



Assessing ATM performance with simulation and optimisation tools: The APACHE Project

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APACHE Doc: DIS_WP6-09



Founding Members



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
- May 2016 – May 2018



<http://apache-sesar.barcelonatech-upc.eu/>

@Apache_SESAR

Objectives of the APACHE project



- New framework to assess European ATM performance based on **simulation, optimisation** and **performance assessment tools**.
- **Fill some gaps in current state of the art** methodologies in ATM performance assessment aiming to better capture:
 - the performance impact of ATM operations on different stakeholders taking into account a **wide range of KPAs**
 - the complex **interdependencies** and **trade-offs** among different KPAs

ATM: Air Traffic Management

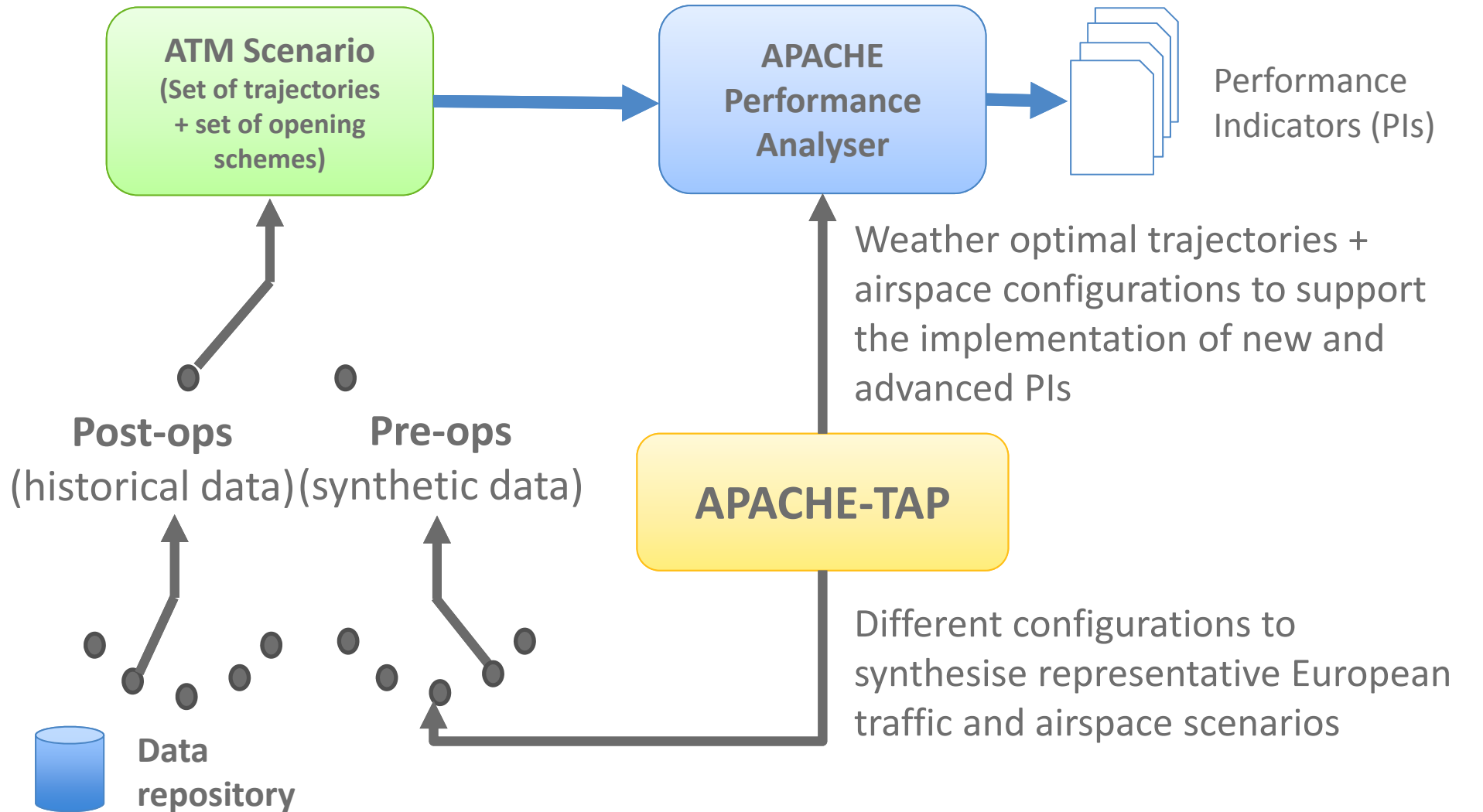
KPA: Key Performance Area

Objectives of the APACHE project



- The specific objectives of the APACHE project are:
 - o To propose **new metrics and indicators** capable of effectively capturing European ATM performance under either **current or future concepts of operation**.
 - o To make a preliminar **impact assessment** of some **SESAR 2020 solutions** (PJ06, PJ07-01, PJ08 and PJ09) using the new APACHE Performance Framework along different KPAs.
 - o To **analyse the interdependencies** between the different KPAs by capturing the **Pareto-front of ATM performance**, and finding the theoretical optimal limits for each KPA.

Methodology and Approach



TAP: Traffic and Airspace Planner

New Performance Indicators (PIs)



ID	Performance Indicator	ID	Performance Indicator
AEQ-1	Percentage of RBTs which are equal to 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	The percentage of RBTs equal to 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	Sectorization 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 route	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

