. • For "post-ops" (if analysing historical data in current ConOps) the last filed flight plan will be used as reference for the AU's most preferred trajectory, since at present, this is the best information available for performance monitoring. Therefore, **regulated trajectories will differ only with delay (if any).** See additional remarks on this limitation in D3.1 (APACHE Consortium, 2017). • Optionally this PI could be normalized per flight hours or per Available Seat Mile (ASM). In this case, it would be required to calculate the variable *EvaluateFlight* (PA-FR-012).

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Indicator	**CE-1.1:** En-route unit economic costs for the Airspace User - Strategic
Calculation	*(RBT cost) – (first submitted SBT cost)* Units: Euros (per flight) Applicable: “Post-ops” and “Pre-ops”. Where: • For “Post-ops” the first submitted SBT will be assumed as the last filled flight plan (PA-DR-006), while the *RBT* is the regulated trajectory (PA-DR-09). See remarks. • For “Pre-ops” the two 4D Trajectory sets are taken from the first submitted SBT from the TP (TP-FR-001) and the regulated trajectory (RBT) is taken from the TCP output (TCP-FR-005). • The PA calculates the variable *EnRouteCharges* (PA-FR-008) for each 4D trajectory set (one vector with the costs of all flights for the SBT and another for the RBT trajectory). • The PA calculates variable *FuelCalculation* (PA-FR-010) for each flight of each 4D trajectory set and builds one vector with the costs of all flights for the SBT and another for the RBT. • The two SBT costs vectors are added into a total number to obtain *SBT cost.* • The two RBT costs vectors are added into a total number to obtain *RBT cost.* • And the variable DelayCostModel (PA-DR-002) will be computed and added to the RBT costs. • Calculate the difference of the two vectors of costs.
Remarks	• For “post-ops” (if analysing historical data in current ConOps) the last filed flight plan will be used as reference for the AU’s most preferred trajectory, since at present, this is the best information available for performance monitoring. Therefore, **regulated trajectories will differ only with delay (if any).** See additional remarks on this limitation in D3.1 (APACHE Consortium, 2017). • Optionally this PI could be normalized per flight hours or per Available Seat Mile (ASM). In this case, it would be required to calculate the variable *EvaluateFlight* (PA-FR-012).
Indicator	**CE-1.2:** En-route unit economic costs for the Airspace User - Tactical
Calculation	*(Actual trajectory cost) – (RBT cost)* Units: Euros (per flight) Applicable: “Post-ops” (see remarks). Where: • All calculations from CE-1 related to actual trajectories are necessary: EnRouteCharges (PA-FR-008), FuelCalculation (PA-FR-010) and DelayCostModel (PA-DR-002). • All calculations from CE-1.1 related to RBT are necessary: EnRouteCharges (PA-FR-008), FuelCalculation (PA-FR-010) and DelayCostModel (PA-DR-002). • Calculate the difference of the actual trajectory cost from RBT cost.
Remarks	• Since APACHE is not providing simulations of tactical operations, this PI can only be used for “Post-ops” assessment with current ConOps historical data (PA-DR-005). When executing for “Pre-ops” mode, this PI will give zero as a result. • Optionally this PI could be normalized per flight hours or per Available Seat Mile (ASM). In this case, it would be required to calculate the variable *EvaluateFlight* (PA-FR-012).
Indicator	**CE-1.3:** En-route ATM charges cost for the Airspace User
Calculation	*(Total en-route charges for the RBT) – (Total en-route charges for the first submitted SBT)* Units: Euros (per flight) Applicable: “Post-ops” and “Pre-ops”. Where: • EnRouteCharges (PA-FR-008) computations from CE-1.1 will be used. The PA calculates the variable *EnRouteCharges* (PA-FR-008) for each 4D trajectory set (one vector with the costs of all flights for the SBT and another for the RBT). • Calculate the difference of the two vectors of costs.
Remarks	• Under the current system, route charges are always computed taking the planned trajectory, regardless of the actual track. This indicator might be helpful if the charging system takes into account the actual en-route trajectory instead of the planned one. See additional remarks in D3.1 (APACHE Consortium, 2017). • Optionally this PI could be normalized per flight hours or per Available Seat Mile (ASM). In this case, it would be required to calculate the variable *EvaluateFlight* (PA-FR-012).
Indicator	**CE-2:** Sectorization Cost

