Enhanced Indicators to Monitor ATM Performance in Europe

Main findings of the APACHE SESAR Exploratory Research Project

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8th SESAR Innovation Days (SIDs)
Salzburg, Austria
Dec 6th 2018
APACHE Doc: DIS_WP6-17
Introduction

The APACHE Project

Assessment of Performance in current ATM operations and of new Concepts of operations for its Holistic Enhancement

- SESAR Exploratory Research (ER) Project
- Topic ER-11-2015 (ATM performance)
- Grant Agreement: 699338
- 9th May 2016 – 8th May 2018

http://apache-sesar.barcelonatech-upc.eu/ @Apache_SESAR
Objectives of the APACHE project

• Propose a new framework to assess European ATM performance based on simulation and optimisation tools.

• Fill some gaps in state-of-the-art methodologies for ATM performance assessment aiming to better capture and understand:
  
  • the impact of ATM operations:
    • considering a wide range of KPAs*
    • proposing a set of new or enhanced PIs
    • focusing in current AND future SESAR 2020 ConOps (SESAR solutions)
  
  • the interdependencies and trade-offs among different KPAs
  
  • the theoretical limits for certain KPAs.

(*) Equity, Capacity, AU Cost-efficiency, ANSP Cost-efficiency, Environment, Flexibility and Safety.

ATM: Air traffic management – KPA: Key performance area – PI: Performance indicator –
ATS: Air traffic services – AU: Airspace User – ANSP: Air navigation service provider
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APACHE Framework

ATM Scenario (Set of trajectories + set of sector opening schemes)

Post-ops (historical data)

Pre-ops (synthetic data)

Data repository

ATM simulator

APACHE Performance Analyser

Performance Indicators (PIs) (current and/or proposed by APACHE)

Optimisation or reconstruction of trajectories + airspace configurations to support the implementation of advanced PIs

APACHE - TAP (Traffic and airspace planner)

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APACHE Framework

Historical (4D) actual and planned trajectories
Eurocontrol DDR2
CPR from Eurocontrol PRU

DDR2: Data Demand Repository 2
PRU: Performance Review Unit
CPR: Correlated Position Reports
CI: Cost Index

APACHE - TAP
(Traffic and airspace planner)

Optimal (4D) trajectory baselines
- \( \min \text{ Distance} \)
- \( \min \text{ Fuel} \)
- \( \min \text{ Cost} = \min (\text{Fuel} + \text{CI} \cdot \text{Time} + \text{Charges}) \)

APACHE Framework (post-ops)

Performance Indicators (PIs)
(current and/or proposed by APACHE)
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APACHE Framework

Historical (4D) actual and planned trajectories
Eurocontrol DDR2
CPR from Eurocontrol PRU

DDR2: Data Demand Repository 2
PRU: Performance Review Unit
CPR: Correlated Position Reports
ATS: Air Traffic Services

Optimal (4D) trajectory baselines
- Assuming Full Free Route
- Following published ATS routes

Performance Indicators (PIs)
(current and/or proposed by APACHE)

APACHE Performance Analyser

APACHE - TAP
(Traffic and airspace planner)

APACHE Framework (post-ops)
APACHE Framework

Historical Sectorisation
Eurocontrol DDR2
French ANSP

DDR2: Data Demand Repository 2
ANSP: Air Navigation Service Provider

Optimal Sectorisation
Assuming current practices
Assuming Dynamic Airspace Configuration (SESAR PJ08)

Performance Indicators (PIs)
(current and/or proposed by APACHE)

APACHE - TAP
(Traffic and airspace planner)

APACHE Framework (post-ops)
Main findings and results

Main Contribution of APACHE: Optimal\(^1\) trajectory as baseline reference to compute performance indicators (PIs)

**Example:** Actual and planned trajectories crossing FABEC (Jul 28\(^{th}\) 2016 post-ops)

\(^1\) Optimal baseline trajectories computed in full free-route airspace, flat-route charges scheme and maximum range operations (i.e. Cost Index = 0)
Main findings and results

**Main Contribution of APACHE: Optimal trajectory** as baseline reference to compute performance indicators (PIs)

**Example:** Actual and planned trajectories crossing FABEC (Jul 28th 2016 post-ops)

1 Actual/Planned trajectory estimated fuel minus weather optimal trajectory fuel

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1 Optimal baseline trajectories computed in full free-route airspace, flat-route charges scheme and maximum range operations (i.e. Cost Index = 0)
Main findings and results