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

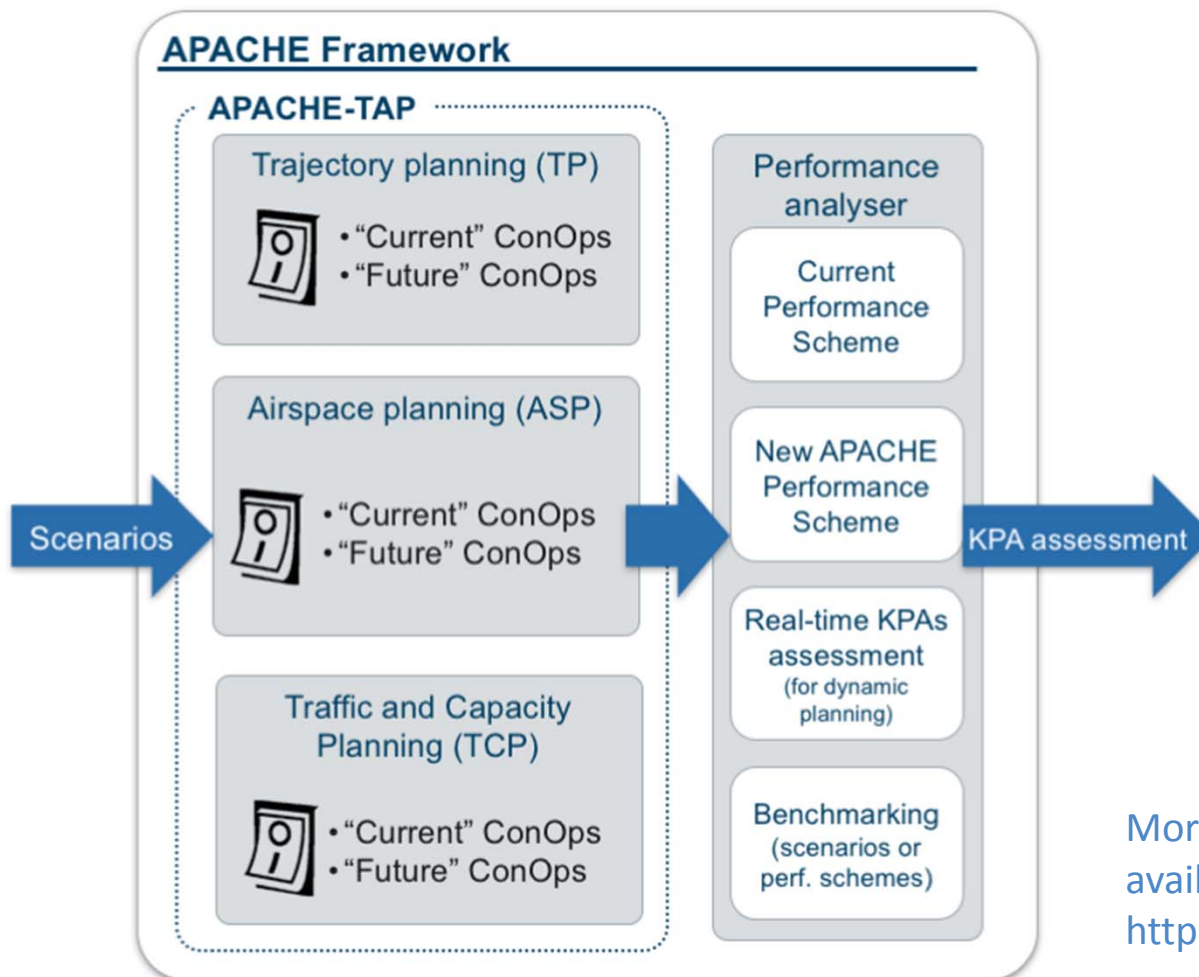
APACHE new (or enhanced) PIs:

- 40 PIs and 18 variants initially proposed
- 25 PIs and 17 variants finally selected for implementation
- Access and Equity: 5 PIs
- Capacity: 3 PIs
- Cost-effectiveness: 3 PIs + 3 variants
- Environment: 2 PIs + 10 variants
- Flexibility: 4 PIs
- Safety: 7 PIs + 4 variants
- Participation: 1 PI

More details in **Deliverable D3.1** available in the **APACHE public web site**:

<http://apache-sesar.barcelonatech-upc.eu/>

APACHE trajectory and airspace planner (APACHE-TAP)



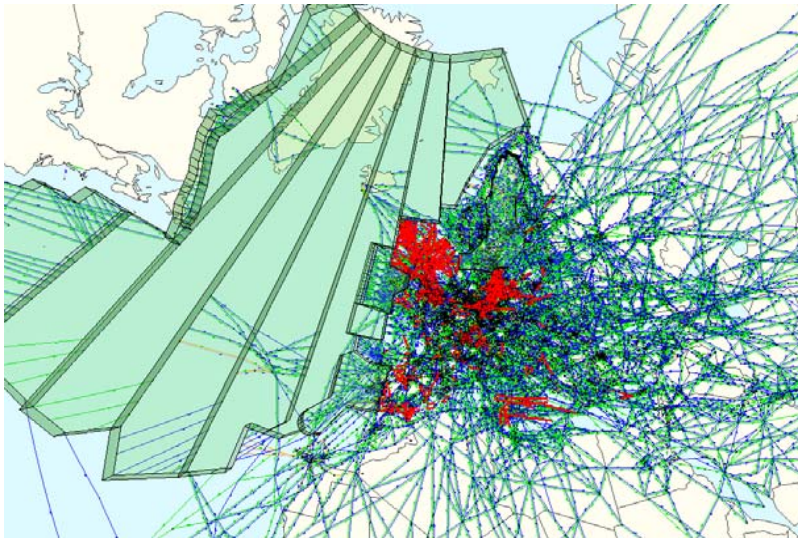
More details in **Deliverables D2.1 and D3.2** available in the **APACHE public web site**:
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APACHE trajectory and airspace planner (APACHE-TAP)

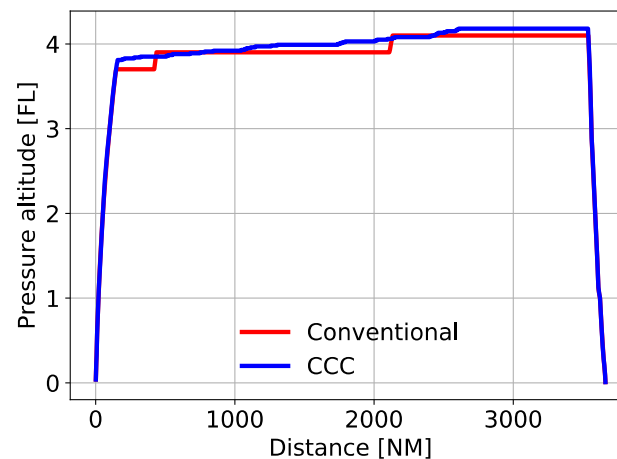


TP: Trajectory Planner

- “Current ConOPS” → Current route including FRA
- “Future ConOPS” → Full free route from origin/destination (theoretical limit of PJ06) + eventually CCC



TP uses network and FRA definition data from Eurocontrol's DDR2



FRA: Free Route Areas
CCC: Continuous Cruise Climbs

APACHE trajectory and airspace planner (APACHE-TAP)

