Enhanced Indicators to Monitor ATM Performance in Europe

Main findings of the APACHE SESAR Exploratory Research Project

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Salzburg, Austria
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APACHE Doc: DIS_WP6-17

Founding Members

EUROPEAN UNION EUROCONTROL

Introduction

The APACHE Project

Assessment of **P**erformance in current **A**TM operations and of new **C**oncepts of operations for its **H**olistic **E**nhancement

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

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ALG TRANSPORTATION INFRASTRUCTURE & LOGISTICS

DIVISION OF AIRPORTS AND AIR TRAFFIC SAFETY
FACULTY OF TRANSPORT AND TRAFFIC ENGINEERING
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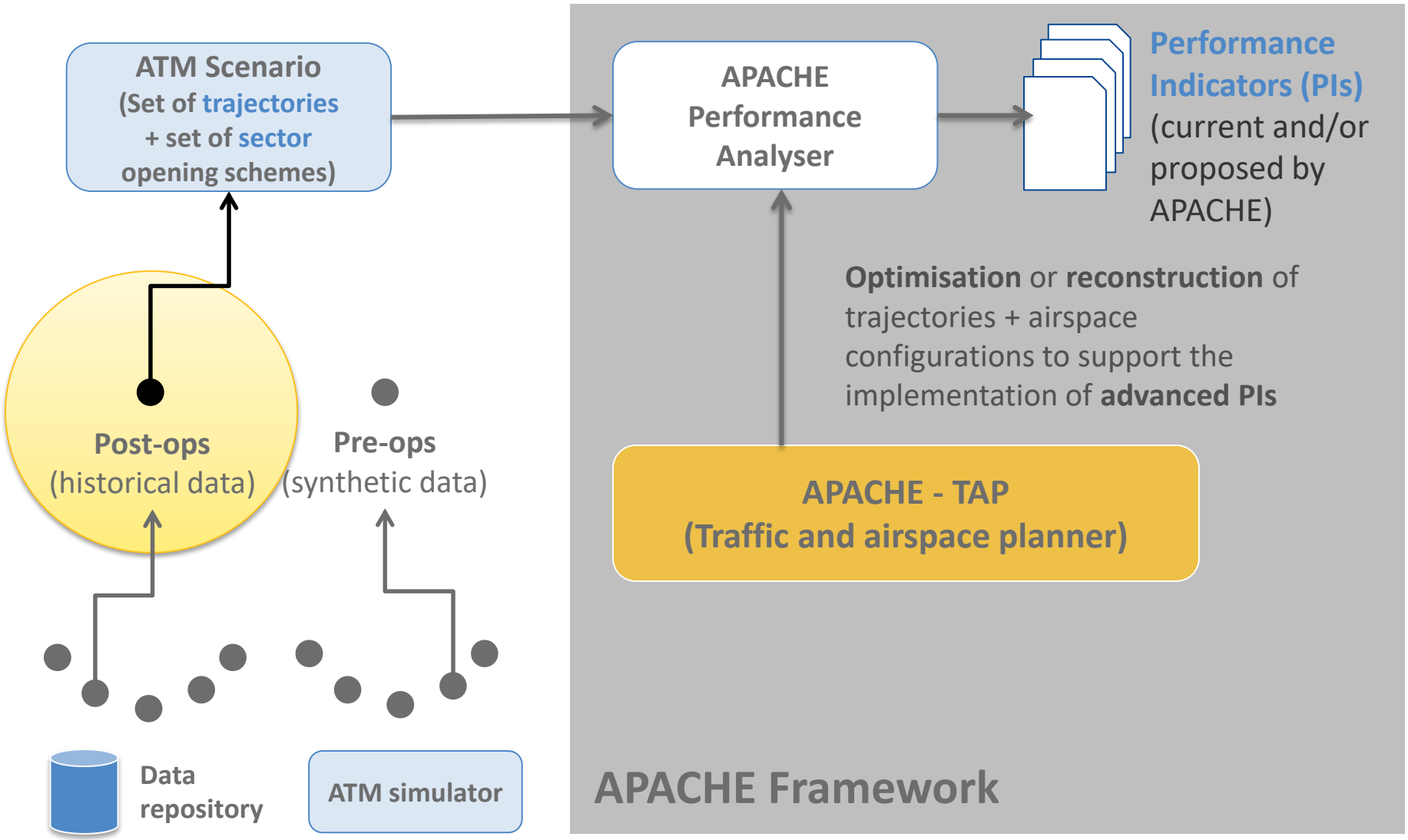
Objectives of the APACHE project

- 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.

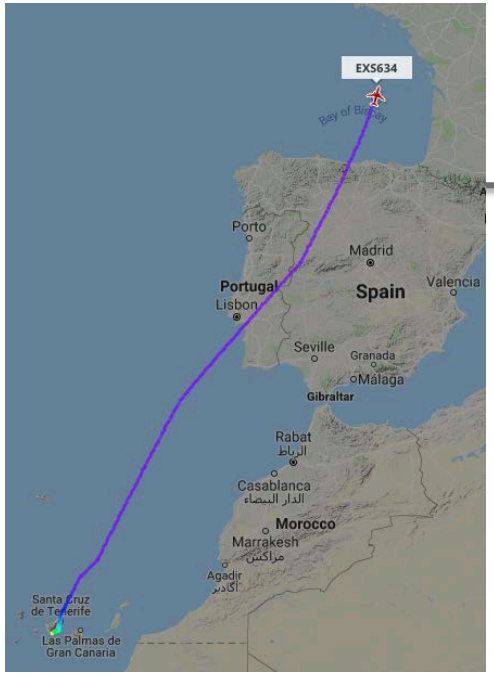
(*) Equity, Capacity, AU Cost-efficiency, ANSP Cost-efficiency, Environment, Flexibility and Safety.

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

APACHE Framework



APACHE Framework



Historical (4D) actual and planned trajectories

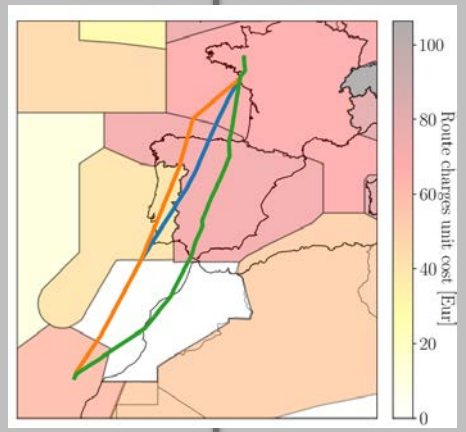
Eurocontrol DDR2

CPR from Eurocontrol PRU

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

APACHE Performance Analyser

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



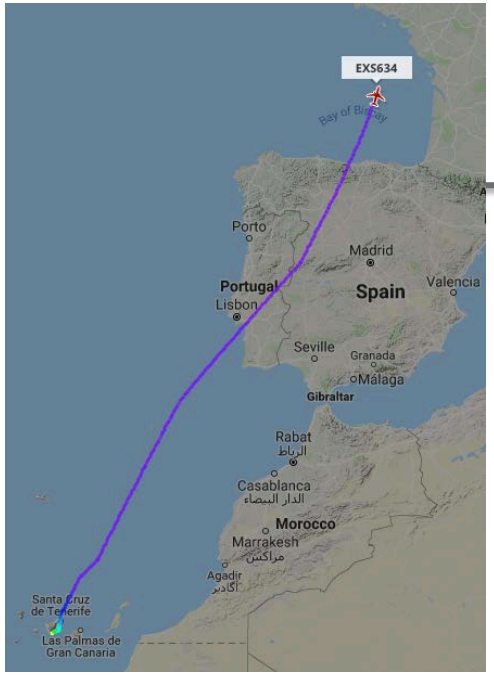
Optimal (4D) trajectory baselines

- min *Distance*
- min *Fuel*
- min *Cost* = min *(Fuel + CI·Time + Charges)*

APACHE - TAP (Traffic and airspace planner)

APACHE Framework (post-ops)

APACHE Framework



Historical (4D) actual and planned trajectories
Eurocontrol DDR2
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DDR2: Data Demand Repository 2
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ATS: Air Traffic Services

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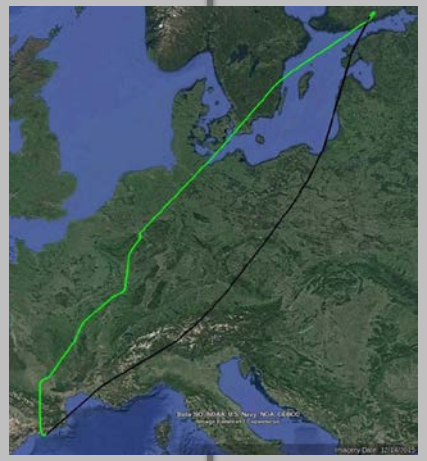