**Environment**

Main Contribution of APACHE: **Optimal trajectory** as baseline reference to compute performance indicators (PIs)

- **Distance-based** performance indicators
  - ✓ Easier to compute
  - ✓ Possibility to *de-couple* inefficiencies due to different *ATM layers*.
  - x Cannot capture the inefficiencies in the *vertical* domain
  - x The same *ground* distance inefficiency could represent different *air* distance inefficiency and, therefore, different fuel (and CO₂) inefficiency.

- **Fuel-based** performance indicators:
  - x More *difficult* to compute → require *fuel estimation* from surveillance data
  - ✓ Directly capture inefficiencies in *fuel* consumption and therefore *CO₂*.
  - ✓ Possibility to *de-couple* inefficiencies due to different *ATM layers*.
  - ✓ Possibility to *de-couple* vertical and horizontal *trajectory* inefficiencies.
Main findings and results

**AU cost-efficiency focus area**

Main Contribution of APACHE: Optimal trajectory as baseline reference to compute performance indicators (PIs)

**Example:** Actual and regulated trajectories crossing FABEC (Jul 28\textsuperscript{th} 2016 post-ops)

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**Actual trajectory** estimated cost (*) minus **Last filed flight plan** estimated cost (*)

(*) Assumptions:
- Cost of fuel: fixed fuel price for all AUs
- Tactical cost of trip time given by the Cost Index
- Cost of delay: model proposed by (Eurocontrol, 2017)

Main findings and results

**AU cost-efficiency focus area**

Main Contribution of APACHE: Optimal trajectory as baseline reference to compute performance indicators (PIs)

**Example:** Actual and regulated trajectories crossing FABEC (Jul 28th 2016 post-ops)

Example: Actual and regulated trajectories crossing FABEC (Jul 28th 2016 post-ops)

**Actual** trajectory _estimated cost_ (*)

**minus**

**Last filed flight plan** _estimated cost_ (*)

**(*) Assumptions:**

- Cost of fuel: fixed fuel price for all AUs
- Tactical cost of trip time given by the Cost Index
- Cost of delay: model proposed by (Eurocontrol, 2017)

Main findings and results

**AU cost-efficiency focus area**

**Main Contribution of APACHE:** Optimal trajectory as baseline reference to compute performance indicators (PIs)

**Example:** Actual and regulated trajectories crossing FABEC (Jul 28th 2016 post-ops)

- **Actual trajectory** estimated cost (*) minus
- **Estimated cost of full free route** with estimated Cost Index (*)

Trip time efficiency is an ambition target in the ATM master plan.
Main findings and results

**AU cost-efficiency focus area**

Main Contribution of APACHE: Optimal\(^1\) trajectory as baseline reference to compute performance indicators (PIs)

- **Cost-based** performance indicators:
  - **Difficult** to compute →
    - require fuel estimation from surveillance data
    - AU’s cost/business model(s): cost of time, delay, fuel, etc.
  - Possibility to de-couple vertical and horizontal trajectory inefficiencies
  - Possibility to de-couple inefficiencies due to different ATM layers.

- **Time-based** performance indicators:
  - **Easier** to compute
  - In line with “Operational Efficiency SESAR ambition target” defined in the ATM master plan (flight time reduction)
  - Possibility to de-couple inefficiencies due to different ATM layers.
  - Not representative of the overall cost for the AU
Main findings and results

ANS cost-efficiency focus area

Main Contribution of APACHE: Propose new approaches to estimate the cost of providing air traffic services

Example: Actual FABEC sectorisations (Jul 28th 2016 and Feb 20th 2017 post-ops)
Main findings and results

Main Contribution of APACHE: Propose indicators by automatically analysing traffic. Independent on AUs or ANSPs reports

Example: Actual trajectories crossing FABEC (Jul 28th 2016 post-ops)

- Loss of separation (5NM, 1000ft)
- TCAS RA (and NMAC)

TCAS: Traffic Collision Avoidance System
RA: Resolution advisory
NMAC: Near mid air collision (500ft, 100ft)
PRU: Performance review unit
CPR: Correlated position reports
DDR2: Demand data repository

Fedja Netjasov, Dusan Crnogorac, Goran Pavlovic Assessment of Future Air Traffic Management System Safety Performances using Network-based Simulation Model. Proceedings of the 8th SESAR Innovation Days

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Main findings and results

Capacity KPA

Main Contribution of APACHE: Propose indicators to complement the information loss in current indicators due to delay averaging.