TP: Trajectory Planner

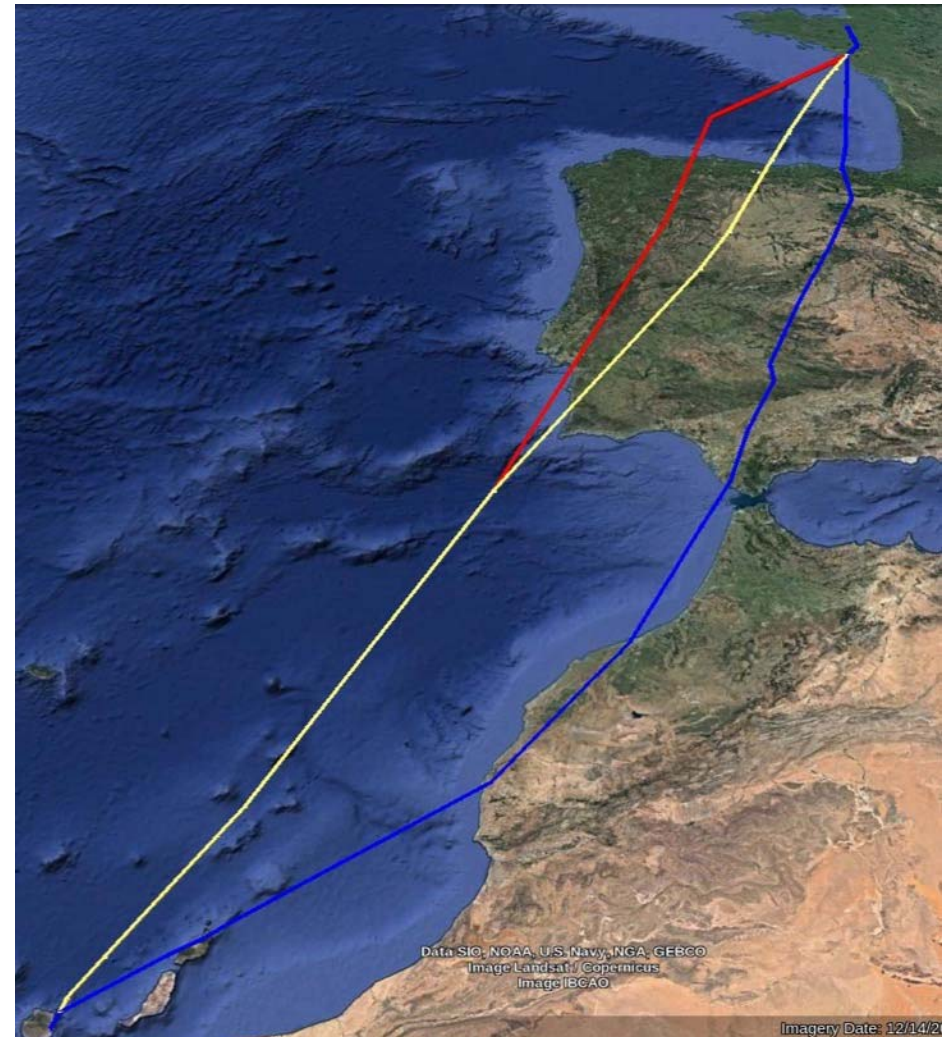
Optimal trajectories considering realistic cost for Airspace Users:

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

 min *Distance*
 min *Fuel*

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

CI: Cost Index



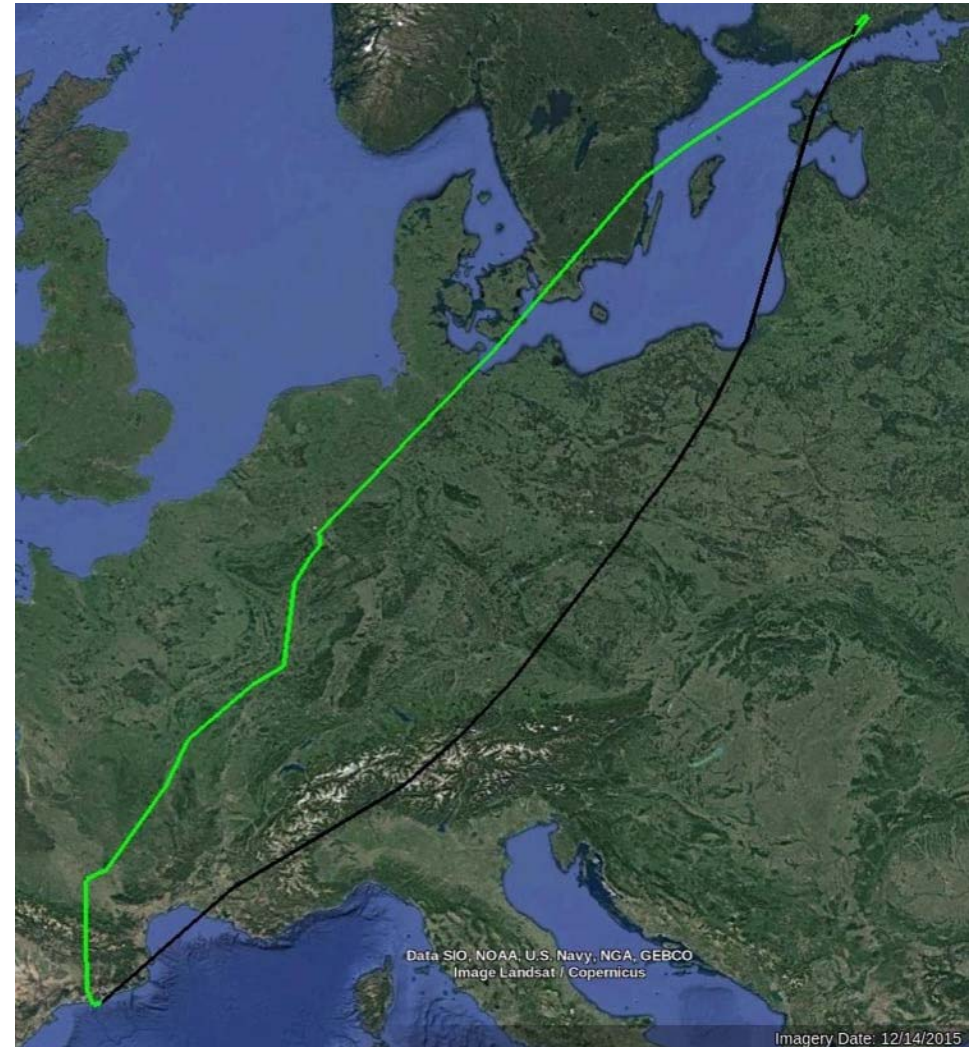
APACHE trajectory and airspace planner (APACHE-TAP)