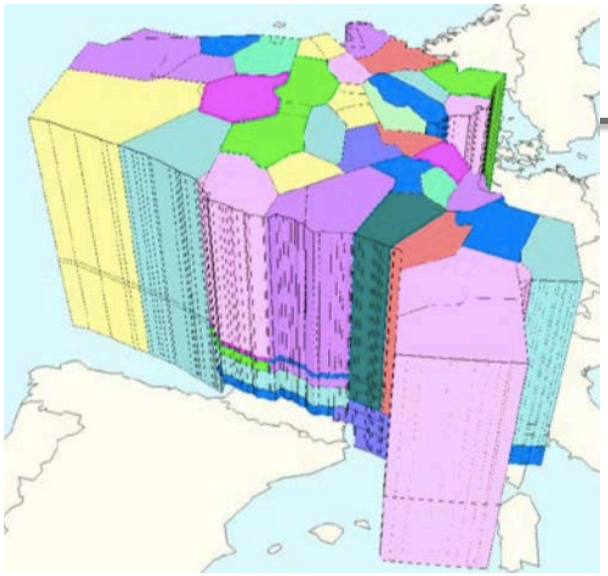
Optimal (4D) trajectory baselines

- Assuming Full Free Route
- Following published ATS routes

APACHE - TAP (Traffic and airspace planner)

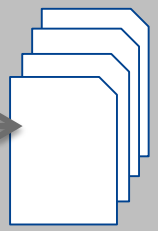
APACHE Framework (post-ops)

APACHE Framework



Historical Sectorisation
Eurocontrol DDR2
French ANSP

APACHE Performance Analyser



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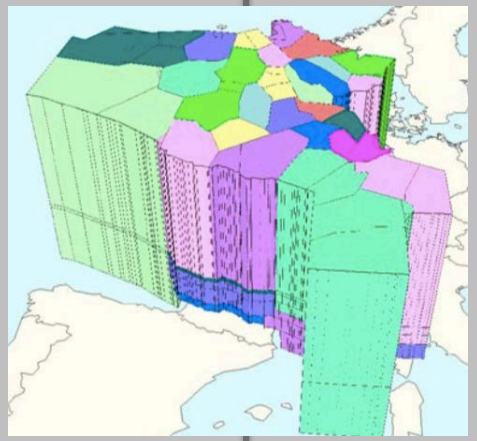


Optimal Sectorisation

Assuming current practices

Assuming Dynamic Airspace Configuration (SESAR PJ08)

APACHE - TAP (Traffic and airspace planner)

APACHE Framework (post-ops)

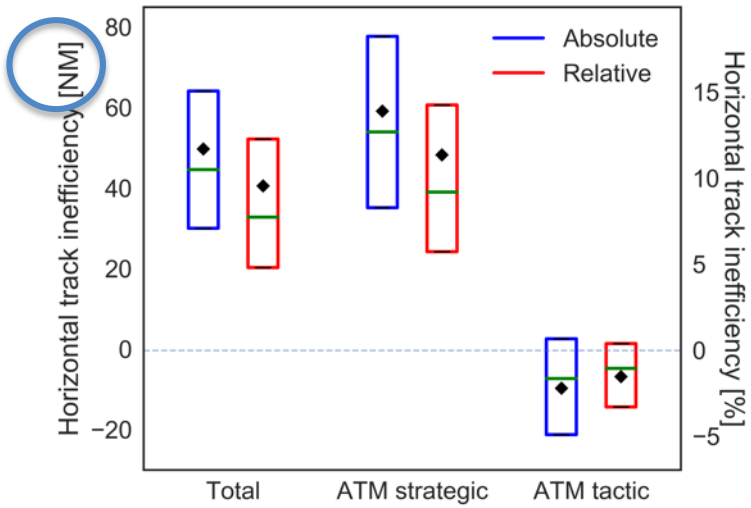
DDR2: Data Demand Repository 2
ANSP: Air Navigation Service Provider

Main findings and results

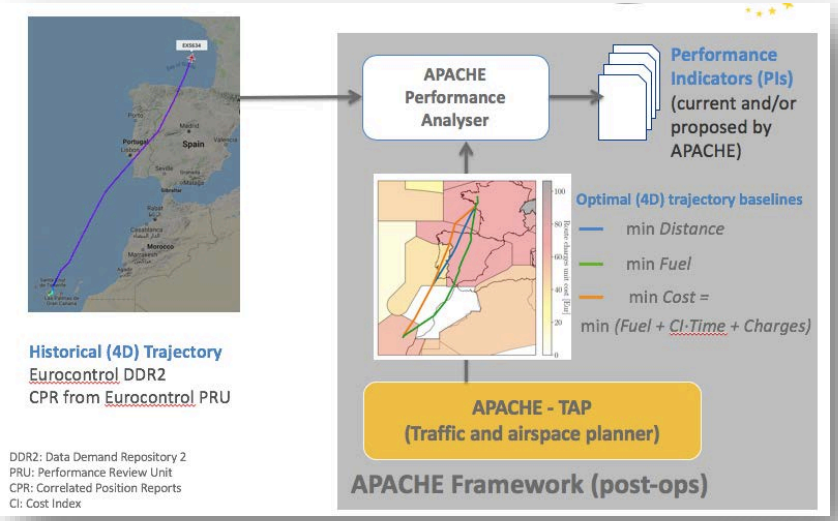
Environment KPA

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

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



Actual/Planned route distance
minus
weather **optimal[1]** route distance



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

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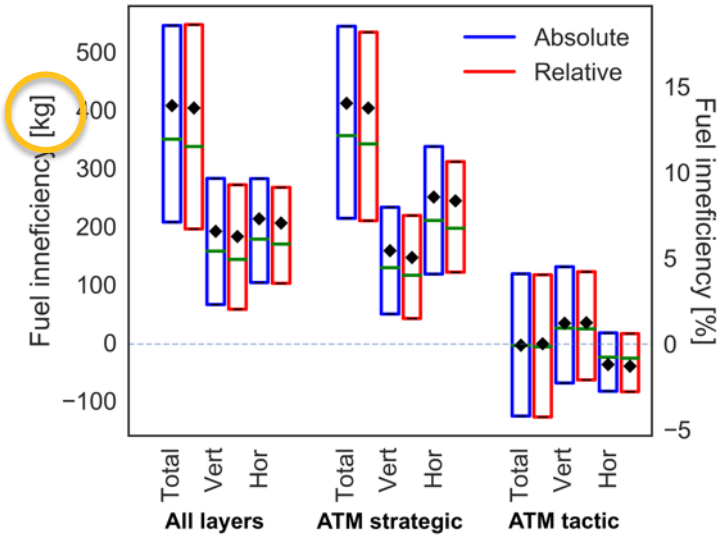
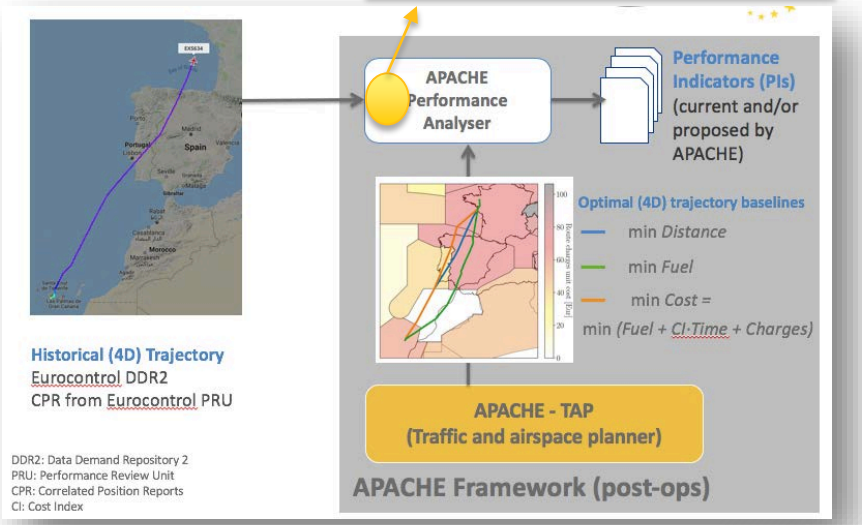


Actual/Planned trajectory *estimated* **fuel**
minus
weather **optimal[1]** trajectory **fuel**

Fuel estimation from surveillance data



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Main findings and results

Environment KPA

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

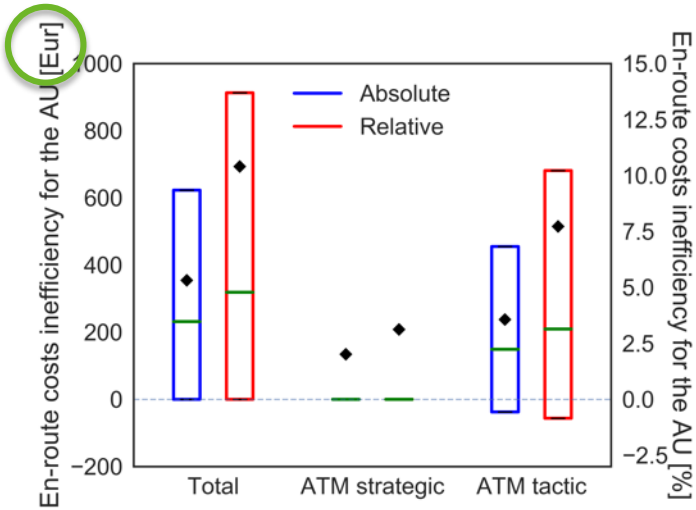
- **Distance-based** performance indicators
  - ✓ Easier to compute
  - ✓ Possibility to de-couple inefficiencies due to different ATM layers.
  - x Cannot capture the inefficiencies in the vertical domain
  - x The same ground distance inefficiency could represent different air distance inefficiency and, therefore, different fuel (and CO_2) inefficiency.
- **Fuel-based** performance indicators:
  - x More difficult to compute → require fuel estimation from surveillance data
  - ✓ Directly capture inefficiencies in fuel consumption and therefore CO_2.
  - ✓ 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