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Calculation	*[(Number of active en-route sectors)·(Time sectors were active)] / [(Number of optimal en-route sectors)·(Time sectors would be active)]*100* Units: % Applicable: Only "Post-ops" (see remarks). Where: • For "Post-ops", given an optimal airspace structure (ASP-FR-003) and an actual airspace structure (PA-DR-010) a comparison is done and the variable *OpeningSchemeEvaluation* (PA-FR-009) will be computed for each.
Remarks	• Given the limitations of the APACHE System (no tactical layer is modelled) for pre-ops this indicator would give "1", since the optimal opening scheme will be used by the ASP when synthesising a scenario.
Indicator	**CE-3:** Flights per ATCO hour on duty
Calculation	*(Count of flights handled) / (Number of ATCO-hours applied by ATCOs on duty)* Units: Number of flights per hour Applicable: "Post-ops" and "Pre-ops". Where: • *Count of flights handled*: The variable *SectorOccupancyPerHour* (PA-FR-007) will be computed and generate the *Count of flights handled* using a 4D trajectories set. • *Number of ATCO-hours applied by ATCOs on duty* is the obtained from variable OpeningSchemeEvaluation (PA-FR-009).
Remarks	-

Table 5-4. Calculation method for APACHE performance indicators on Cost-efficiency KPA

Indicator	**ENV-1:** ATM inefficiency on the horizontal track.
Calculation	*ABS ((Actual route distance) – (Optimal route distance))* Units: NM Applicable: "Post-ops" (see remarks). Where: • *Actual route* comes from the 4D Trajectory set obtained from a historical database of radar tracks or similar (PA-DR-005). • *Optimal route* comes from a 4D trajectory set obtained with the TP of the APACHE-TAP (TP-FR-001) in "pre-" and "Post-ops". Several TP configurations might be considered to produce these optimal trajectories, consequently leading to several potential sub-metrics. Examples: the optimal trajectories could consider a full free route scenario or the current route network, continuous cruise climbs could be enabled, the Cost Index could be set to zero to also capture ENV inefficiencies due to the AU operation, etc. • Variable *EvaluateFlight* (PA-FR-012) will be calculated for each flight to obtain individual flight distances
Remarks	• Since APACHE is not providing simulations of tactical operations, this PI can only be used for "Post-ops" assessment with current ConOps historical data (PA-DR-005). When executing for "Pre-ops" mode, this PI will give the same result as ENV-1.1.
Indicator	**ENV-1.1:** Strategic ATM inefficiency on the horizontal track
Calculation	*ABS ((Route distance of the RBT) – (Optimal route distance))* Units: NM Applicable: "Post-ops" and "Pre-ops". Where: • For "Pre-ops" the RBT is the regulated trajectory from the TCP (TCP-FR-005). • For "Post-ops" the RBT is the regulated flight plan (PA-DR-009). • *Optimal route* calculated as in ENV-1. • Variable EvaluateFlight (PA-FR-012) will be calculated for each flight to obtain individual flight distances
Remarks	-
Indicator	**ENV-1.2:** Tactical ATM inefficiency on the horizontal track
Calculation	*(Actual route distance) – (Route distance of the RBT)*