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)

- Current route structure + FRA
- Full free route from Origin to Destination



APACHE trajectory and airspace planner (APACHE-TAP)



ASP: Airspace planner: “current ConOps”

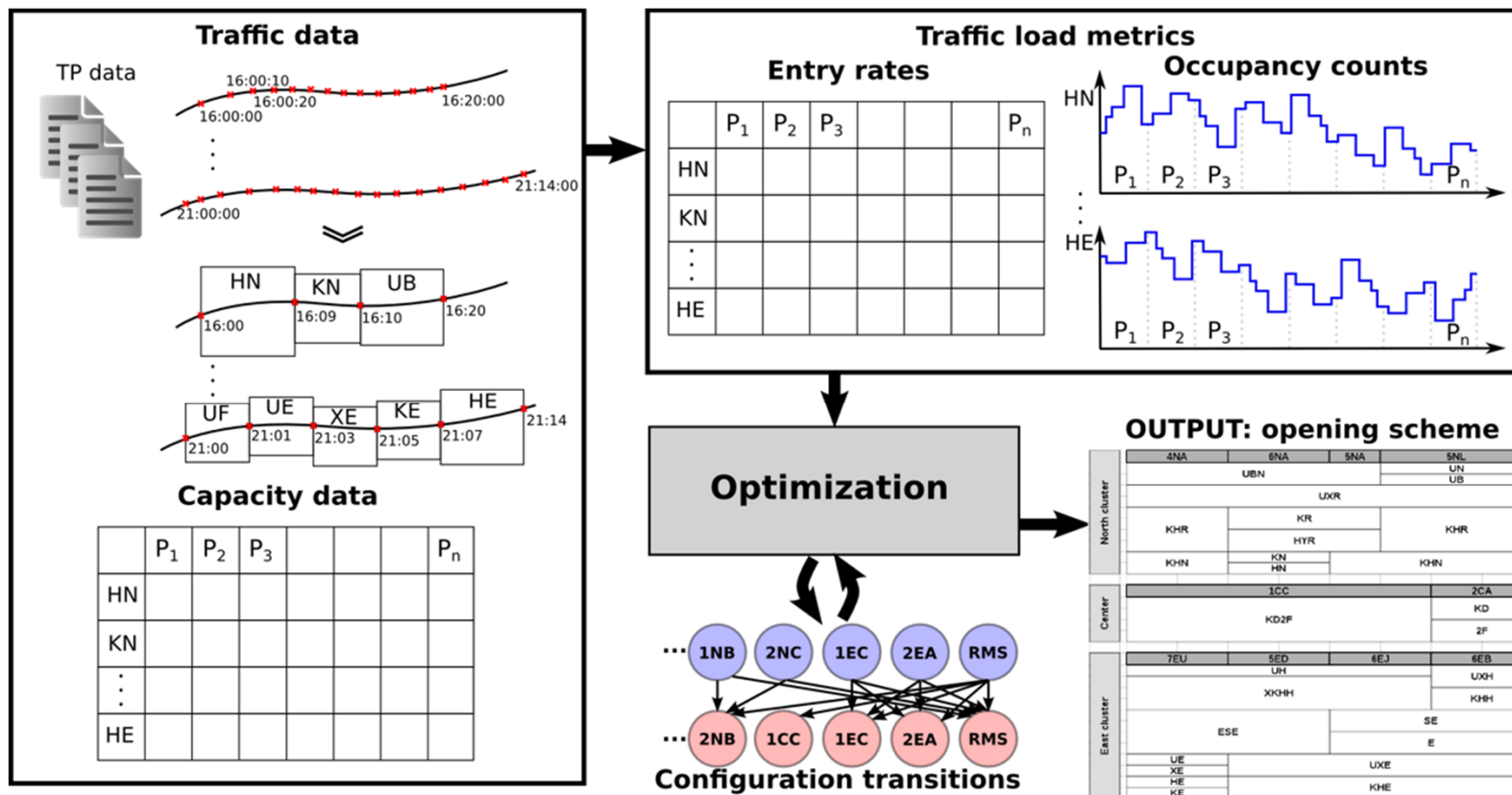
- Replicate the work done by FMP for each ACCs
- Given a traffic demand and time period → **optimal opening scheme minimising the number of open sectors and providing the best overall load balance**
- Minimize sector underloads; while limiting (avoiding) overloads and considering a comprehensive set 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 (APACHE-TAP)

ASP: Airspace planner: "current ConOps"



APACHE trajectory and airspace planner (APACHE-TAP)