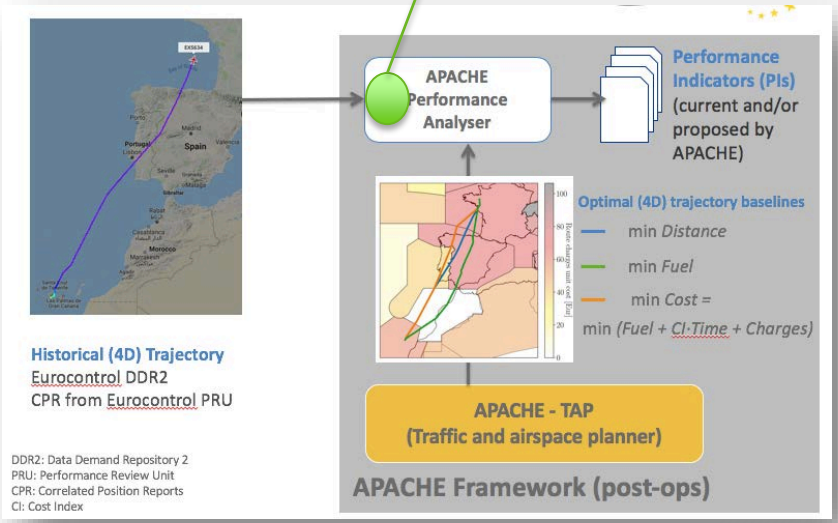
Main Contribution of APACHE: Optimal trajectory as baseline reference to compute performance indicators (PIs)

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



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

Cost estimation from surveillance data



(*) 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)

Eurocontrol, 2015 (nov). **Standard Inputs for EUROCONTROL Cost-Benefit Analyses**. *Technical Report* Ed. 7.0.

Main findings and results

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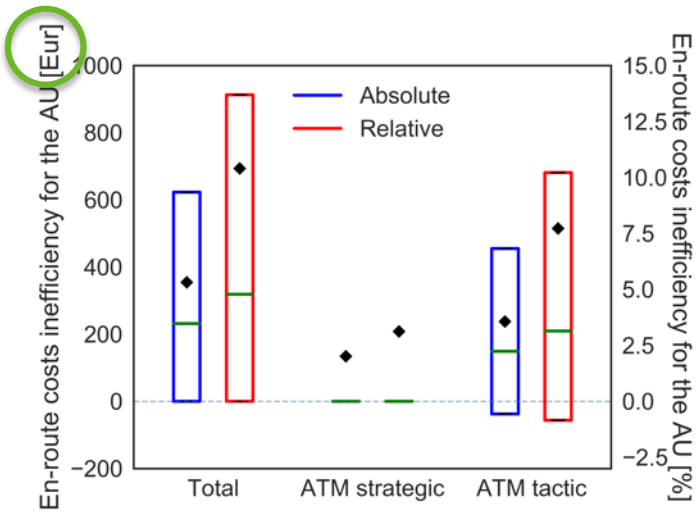

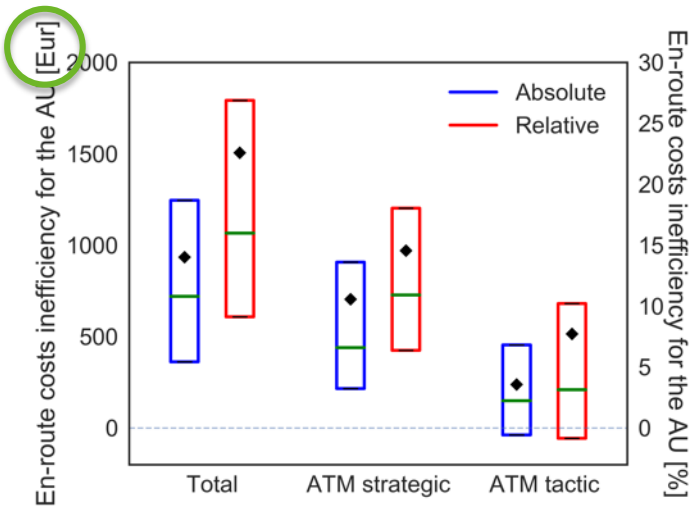

Actual trajectory *estimated* **cost** (*)
minus
Last filed flight plan *estimated* **cost** (*)

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

(*) 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)

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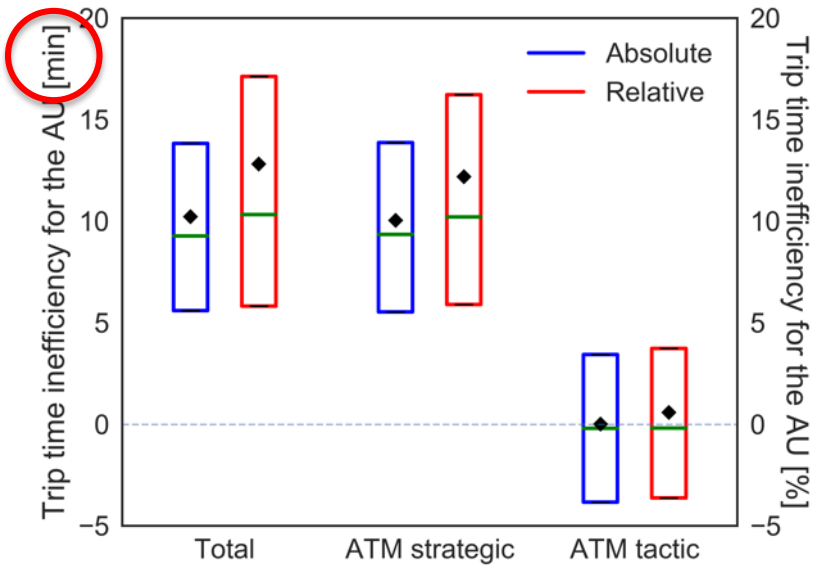
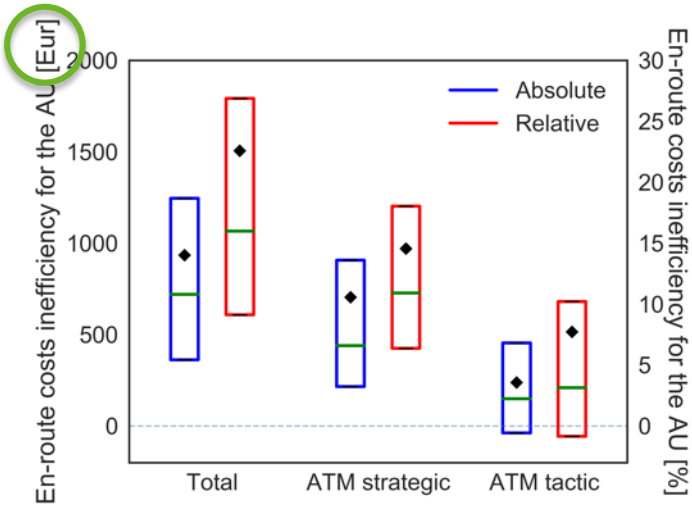




Actual trajectory *estimated* **cost** (*)
minus
Estimated **cost** of **full free route** with *estimated* Cost Index (*)

Actual trajectory **time**
minus
Full free route trajectory **time** with *estimated* CI

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)