Examples: Actual trajectories crossing FABEC (Jul 28\textsuperscript{th} 2016 + Feb 20\textsuperscript{th} 2017 post-ops)

Robust maximum en-route delay:

Average (en-route ATFM delay greater than (mean value + Standard deviation of en-route ATFM delay))

- Robust maximum en-route delay
- Average en-route delay (current indicator)
# Main Contributions per KPA

<table>
<thead>
<tr>
<th>Environment KPA</th>
<th><strong>Optimal trajectory</strong> as baseline reference to compute performance indicators (PIs) <strong>in post-ops mode</strong>: distance- and fuel-based indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>AU cost-efficiency focus area</td>
<td><strong>Optimal trajectory</strong> as baseline reference to compute performance indicators (PIs) <strong>in post-ops mode</strong>: cost- and time-based indicators</td>
</tr>
<tr>
<td>ANS cost-efficiency focus area</td>
<td><strong>Optimal sectorisation</strong> as baseline reference to compute performance indicators (PIs) <strong>in post-ops mode</strong>: cost-based indicator</td>
</tr>
<tr>
<td>Safety KPA</td>
<td><strong>Pro-active safety approach</strong>, by <strong>automatically</strong> analysing traffic samples estimating system risk by means of counts of different safety related occurrences. Independent on AUs or ANSPs reports</td>
</tr>
<tr>
<td>Capacity KPA</td>
<td><strong>New indicators</strong> to complement information loss due to (current) delay averaging</td>
</tr>
</tbody>
</table>

KPA: Key Performance Area - AU: Airspace User - ANS: Air Navigation Services
Conclusions

• APACHE new Performance Indicators based on optimisation and simulation.

• The APACHE framework enables proactive and predictive analysis of the current and future ATM system, as a first step towards PBO.

• The APACHE framework is designed with a service oriented architecture

• Holistic approach to overcome current limitations in performance assessment to better capture:
  • the impact of new concepts (SESAR solutions);
  • the complex interdependencies among KPAs;
  • the theoretical limits of each KPA

ATM: Air traffic management
PBO: Performance based operations
KPA: Key performance area
ANS: Air navigation services
Further reading

Project Deliverable D1.2: Final project results report

Project Deliverable D3.1: Review of current KPIs and proposal for new ones

Project Deliverable D3.2: Functional requirements and specifications for the ATM performance assessment framework

Project Deliverable D4.1: Report on the availability of the APACHE framework

Project Deliverable D5.1: Results from simulation and analysis of results


http://apache-sesar.barcelonatech-upc.eu/
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Main findings of the APACHE SESAR Exploratory Research Project

Thank you very much for your attention!
Enhanced Indicators to Monitor ATM Performance in Europe
Main findings of the APACHE SESAR Exploratory Research Project
Scope of the research

Real data (coming from ANSPs, network manager, etc.)

Post-ops (monitoring)

New PIs  Current PIs

Synthesized data with the APACHE-TAP

Pre-ops (planning)

New PIs  Current PIs

SESAR2020 ConOps

Executed RBT

RBT\(^1\)

SBT\(^2\)

Current ConOps

Actual trajectory

Regulated trajectory\(^3\)

First filled trajectory\(^4\)

SESAR2020 ConOps

Executed RBT

RBT\(^1\)

SBT\(^2\)

Current ConOps

Actual trajectory

Regulated trajectory\(^3\)

First filled trajectory\(^4\)

Out of scope of PACHE because we don’t have REAL data of future ConOps because we are not still in the future 😊

Done in APACHE project for demonstration purposes (demonstrate that our tool can be used for post-ops too). If better data is not available we will take DDR2 trajectories (Respectively M3, M2 and M1 for the 3 types of trajectories). Enough for demonstration purposes of our project.