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	Units: NM Applicable: "Post-ops" (see remarks). Where: • *Actual route distance*: Calculated as in ENV-1. • *Route distance of the RBT:* Calculated as in ENV-1.1.
Remarks	• Since APACHE is not providing simulations of tactical operations, this PI can only be used for "Post-ops" assessment with current ConOps historical data (PA-DR-005). When executing for "Pre-ops" mode, this PI will give zero as a result. • This indicator could give a negative value.
Indicator	**ENV-2:** ATM inefficiency on trip fuel (or emissions)
Calculation	*(Actual trip fuel) – (Optimal trip fuel)* Units: kg or Tons of fuel (or CO_2) Applicable: "Post-ops" (see remarks). Where: • *Actual trajectories* come from the 4D Trajectory set obtained from a historical database of radar tracks or similar (PA-DR-005). • *Optimal trajectories* come from the 4D trajectory set obtained with the TP of the APACHE-TAP (TP-FR-001) in "pre-" and "Post-ops". Several TP configurations might be considered to produce these optimal trajectories, consequently leading to several potential sub-metrics. Examples: the optimal trajectories could consider a full free route scenario or the current route network, continuous cruise climbs could be enabled, the Cost Index could be set to zero to also capture ENV inefficiencies due to the AU operation, etc. • *Trip fuel in post-ops:* is calculated for each flight of the Actual route with *FuelCalculation* (PA-FR-010) or obtained directly from the TP for the optimal route (TP-FR-001).
Remarks	• Since APACHE is not providing simulations of tactical operations, this PI can only be used for "Post-ops" assessment with current ConOps historical data (PA-DR-005). When executing for "Pre-ops" mode, this PI will give the same result as ENV-2.3.
Indicator	**ENV-2.1:** ATM vertical trajectory inefficiency on trip fuel (or emissions)
Calculation	*(Actual trip fuel) – (Optimal trip fuel fixing the actual route)* Units: kg or Tons of fuel (or CO_2) Applicable: "Post-ops" (see remarks). Where: • *Actual trip fuel:* Calculated as in ENV-2. • *Optimal route fixing route:* in calculated by the TP (TP-FR-013). • *Optimal trip fuel fixing the actual route in post-ops:* is calculated for each flight of the optimal route with *FuelCalculation* (PA-FR-010).
Remarks	• Since APACHE is not providing simulations of tactical operations, this PI can only be used for "Post-ops" assessment with current ConOps historical data (PA-DR-005). When executing for "Pre-ops" mode, this PI will give the same result as ENV-2.4.
Indicator	**ENV-2.2:** ATM horizontal trajectory inefficiency on trip fuel (or emissions)
Calculation	*(Optimal trip fuel fixing the actual route) – (Optimal trip fuel)* Units: kg or Tons of fuel (or CO_2) Applicable: "Post-ops" (see remarks). Where: • *Optimal trip fuel fixing the actual route*: Calculated as in ENV-2.1. • *Optimal trip fuel:* Calculated as in ENV-2. • *Fast calculation method:* (ENV-2) – (ENV-1)
Remarks	• Since APACHE is not providing simulations of tactical operations, this PI can only be used for "Post-ops" assessment with current ConOps historical data (PA-DR-005). When executing for "Pre-ops" mode, this PI will give the same result as ENV-2.5.
Indicator	**ENV-2.3:** Strategic ATM inefficiency on trip fuel (or emissions)
Calculation	*(RBT trip fuel) – (Optimal trip fuel)* Units: kg or Tons of fuel (or CO_2) Applicable: "Post-ops" and "Pre-ops". Where:

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	• For "Pre-ops" the RBT is the regulated trajectory from the TCP (TCP-FR-005). • For "Post-ops" the RBT is the regulated flight plan (PA-DR-009). • *Optimal trajectories* as calculated as in ENV-2. • For "Post-ops": *RBT trip fuel* is calculated for each flight of the RBT route with *FuelCalculation* (PA-FR-010). • For "Pre-ops": *RBT trip fuel* is taken directly from the TP (TP-FR-001). • *Optimal trip fuel:* Calculated as in ENV-2. • *Fast calculation:* (ENV-2) – (ENV-2.6)
Remarks	-
Indicator	**ENV-2.4**: Strategic ATM vertical trajectory inefficiency on trip fuel (or emissions)
Calculation	*(RBT trip fuel) – (Optimal trip fuel fixing the RBT route)* Units: kg or Tons of fuel (or CO_2) Applicable: "Post-ops" and "Pre-ops". Where: • *RBT trip fuel:* Calculated as in ENV-2.3 • *Optimal route fixing the RBT route:* is calculated by the TP (TP-FR-013). • *Optimal trip fuel fixing the RBT route:* is also calculated by the TP (TP-FR-001).
Remarks	-
Indicator	**ENV-2.5:** Strategic ATM horizontal trajectory inefficiency on trip fuel (or emissions)
Calculation	*(Optimal trip fuel fixing the RBT route) – (Optimal trip fuel).* Units: kg or Tons of fuel (or CO_2) Applicable: "Post-ops" and "Pre-ops". Where: • *Optimal trip fuel fixing the RBT route:* Calculated as in ENV-2.4. • *Optimal trip fuel:* Calculated as in ENV-2. • *Fast calculation:* (ENV-2.2) – (ENV-2.8)
Remarks	-
Indicator	**ENV-2.6:** Tactical ATM inefficiency on trip fuel (or emissions)
Calculation	*(Actual trip fuel) – (RBT trip fuel)* Units: kg or Tons of fuel (or CO_2) Applicable: "Post-ops" (see remarks). Where: • *Actual trip fuel:* Calculated as in ENV-2. • *RBT trip fuel:* Calculated as in ENV-2.3. • *Fast calculation:* (ENV-2) – (ENV-2.3)
Remarks	• Since APACHE is not providing simulations of tactical operations, this PI can only be used for "Post-ops" assessment with current ConOps historical data (PA-DR-005). When executing for "Pre-ops" mode, this PI will give zero as a result. • This indicator could give a negative value.
Indicator	**ENV-2.7:** Tactical ATM vertical trajectory inefficiency on trip fuel (or emissions)
Calculation	*(ENV-2.6) – (ENV-2.8)* Units: kg or Tons of fuel (or CO_2) Applicable: "Post-ops" (see remarks). Where: • *ENV-2.6:* Needs Actual trip fuel and RBT trip fuel. • *ENV-2.8:* Needs Optimal trip fuel fixing the actual route and Optimal trip fuel fixing the RBT route.
Remarks	• Since APACHE is not providing simulations of tactical operations, this PI can only be used for "Post-ops" assessment with current ConOps historical data (PA-DR-005). When executing for "Pre-ops" mode, this PI will give zero as a result.
Indicator	**ENV-2.8:** Tactical ATM horizontal trajectory inefficiency on trip fuel (or emissions)
Calculation	(*Optimal trip fuel fixing the actual route) – (Optimal trip fuel fixing the RBT route)* Units: kg or Tons of fuel (or CO_2) Applicable: "Post-ops" (see remarks).

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	Where: • *Optimal trip fuel fixing the actual route:* Calculated as in ENV-2.1. • *Optimal trip fuel fixing the RBT route:* Calculated as in ENV-2.4. • *Fast Calculation:* (ENV-2.6) – (ENV-2.7)
Remarks	• Since APACHE is not providing simulations of tactical operations, this PI can only be used for "Post-ops" assessment with current ConOps historical data (PA-DR-005). When executing for "Pre-ops" mode, this PI will give zero as a result.