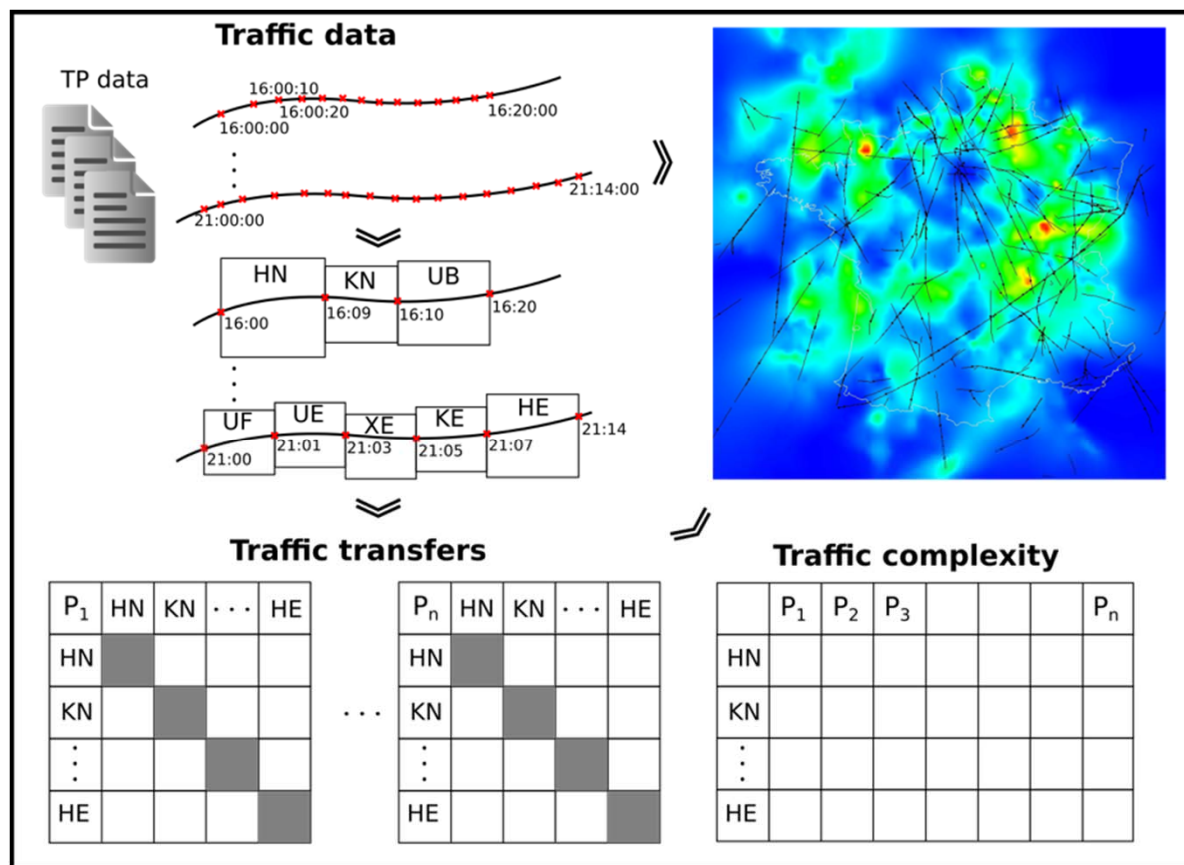


ASP: Airspace planner: "future ConOps"

- **SESAR solution PJ08: Dynamic airspace configuration (DAC)**
- 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

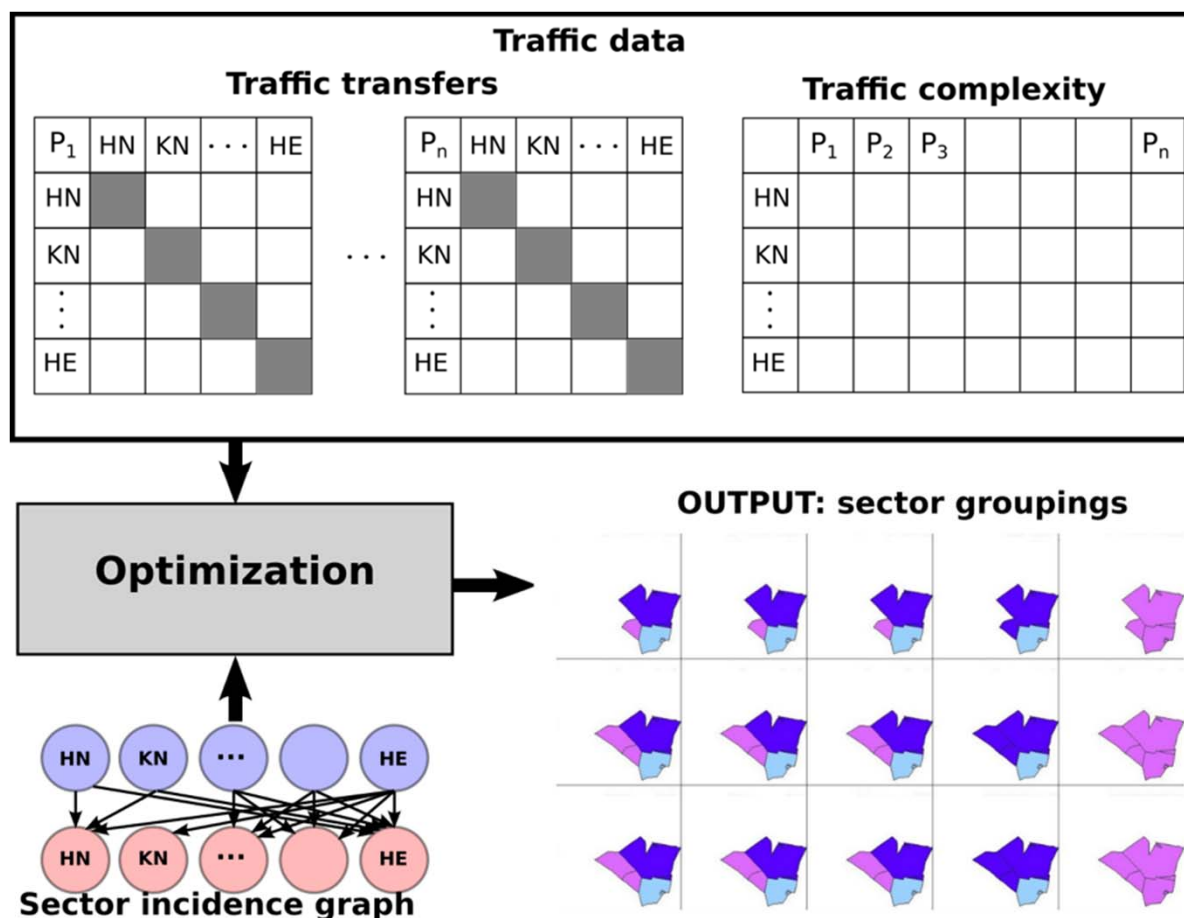
APACHE trajectory and airspace planner (APACHE-TAP)

ASP: Airspace planner: "future ConOps"



APACHE trajectory and airspace planner (APACHE-TAP)

ASP: Airspace planner: "future ConOps"



APACHE trajectory and airspace planner (APACHE-TAP)