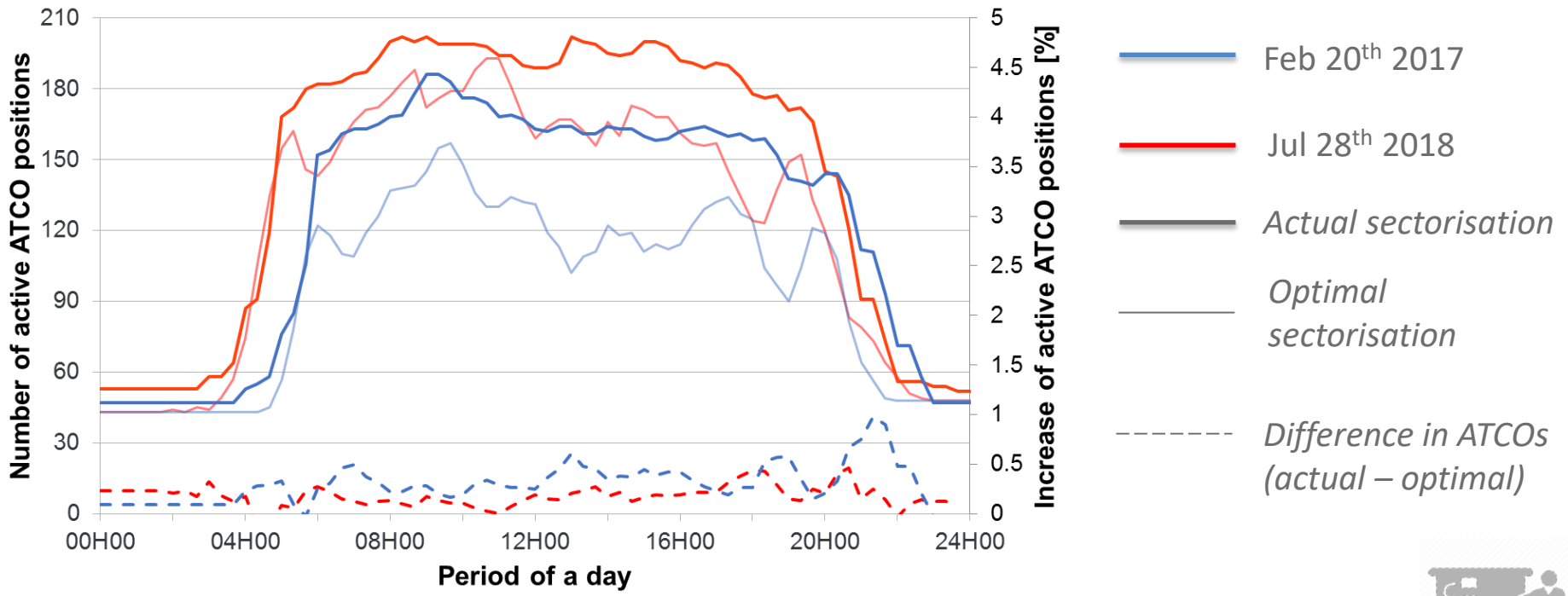
- **Cost-based** performance indicators:
  - x Difficult to compute →
    - require fuel estimation from surveillance data
    - AU's cost/business model(s): cost of time, delay, fuel, etc.
  - ✓ Possibility to de-couple vertical and horizontal trajectory inefficiencies
  - ✓ Possibility to de-couple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

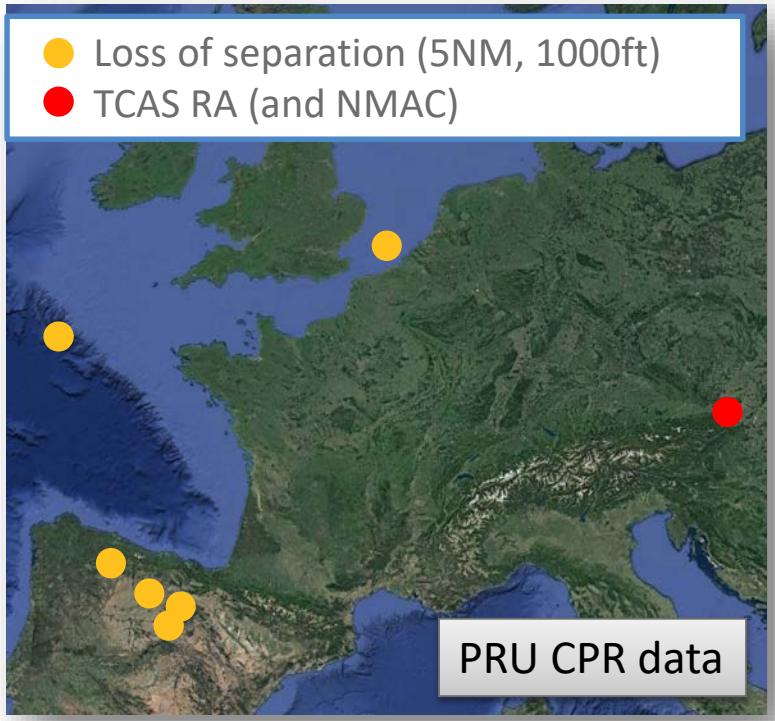


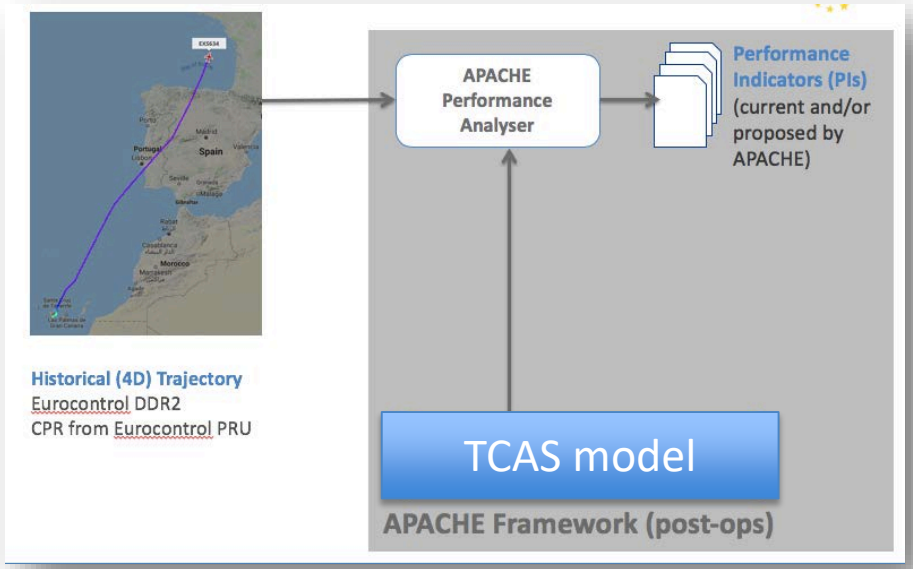
Main findings and results

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**)





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*

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

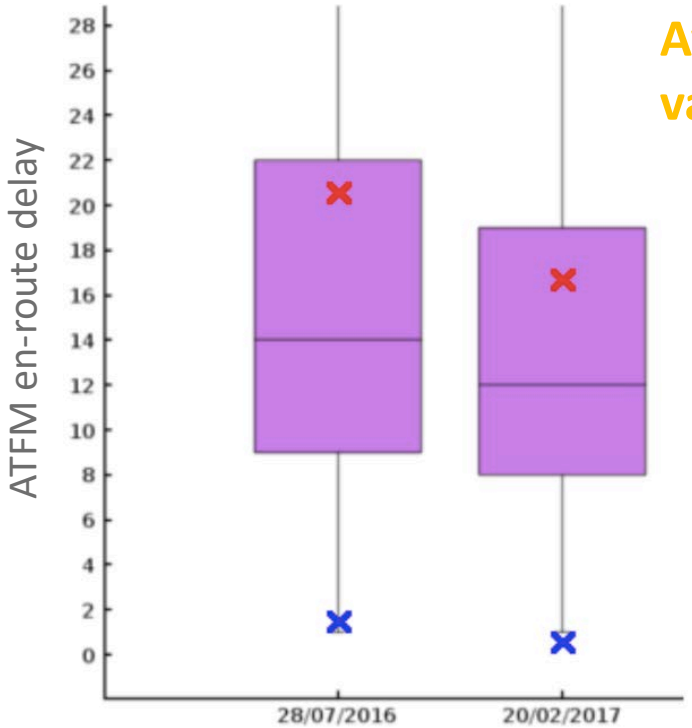
PRU: Performance review unit
CPR: Correlated position reports
DDR2: Demand data repository

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 28th 2016 + Feb 20th 2017 **post-ops**)



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

x Robust maximum en-route delay

x Average en-route delay (current indicator)

Main Contributions per KPA

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

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

X. Prats, C. Barrado, A. Vidosavljevic, D. Delahaye, F. Netjasov and D. Crnogorac. 2017 (Nov). **Assessing ATM Performance with Simulation and Optimisation Tools: The APACHE Project**. *In proceedings of the 7th SESAR Innovation Days.* SESAR JU. Belgrade (Serbia).

F. Netjasov and D. Crnogorac. 2017 (Sep). **Assessment of safety performance indicators of future air traffic management system.** *In proceedings of the XLIV Symposium on operational research*. Zlatibor (Serbia).

Dalmau, R., Melgosa, M., Vilardaga, S. and Prats, X. 2018 (Jun). **A Fast and Flexible Aircraft Trajectory Predictor and Optimiser for ATM Research Applications**. Proceedings of the 8th International Conference on Research on Air Transportation (ICRAT). Castelldefels, Catalonia

Xu, Y., Dalmau, R., Melgosa, M., de Montlaur, A. and Prats, X. 2018 (Jun). **Alternative Trajectory Options for Delay Reduction in Demand and Capacity Balancing**. Proceedings of the 8th International Conference on Research on Air Transportation (ICRAT). Castelldefels, Catalonia.

Netjasov, F. and Crnogorac, D. 2018 (Jun). **Potential Safety Occurrences as Indicators of Air Traffic Management Safety Performances: A network based simulation model**. Proceedings of the 8th International Conference on Research on Air Transportation (ICRAT). Castelldefels, Catalonia

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Enhanced Indicators to Monitor ATM Performance in Europe
Main findings of the APACHE SESAR Exploratory Research Project

Thank you very much for your attention!