Table 5-5. Calculation method for APACHE performance indicators on Environment KPA

Indicator	**FLEX-1:** Percentage of RBTs which are equal to the first submitted SBTs
Calculation	*[(Total number of RBTs equal to the first submitted SBTs) / (Total number of first SBTs submitted)]*100* Units: % Applicable: "Post-ops" and "Pre-ops" (see remarks). Where: • Calculated by adding all AU values calculated in AEQ-1.
Remarks	• For "post-ops" (if analysing historical data in current ConOps) the last filed flight plan will be used as reference for the AU's most preferred trajectory, since at present, this is the best information available for performance monitoring. Therefore, **regulated trajectories will differ only with delay (if any)**. See additional remarks on this limitation in D3.1 (APACHE Consortium, 2017).
Indicator	**FLEX-2:** Spare capacity
Calculation	*[1 - (Capacity utilized/Capacity available)]*100* Units: % Applicable: "Post-ops" and "Pre-ops", but only in current ConOps (see remarks). Where: • *Capacity utilized*: PA will compute the variable denominated *SectorOccupancyPerHour* (PA-FR-007) of a traffic pattern. • *Capacity available:* Calculated from PA variable *OpeningSchemeEvaluation* (PA-FR-009) applied to the actual opening scheme in "Post-ops" (PA-DR-010) or, in "Pre-ops", to the ASP selected opening scheme (ASP-FR-001).
Remarks	• In the SESAR 2020 ConOps "sector capacity" term is no longer applicable.
Indicator	**FLEX-3:** Sector changes relative to time/distance
Calculation	*[Sum (Average number of sector changes per hour per flight)]/(Total number of flights)* Units: - Applicable: "Post-ops" and "Pre-ops". Where: • *Number of sector changes of one flight:* It is calculated by the PA from variable *Transfers* (PA-FR-011) from a given traffic pattern. • *Total time flown by one flight:* It is calculated by the PA from variable *EvaluateFlight* (PA-FR-012) from a given 4D trajectory set. • Data for all flights of the given 4D trajectory set will be added to obtain numerator and denominator
Indicator	**FLEX-4:** Flexibility of DCB solutions
Calculation	*(Total number of DCB solutions for all regulated flights) / (Number of regulated trajectories)* Units: - Applicable: "Pre-ops" (see remarks). Where: • *Number of DCB solutions* is the absolute number of different solutions to solve a demand/capacity imbalance problem. It will be calculated by the TCP-TP loop iteration process (LI-FR-001). • *Number of regulated trajectories:* It will be calculated by the TCP-TP loop iteration process (LI-FR-001).
Remarks	• The PA is only slightly involved in calculating this PI (all information coming from the TCP). • For current ConOps this PI gives "1" (lowest flexibility). • It could be used in "Post-ops" if historical data contains these details on the Network Manager processes. These data are, however, not avaialbe to the APACHE Consortium and it will be used only in pre-ops.

Table 5-6. Calculation method for APACHE performance indicators on Fexibility KPA

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Indicator	**SAF-1:** Number of Traffic Alerts warnings
Calculation	*Number of TA:* total number of situations in which TA of TCAS are activated. Units: - Applicable: "Post-ops" and "Pre-ops". Where: • Activation of TA is based on a model of the TCAS logic contained in the RA component. Given a 4D trajectory set, this model of the RA calculates the number of traffic alert warnings (RA-FR-006).
Remarks	• Could be normalized by number of flights or by number of flight hours
Indicator	**SAF-1.1:** Traffic Alerts warnings
Calculation	*(Number of TA)/(Number of flights or flight hours)* Units: - Applicable: "Post-ops" and "Pre-ops".
Remarks	• SAF-1 Normalised
Indicator	**SAF-2:** Number of Resolution Advisories issued
Calculation	*Number of RA:* total number of situations in which RA of TCAS are activated. Units: - Applicable: "Post-ops" and "Pre-ops". Where: • Activation of RA is based on model of TCAS logic contained in RA. Given a 4D trajectory set this model of the RA calculates the number of resolution advisories (RA-FR-006).
Remarks	• Could be normalized by number of flights or by number of flight hours
Indicator	**SAF-2.1:** Resolution Advisories issued
Calculation	*(Number of RA)/(Number of flights or flight hours)* Units: - Applicable: "Post-ops" and "Pre-ops".
Remarks	• SAF-2 Normalised
Indicator	**SAF-3:** Number of Near Mid Air Collisions (NMACs)
Calculation	*Number of NMAC:* total number of situations in which minimal horizontal and/or vertical separations (so called Closest Point of Approach) after resolution advisor is activated, are lower than NMAC minima. Units: - Applicable: "Post-ops" and "Pre-ops". Where: • Given a 4D trajectory set, the TCAS activation module of the RA estimates the number of NMACs (RA-FR-006).
Remarks	• Could be normalized by number of flights or by number of flight hours • NMAC minima is usually: 500 ft horizontally and 100 ft vertically (Netjasov et al, 2013).
Indicator	**SAF-3.1:** Near Mid Air Collisions (NMACs)
Calculation	*(Number of NMAC)/(Number of flights or flight hours)* Units: - Applicable: "Post-ops" and "Pre-ops".
Remarks	• SAF-3 Normalised
Indicator	**SAF-4:** Number of Separation Violations
Calculation	*Number of separation violations:* total number of situations in which minimal horizontal and/or vertical separations are violated considering all flights in a given sector. Units: - Applicable: "Post-ops" and "Pre-ops". Where: • Given a 4D trajectory set, the separation violation detection module of the RA calculates the number of separation violations (RA-FR-003).