TCP: Traffic and Capacity Planner

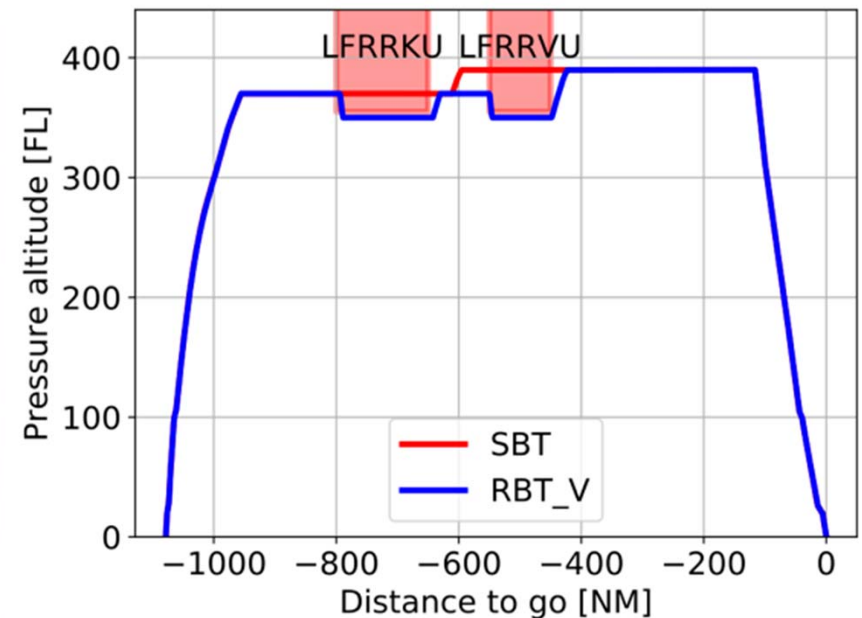
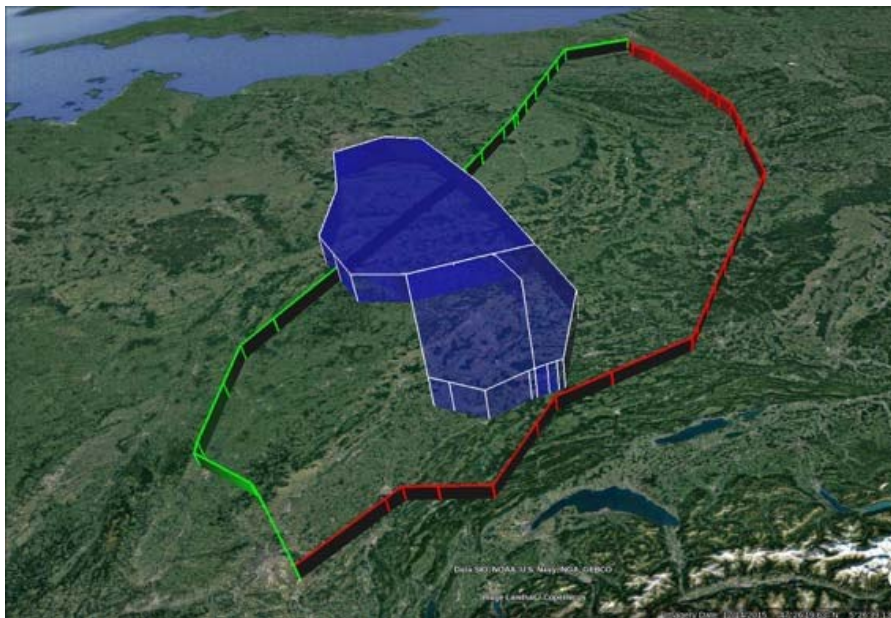
- “Current ConOPS” → ATFM with delays (CASA algorithm)
- “Future ConOPS” → Advanced DCB (theoretical limits of PJ09)
- Advanced DCB algorithm:
 - Minimises the **total system cost** (sum of all trajectory costs), such that the maximum **capacity** at all sectors is not exceeded.
 - Considering **cost of fuel and cost of delay**.
 - Considering for each concerned flight:
 - o Original trajectory (+ delay)
 - o Horizontal re-route (+ delay)
 - o Vertical “re-route” (+ delay)

APACHE trajectory and airspace planner (APACHE-TAP)



TCP: Traffic and Capacity Planner

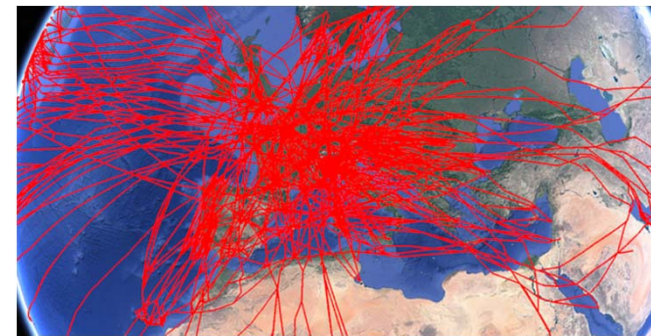
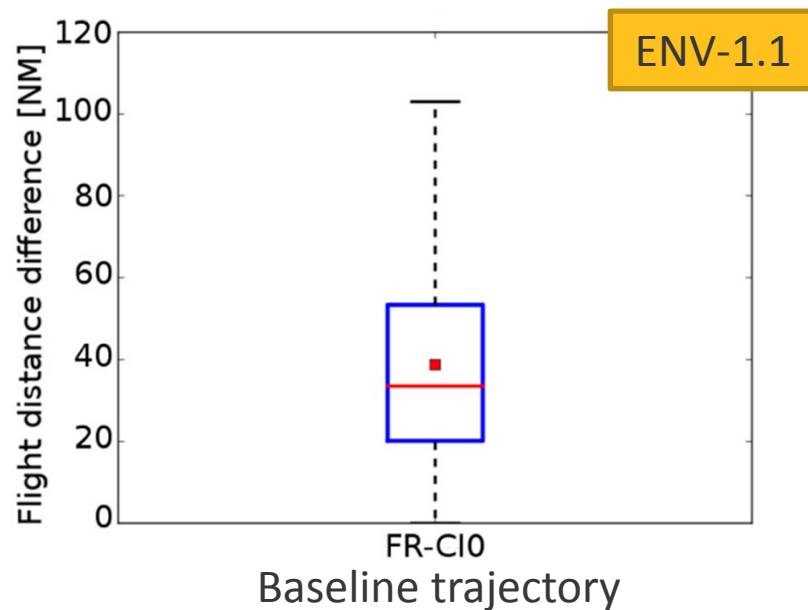
- **Advanced DCB algorithm:** The APACHE TP (trajectory planner) provides to the TCP with optimal **re-routing** and **optimal flight level capping** trajectories (minimising total trajectory cost).