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No [number]

Enhanced Indicators to Monitor ATM Performance in Europe
Main findings of the APACHE SESAR Exploratory Research Project

Backup Slides

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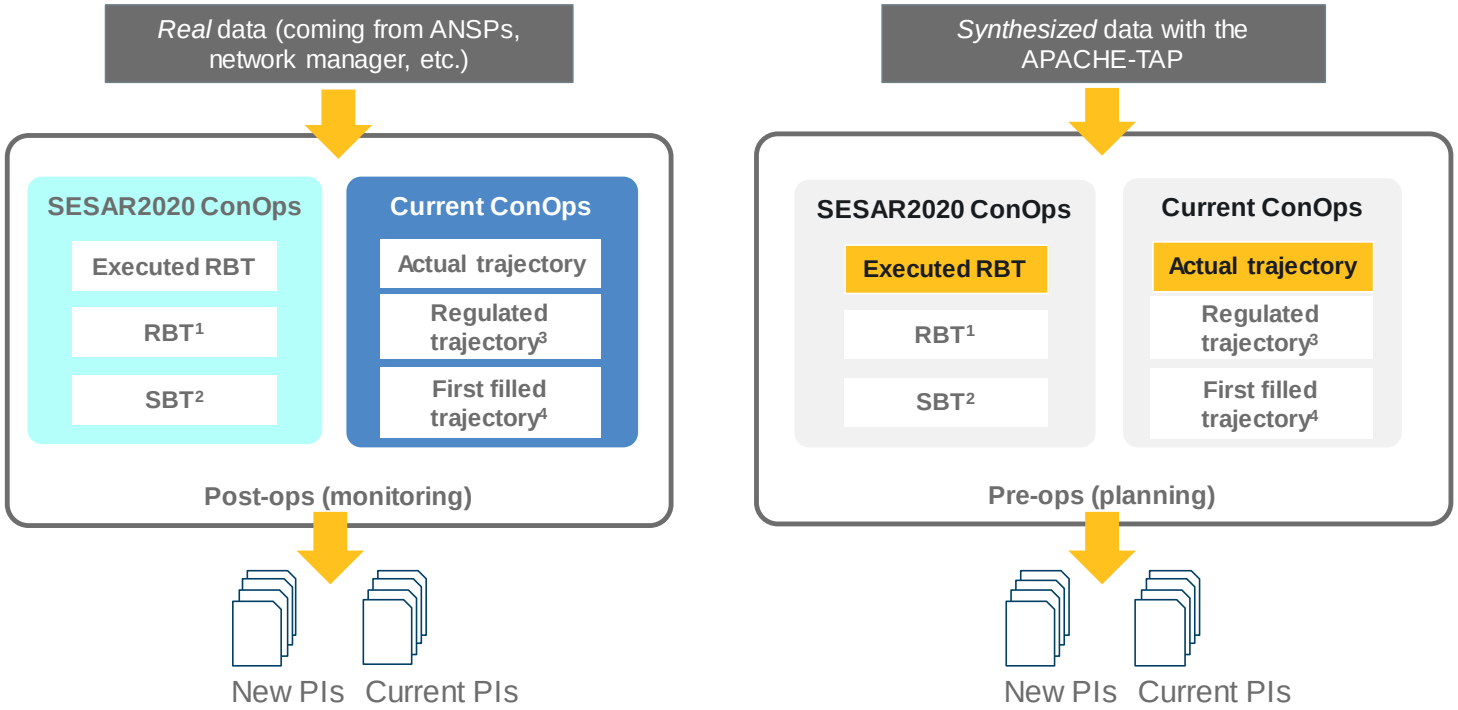
Scope of the research



Out of scope of PACHE because we don't have REAL data of future ConOps because were 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.

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).

- [1] Referring to the "first" RBT i.e. the "last" SBT
- [2] Referring to the "first" SBT (as submitted initially by the AU before staring 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).

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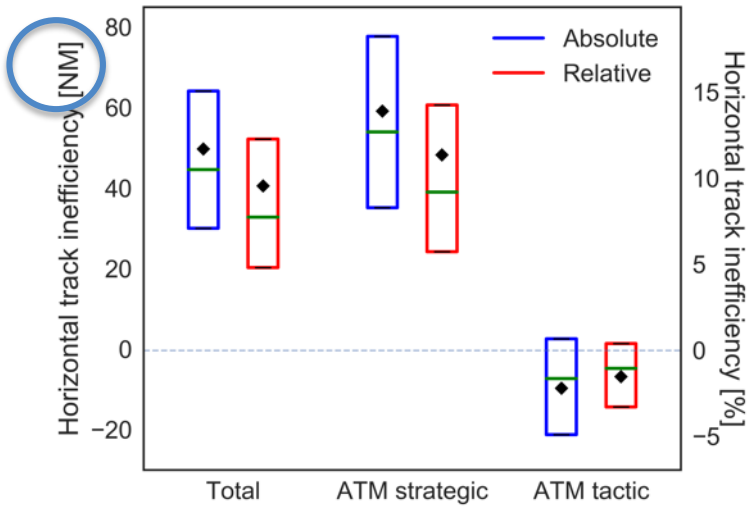
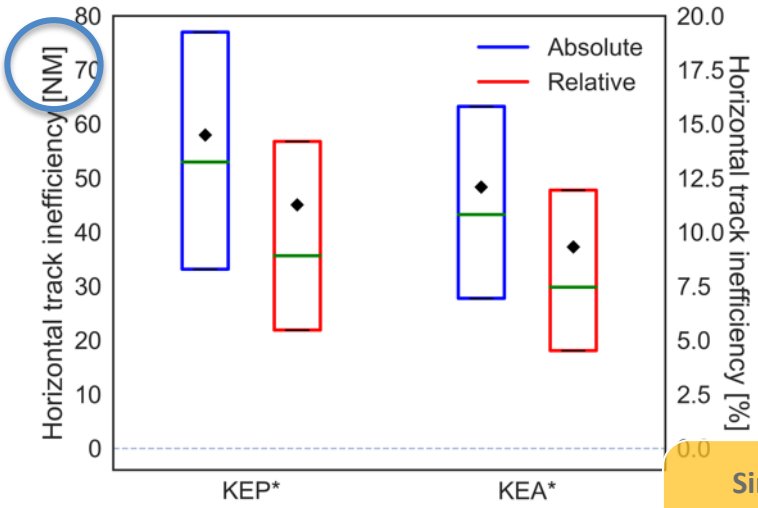


Actual/Planned route distance
minus
weather **optimal[1]** route distance



Actual/Planned route distance
minus
OD **geodesic** distance

OD: origin-destination

Similar to current SES PRU indicators

[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

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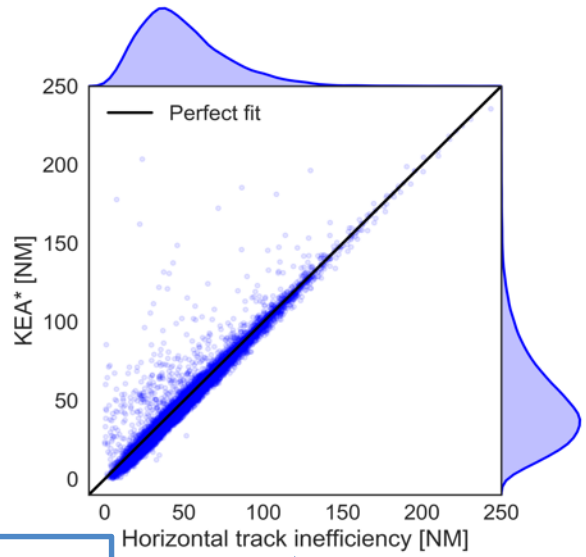

Actual route distance
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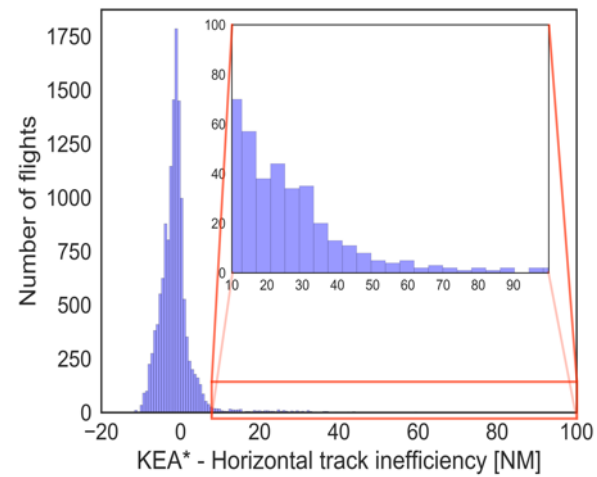