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Remarks	• Same indicator as C-SAF-1 but used here for pre-ops too. Furthermore, it could be normalized by number of flights or by number of flight hours.
Indicator	**SAF-4.1:** Separation Violations
Calculation	*(Number of separation violation)/(Number of flights or flight hours)* Units: - Applicable: "Post-ops" and "Pre-ops".
Remarks	• SAF-4 Normalised
Indicator	**SAF-5:** Severity of separation violations
Calculation	*([(Separation minima) – (minimum of Actual separation)] / (Separation minima)* Units: - Applicable: "Post-ops" and "Pre-ops". Where: • Given a 4D trajectory set, the separation violation detection module of the RA calculates the severity of separation violations by comparing the minimum of actual distance between pair of aircraft against the separation minima (RA-FR-004). • The severity of separation violation is calculated for each conflict situation separately.
Remarks	• It is computed by simulation of traffic within given airspace. • If more than one separation violation is given, this PI returns the average of the severity of all.
Indicator	**SAF-6:** Duration of separation violations
Calculation	*Time period in which (Actual separation) is less than (Separation minima)* Units: seconds Applicable: "Post-ops" and "Pre-ops". Where: • Given a 4D trajectory set, the separation violation detection module of RA calculates the duration of separation violations (RA-FR-005). • The duration of separation violation is calculated for each conflict situation separately.
Remarks	• It is computed by simulation of traffic within given airspace. • If more than one separation violation is given, this PI returns the sum of all as well as average of all.
Indicator	**SAF-7:** Risk of conflicts/accidents
Calculation	Units: - Applicable: "Post-ops" and "Pre-ops". Where: • *Risk of conflict/accident* will be computed by risk of conflict/accident assessment module of RA (RA-FR-007). • In case of one conflict situation, the risk is defined as the ratio between the ''Elementary risk'' and the observed period of time (e.g. 1 h, or 15 min). In case of N conflicts, a total risk is given as sum of N ''Elementary risks''. • "Elementary risk" is defined as the area between the surface limited by minimum separation line and function representing the change of aircraft actual separation. • "Elementary risk" is calculated for each conflict situation separately combining *SAF-5 and SAF-6*.

Table 5-7. Calculation method for APACHE performance indicators on Safety KPA

Indicator	**PAR-1:** Collaborative SBT updates
Calculation	*(Number of SBT update requests) / (Number of RBT different from first submitted SBTs)* Units: % Applicable: "Pre-ops" (see remarks). Where: • *Number of SBT update requests:* It will be calculated by the TCP-TP loop iteration process (LI-FR-001). • *Number of RBT different from SBTs:* calculated in FLEX-1.
Remarks	• For current ConOps this PI gives "1" (lowest participation). • It could be used in "Post-ops" if historical data contains these details on the Network Manager processes. These data are, however, not avaialbe to the APACHE Consortium and it will be used only in pre-ops

Table 5-8. Calculation method for APACHE performance indicators on Participation KPA

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5.3 Cross-reference summary

The table 5-9 presents the list of all the Performance Analyser intermediate variables and a cross-reference of the PI they provide support to. The intermediate variables are defined to optimise computing time. By computing only once each variable and then using it in different PI calculations we avoid repeating the execution of some code. The table also provides at first look the relation among different PIs. Table 5-10 shows the same relations ordered by PIs.