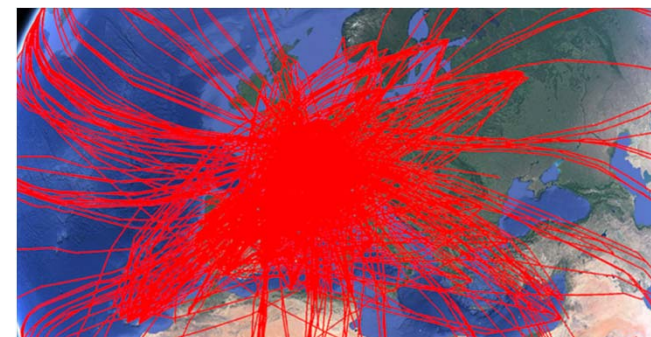
Illustrative examples

Pre-ops assessment (demand for Feb 20th 2017 crossing FABEC)

- ENV-1.1: Strategic ATM inefficiency on the **horizontal track**



Current network + FRA



Full free-routing

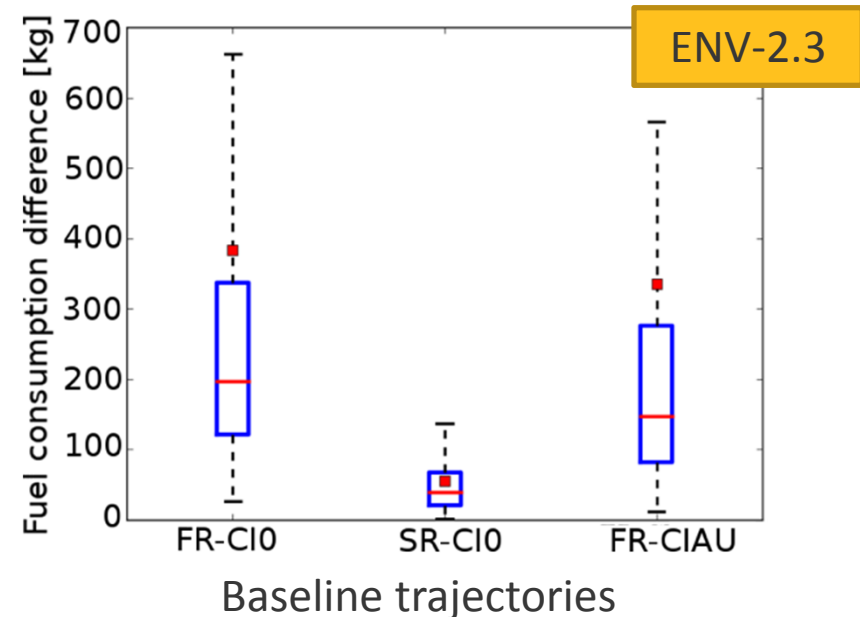
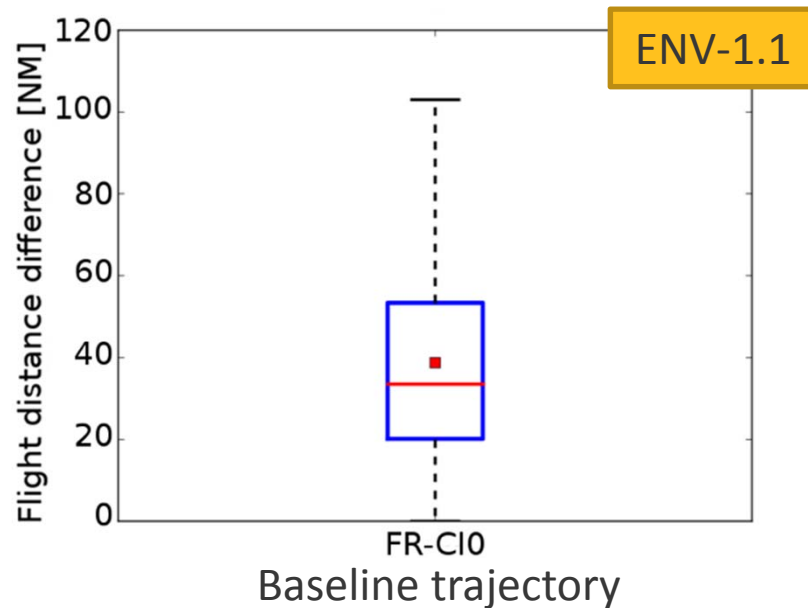
FR: full free route

SR: current (structured) network

Illustrative examples

Pre-ops assessment (demand for Feb 20th 2017 crossing FABEC)

- ENV-1.1: Strategic ATM inefficiency on the **horizontal track**
- ENV-2.3: Strategic ATM inefficiency on the **trip fuel**



FR: full free route

SR: current (structured) network

CIO: Cost Index = 0

CIAU: Same Cost Index than chosen by the Airspace User

Illustrative examples

Pre-ops assessment (demand for Feb 20th 2017 crossing FABEC)

SAFETY PIS COMPUTED BY THE RA MODULE FOR FRENCH AIRSPACE

PI	Description	Current network	Full free route
SAF-1	Number of Traffic Alerts warnings	300	131
SAF-2	Number of Resolution Advisories issued	73	1
SAF-3	Number of Near Mid Air Collisions (NMACs)	50	1
SAF-4	Number of Separation Violations	1376	939
SAF-7	Risk of conflicts/accidents	$5.5 \cdot 10^{-3}$	$3.0 \cdot 10^{-3}$