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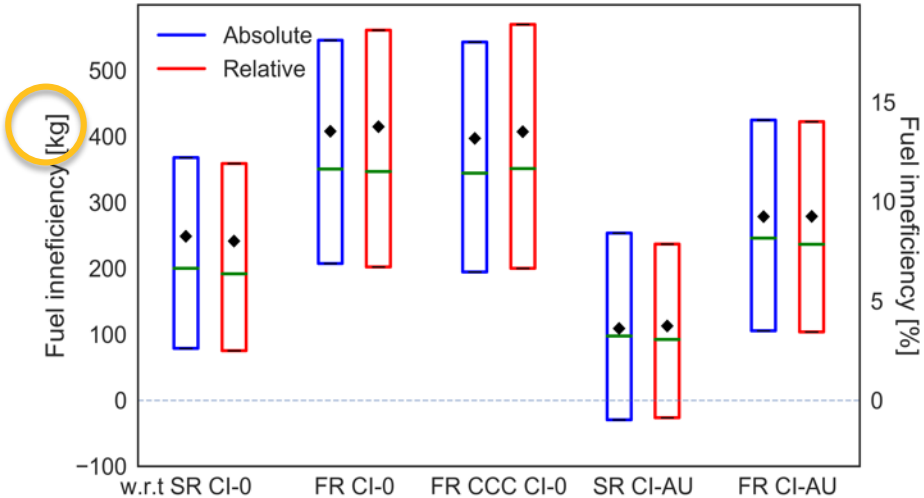


Actual trajectory *estimated* **fuel**
minus
weather **optimal[1]** trajectory **fuel**

- *[1] But… what is the "best" trajectory?*
- *And what about environmental inefficiencies **due** to the Airspace User (AU)?*

[1] **Different optimal baseline trajectories computed in the following conditions:**

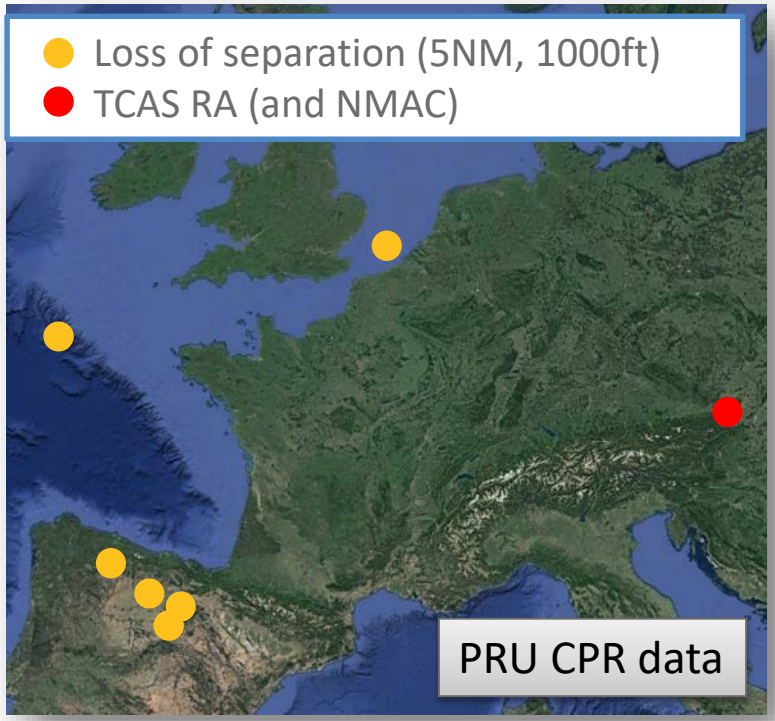
- **FR CI=0**: Full free route airspace and maximum range operations (Cost Index =0)
- **SR CI=0**: Current structured route airspace and maximum range operations
- **FR CCC CI=0:** Full free route airspace, continuous cruise climbs and maximum range operations
- **SR CI-AU**: Current structured route airspace and Cost Index chosen by the Airspace User
- **FR CI-AU**: Full free route airspace and Cost Index chosen by the Airspace User

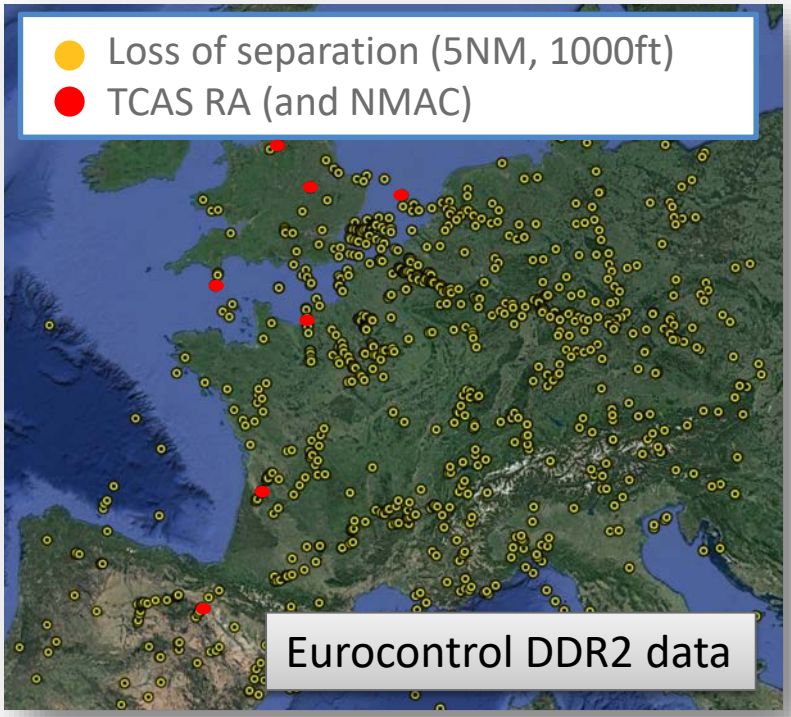
Main findings and results

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**)





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

Scenarios → APACHE-TAP → Performance analyser

Performance analyser

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

→ KPA assessment

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**)

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

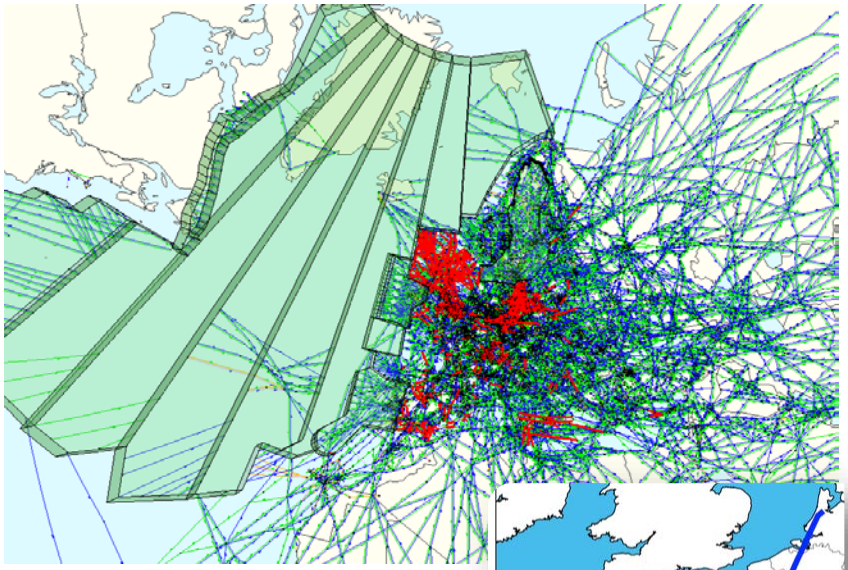
More details in **Deliverables D2.1** and **D3.2** available in the **APACHE public web site**: http://apache-sesar.barcelonatech-upc.eu/

APACHE trajectory and airspace planner

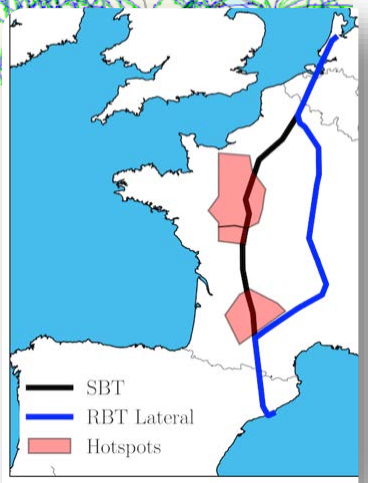
TP: Trajectory Planner

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**



Dalmau, R., Melgosa, M., Vilardaga, S. and Prats, X. 2018 (Jun). **A Fast and Flexible Aircraft Trajectory Predictor and Optimiser for ATM Research Applications**. Proceedings of the 8th International Conference on Research on Air Transportation (ICRAT). Castelldefels, Catalonia