PA variable	Relates to the following PIs
DelayPerFlight (PA-FR-006)	C-CAP-1, AEQ-3, CAP-1, CAP-2.
SectorOccupancyPerHour (PA-FR-007),	CE-3, FLEX-2
EnRouteCharges (PA-FR-008)	AEQ-2, AEQ-5, CE-1, CE-1.1, CE-1.2, CE-1.3
OpeningSchemeEvaluation (PA-FR-009)	CE-2, CE-3, FLEX-2
FuelCalculation (PA-FR-010)	AEQ-2, AEQ-5, CE-1, CE-1.1, CE-1.2, ENV-2, ENV-2.1, ENV-2.2, ENV-2.3, ENV-2.4, ENV-2.5, ENV-2.6, ENV-2.7, ENV-2.8
Transfers (PA-FR-011)	FLEX-3
EvaluateFlight (PA-FR-012)	C-ENV-1, C-ENV-2, CE-1, CE-1.1, CE-1.2, CE-1.3, ENV-1, ENV-1.1, ENV-1.2, FLEX-4
CutTrajectorySet_xAU (PA-FR-013)	AEQ-1, AEQ-2, AEQ-4, CAP-3, FLEX-1,
GreatCircleDistance (PA-FR-015)	C-ENV-1, C-ENV-2
DelayCostModel (PA-DR-002)	AEQ-2, CE-1, CE-1.1, CE-1.2

Table 5-9. Performance Analyser intermediate variables and PI cross reference table

PI	Relates to the following PA variable
C-ENV-1, C-ENV-2	EvaluateFlight (PA-FR-012), GreatCircleDistance (PA-FR-015)
C-CAP-1, AEQ-3	DelayPerFlight (PA-FR-006)
AEQ-1, AEQ-4, CAP-3, FLEX-1	CutTrajectorySet_xAU (PA-FR-013)
AEQ-2	CutTrajectorySet_xAU (PA-FR-013), EnRouteCharges (PA-FR-008), FuelCalculation (PA-FR-010), DelayCostModel (PA-DR-002)
AEQ-5	EnRouteCharges (PA-FR-008), FuelCalculation (PA-FR-010)
CAP-1, CAP-2	DelayPerFlight (PA-FR-006)
CE-1, CE-1.1, CE-1.2	EnRouteCharges (PA-FR-008), FuelCalculation (PA-FR-010), DelayCostModel (PA-DR-002), EvaluateFlight (PA-FR-012)
CE-1.3	EnRouteCharges (PA-FR-008), EvaluateFlight (PA-FR-012)
CE-2	OpeningSchemeEvaluation (PA-FR-009)
CE-3	SectorOccupancyPerHour (PA-FR-007), OpeningSchemeEvaluation (PA-FR-009)
ENV-1, ENV-1.1, ENV-1.2	EvaluateFlight (PA-FR-012)
ENV-2, ENV-2.1, ENV-2.2, ENV-2.3, ENV-2.4, ENV-2.5, ENV-2.6, ENV-2.7, ENV-2.8	FuelCalculation (PA-FR-010)
FLEX-2	SectorOccupancyPerHour (PA-FR-007), OpeningSchemeEvaluation (PA-FR-009)
FLEX-3	Transfers (PA-FR-011), Evaluate Flight (PA-FR-012)

Table 5-10. PIs and Performance Analyser intermediate variables cross reference table

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