• \(^1\) Referring to the “first” RBT i.e. the “last” SBT

• \(^2\) Referring to the “first” SBT (as submitted initially by the AU before starting the negotiation process with the NM).

• \(^3\) It comes from the first filled flight plan. Assuming this is what really the AU would like to fly.

• \(^4\) It comes from the regulated FP, which includes ATFM re-routings and/or ATFM delays (if any).

Out of scope of APACHE because we don’t simulate the tactical layer. Therefore, the output of the APACHE-TAP are only RBT (future conops) or regulated trajectories (with CASA)

Done in APACHE to benchmark current ConOps with future ConOps (implement here all the scenarios of D2.1).
Main findings and results

Main Contribution of APACHE: Optimal\(^1\) trajectory as baseline reference to compute performance indicators (PIs)

*Example:* Actual and planned trajectories crossing FABEC (Jul 28\(^{th}\) 2016 *post-ops*).

1. Optimal baseline trajectories computed in full free-route airspace, flat-route charges scheme and maximum range operations (i.e. Cost Index = 0).

* KEA/KEP computed independently per flight

\(^1\) KEA/KEP computed independently per flight
Main findings and results

**Main Contribution of APACHE**: Optimal\(^1\) trajectory as baseline reference to compute performance indicators (PIs)

**Example**: Actual and planned trajectories crossing FABEC (Jul 28\(^{th}\) 2016 post-ops)

\(^1\) Optimal baseline trajectories computed in full free-route airspace, flat-route charges scheme and maximum range operations (i.e. Cost Index = 0)

* KEA/KEP computed independently per flight

\[\text{Actual route distance minus \ OD geodesic distance} \]

\[\text{Actual route distance minus \ weather optimal\(^1\) route distance} \]
Main findings and results

Main Contribution of APACHE: Optimal<sup>1</sup> trajectory as baseline reference to compute performance indicators (PIs)

Example: Actual trajectories crossing FABEC (Jul 28<sup>th</sup> 2016 post-ops)

![Graph showing fuel inefficiency for different conditions](image)

**Actual trajectory estimated fuel minus weather optimal<sup>1</sup> trajectory fuel**

- **<sup>1</sup> But... what is the “best” trajectory?**
- **And what about environmental inefficiencies due to the Airspace User (AU)?**

<sup>1</sup> Different optimal baseline trajectories computed in the following conditions:
- **FR CI=0**: Full free route airspace and maximum range operations (Cost Index =0)
- **SR CI=0**: Current structured route airspace and maximum range operations
- **FR CCC CI=0**: Full free route airspace, continuous cruise climbs and maximum range operations
- **SR CI-AU**: Current structured route airspace and Cost Index chosen by the Airspace User
- **FR CI-AU**: Full free route airspace and Cost Index chosen by the Airspace User
Main findings and results

Safety KPA

Main Contribution of APACHE: Propose indicators by automatically analysing traffic. Independent on AUs or ANSPs reports

Example: Actual trajectories crossing FABEC (Jul 28th 2016 post-ops)

- Loss of separation (5NM, 1000ft)
- TCAS RA (and NMAC)

PRU CPR data

Eurocontrol DDR2 data

TCAS: Traffic Collision Avoidance System
RA: Resolution advisory
NMAC: Near mid air collision (500ft, 100ft)

PRU: Performance review unit
CPR: Correlated position reports
DDR2: Demand data repository
APACHE trajectory and airspace planner

APACHE Framework

APACHE-TAP

- Trajectory planning (TP)
  - “Current” ConOps
  - “Future” ConOps

- Airspace planning (ASP)
  - “Current” ConOps
  - “Future” ConOps

- Traffic and Capacity Planning (TCP)
  - “Current” ConOps
  - “Future” ConOps

Performance analyser

- Current Performance Scheme
- New APACHE Performance Scheme
- Real-time KPAs assessment (for dynamic planning)
- Benchmarking (scenarios or perf. schemes)

KPA assessment

Synthetisation of representative traffic and airspace scenarios (for PRE-OPS)

Optimisation or reconstruction of trajectories + airspace configurations to support the implementation of advanced Performance Indicators (for POST-OPS and PRE-OPS)

More details in Deliverables D2.1 and D3.2 available in the APACHE public web site: http://apache-sesar.barcelonatech-upc.eu/
Optimal trajectories considering realistic cost for Airspace Users:

- The whole route
- Weather forecast(s)
- Route charges
- Cost of time (in terms of CI)

- TP uses network and FRA definition data from Eurocontrol’s DDR2.
- Might be configured to avoid hotspots


FRA: Free Route Areas
TP: Trajectory Planner

4D Trajectory reconstruction

- Allowing to estimate **fuel burnt** and **Cost Index**
- Using flight plans or surveillance data (radar tracks, ADS-B reports, ...) + realised weather
- **Not** requiring confidential information from AUs
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More than 1M trajectories will be simulated (optimised) in APACHE

FRA: Free Route Areas

APACHE trajectory and airspace planner

TP: Trajectory Planner

Computer cluster

Slave X

Slave Y

Slave W

Slave Z

Master

Applications

Batch System

Open LDAP / NFS

Ubuntu

Operating System

Trajectory Planner (TP)

PBS Torque

Meta

Traffic files

so6

exp2

eSo6

Parallel Launcher

DYNAMO instance

Flights Chunk 1

Core splitter

Slave 1

C1

C2

C3

CF

Flights Chunk 2

Core splitter

Slave 2

C1

C2

C3

CF

Flights Chunk M

Core splitter

Slave M

C1

C2

C3

CF

Optimal/predicted trajectories

DYNAMO inputs

F1

F2

... 

DYNAMO outputs

F1

F2

... 

Official sources

BADA

B RBS

Airspace

More than 1M trajectories will be simulated (optimised) in APACHE

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C2

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CF

Flights Chunk M

Core splitter

Slave M

C1

C2

C3

CF

Optimal/predicted trajectories

DYNAMO inputs

F1

F2

... 

DYNAMO outputs

F1

F2

... 

Official sources

BADA

B RBS

Airspace

More than 1M trajectories will be simulated (optimised) in APACHE
APACHE trajectory and airspace planner

APACHE-TAP double functionality:

- **Optimisation** or **reconstruction** of trajectories + airspace configurations to support the implementation of **advanced** Performance Indicators (for POST-OPS and PRE-OPS)
- **Different configurations to synthesise** representative European traffic and airspace scenarios (for PRE-OPS)

**APACHE Framework**

- **APACHE-TAP**
  - Trajectory planning (TP)
    - “Current” ConOps
    - “Future” ConOps
  - Airspace planning (ASP)
    - “Current” ConOps
    - “Future” ConOps
  - Traffic and Capacity Planning (TCP)
    - “Current” ConOps
    - “Future” ConOps

**Performance analyser**

- Current Performance Scheme
- New APACHE Performance Scheme
- Real-time KPAs assessment (for dynamic planning)
- Benchmarking (scenarios or perf. schemes)

- Scenarios
- KPA assessment

More details in **Deliverables D2.1 and D3.2** available in the **APACHE public web site**: http://apache-sesar.barcelonatech-upc.eu/
APACHE trajectory and airspace planner

ASP: Airspace Planner ("Current ConOPS"):  

• Replicate the work done by FMP for each ACCs
• Given a traffic demand and time period $\rightarrow$ optimal opening scheme minimising the number of open sectors and providing the best overall load balance
• Minimize sector underloads; while limiting (avoiding) overloads and considering a comprehensive set of operational constraints
• Existing set of airspace configuration is used
• Existing collapsed sectors – no new sector groupings

FMP: Flow Management Position
ACC: Area Control Centre
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ASP: Airspace Planner ("Current ConOPS"):
APACHE trajectory and airspace planner

ASP: Airspace Planner ("Future ConOPS"): 

• DAC: Dynamic airspace configuration (in line with SESAR PJ08)

• Given a traffic demand and time period → optimal grouping of the Sector Building Blocks (SBB)* providing the best overall load balance in terms of traffic complexity

• Minimize number of open sectors, traffic transfer between active sectors, and considering a comprehensive set of operational constraints

(*) In APACHE, existing elementary sectors are used as SBB
APACHE trajectory and airspace planner

ASP: Airspace Planner ("Future ConOPS"):

Traffic data

Traffic transfers

Traffic complexity
APACHE trajectory and airspace planner

ASP: Airspace Planner (”Future ConOPS”):

![Diagram showing traffic transfers, complexity, optimization, and sector groupings.](image)