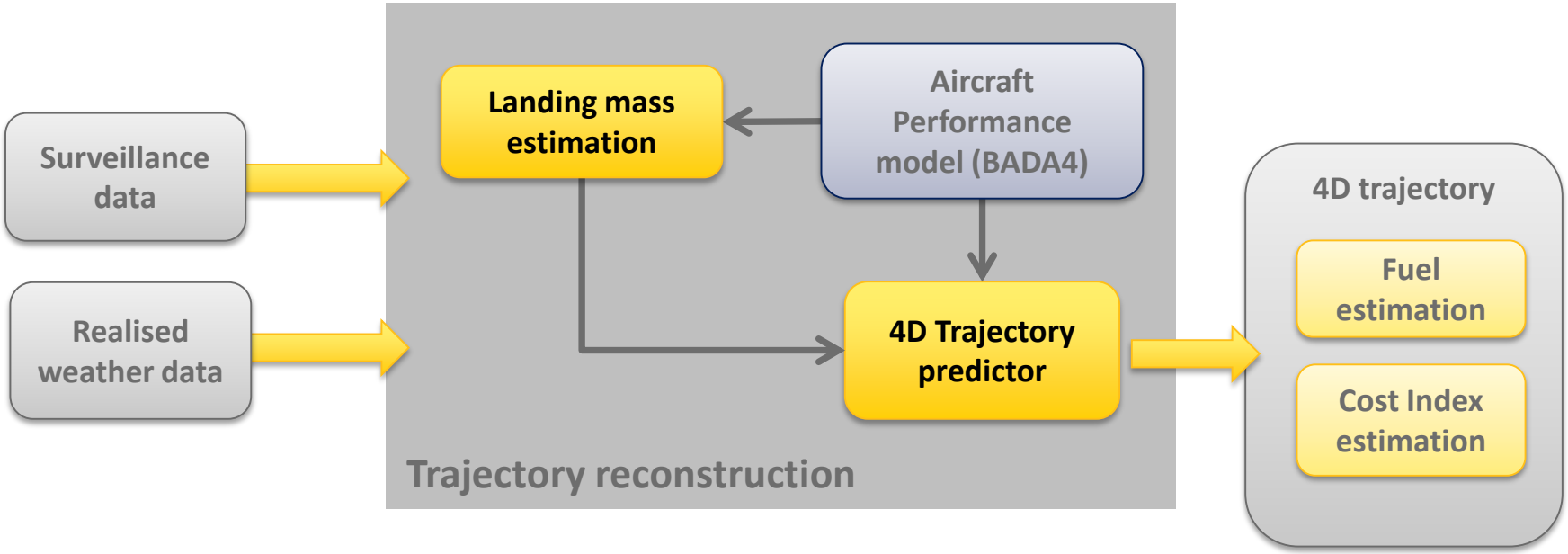
FRA: Free Route Areas

APACHE trajectory and airspace planner

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

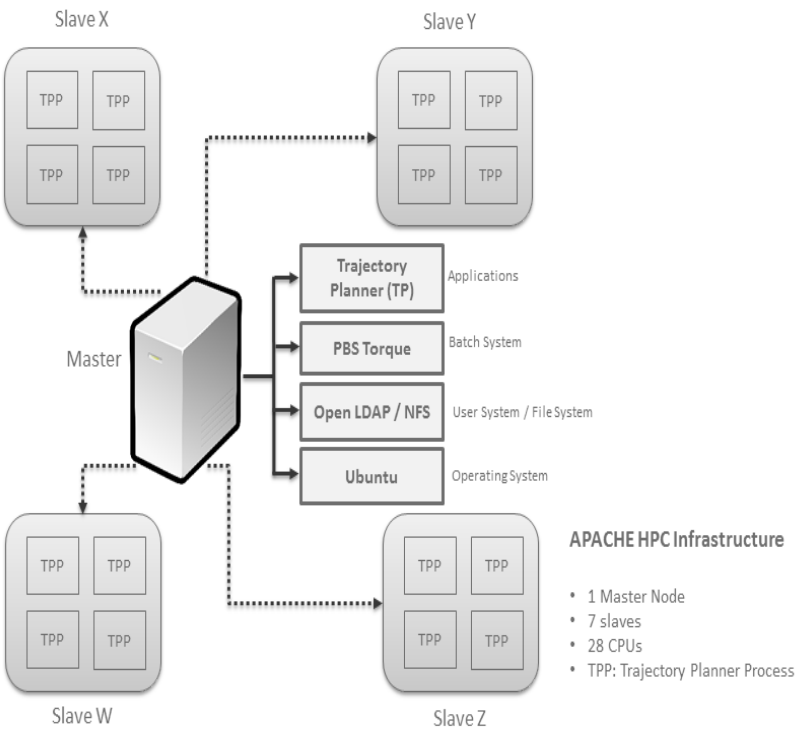


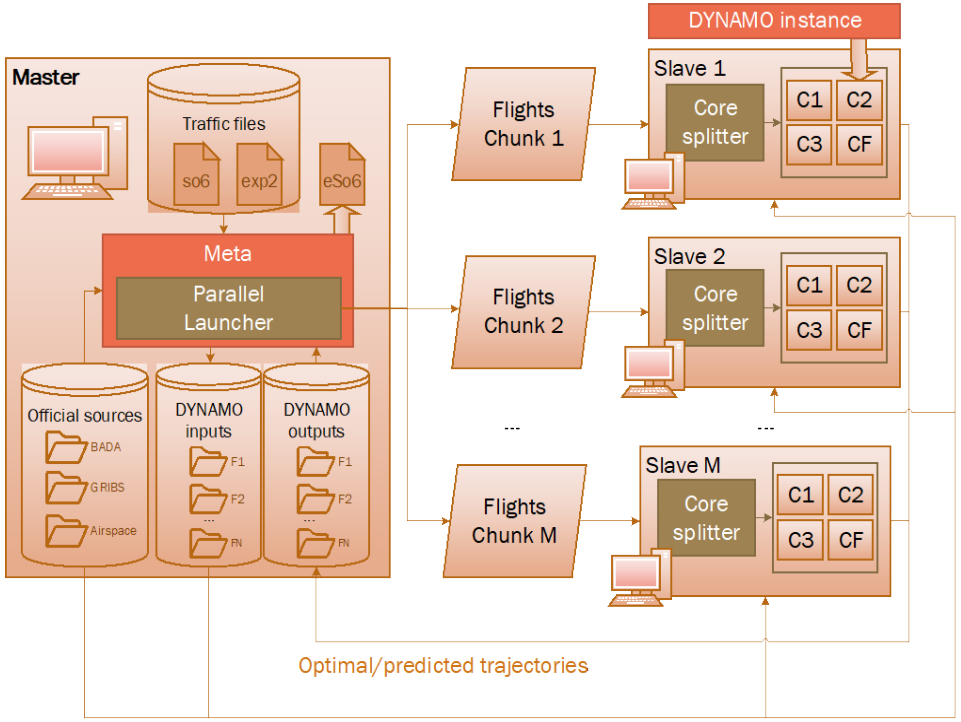
AU: Airspace User
BADA: Base of Aircraft Data
ADS-B: Automatic Dependent Surveillance – Broadcast

APACHE trajectory and airspace planner

TP: Trajectory Planner

Computer cluster



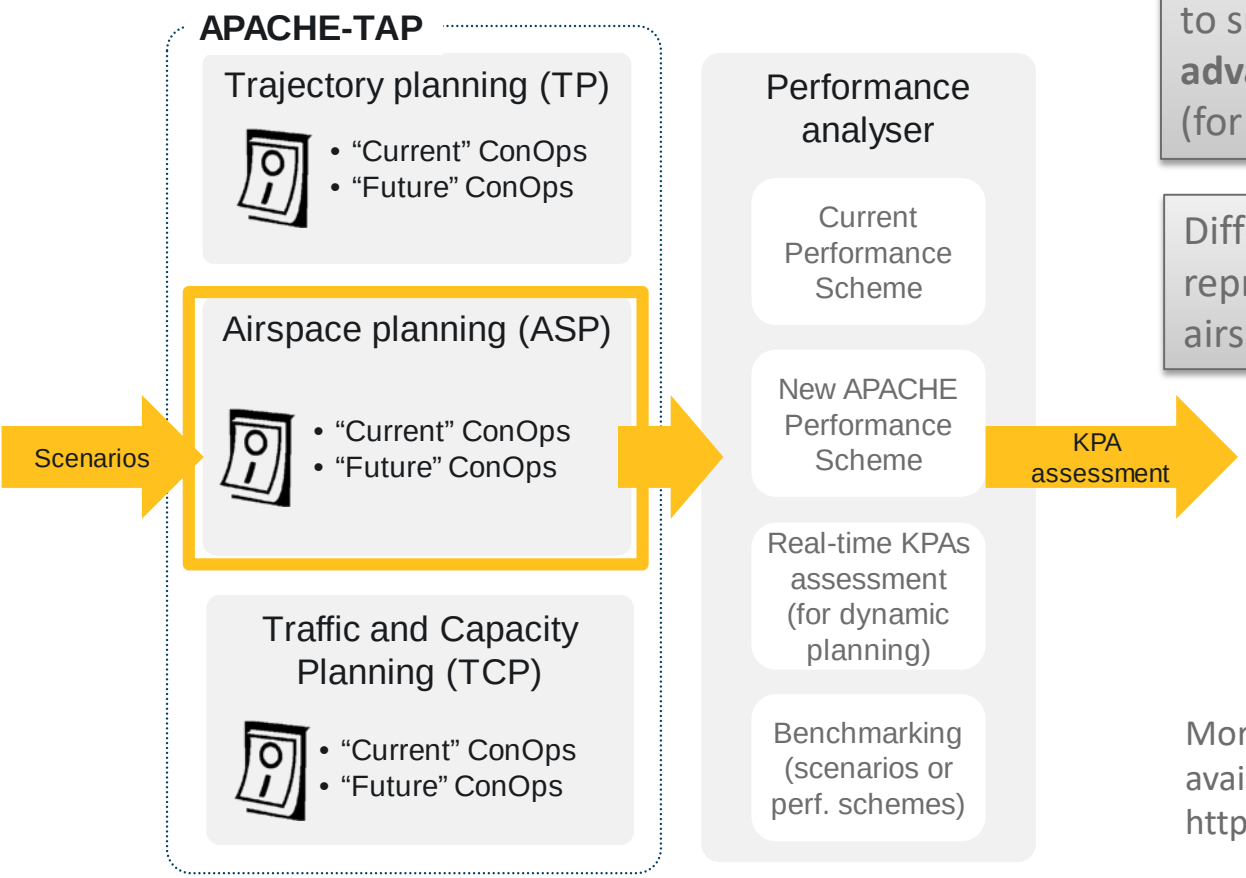


More than 1M trajectories will be simulated (optimised) in APACHE

FRA: Free Route Areas

APACHE trajectory and airspace planner

APACHE Framework



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**)

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

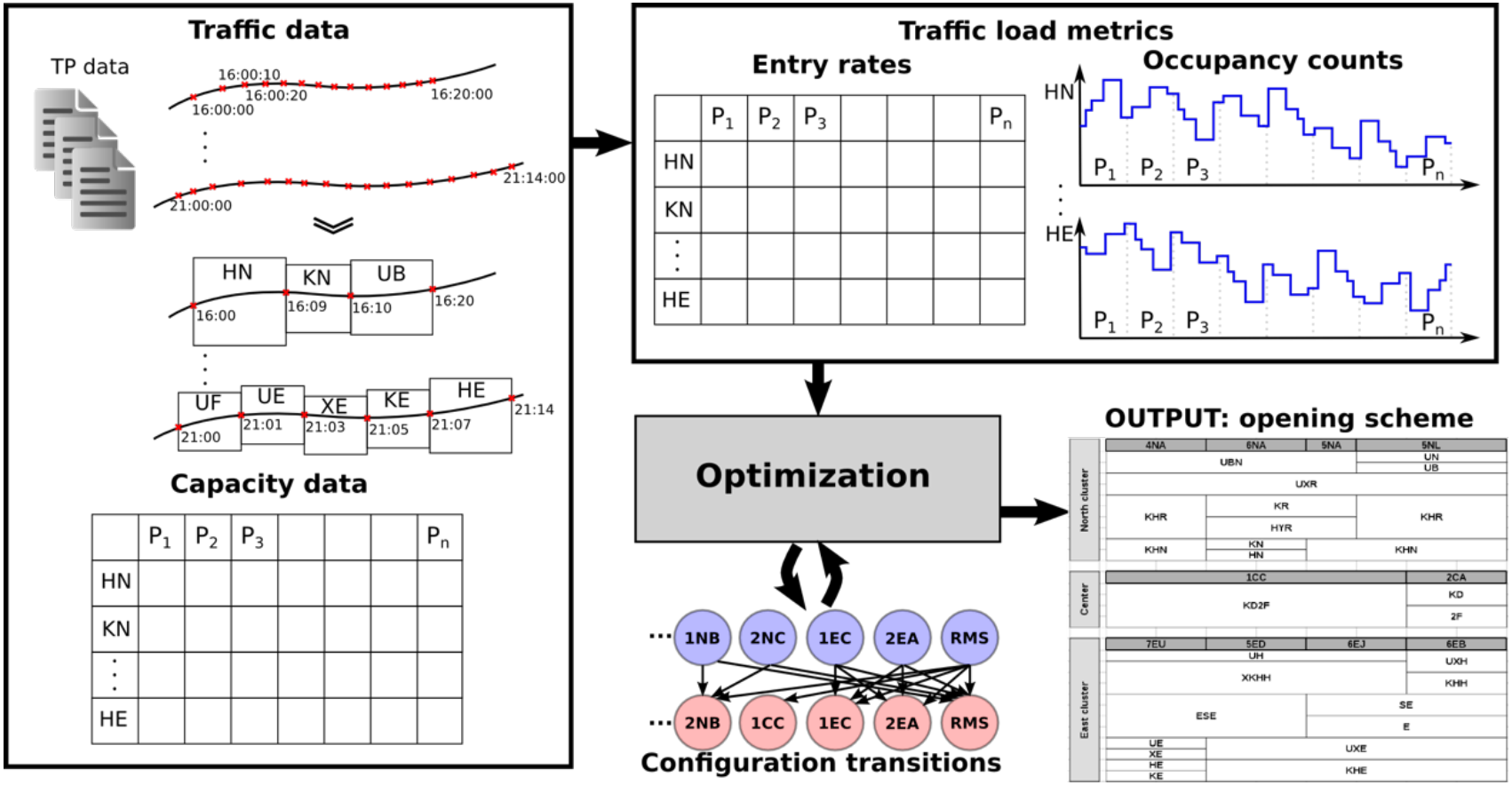
ASP: Airspace Planner ("Current ConOPS"):

- Replicate the work done by FMP for each ACCs
- Given a traffic demand and time period → 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

APACHE trajectory and airspace planner

ASP: Airspace Planner ("Current ConOPS"):



APACHE trajectory and airspace planner

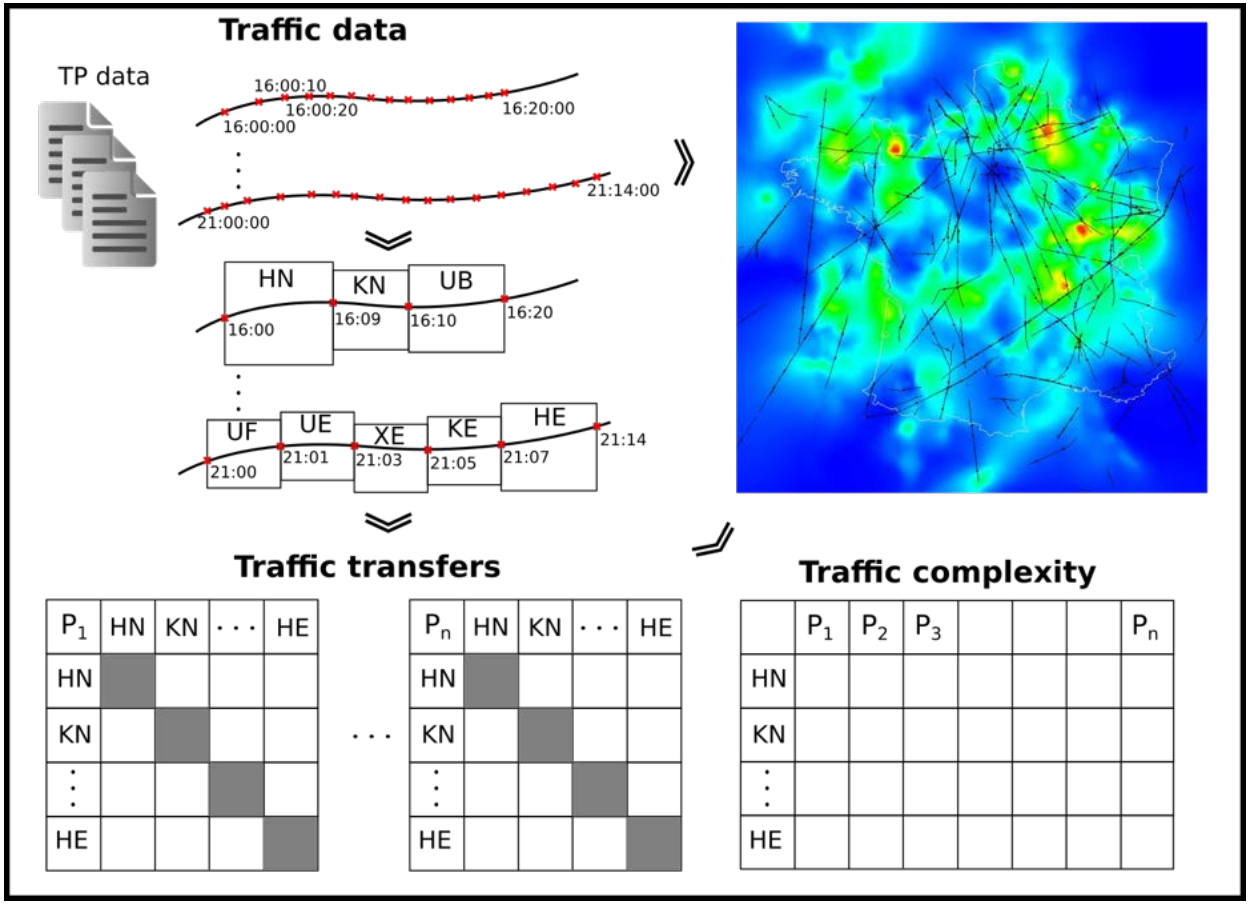
ASP: Airspace Planner ("Future ConOPS"):

- 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"):



APACHE trajectory and airspace planner

ASP: Airspace Planner ("Future ConOPS"):