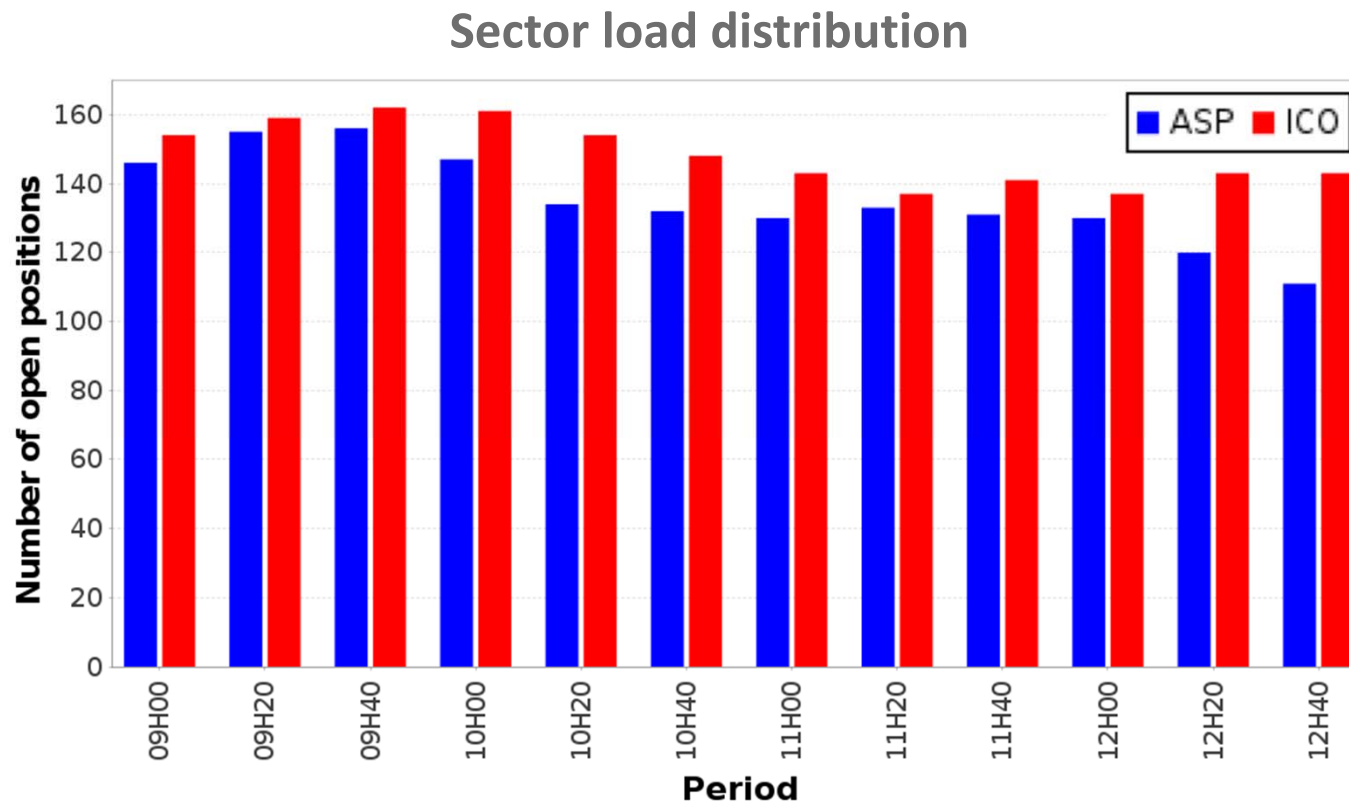
Full free Route

Current route structure

Illustrative examples

Pre-ops assessment (demand for Feb 20th 2017 crossing FABEC)

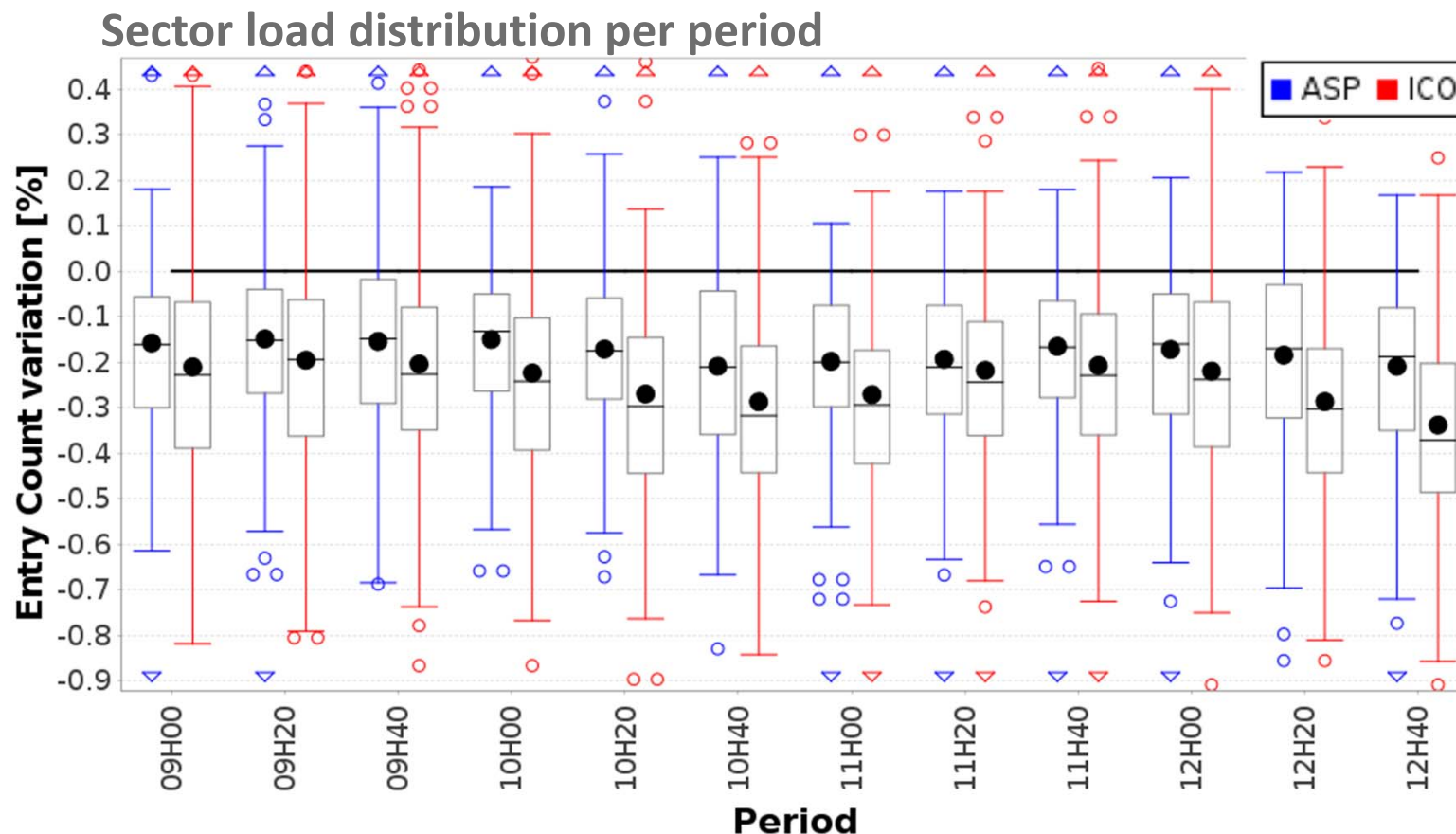
- **ASP validation** (compared with NEST ICO tool).



Illustrative examples

Pre-ops assessment (demand for Feb 20th 2017 crossing FABEC)

- **ASP validation** (compared with NEST ICO tool).



Illustrative examples

Pre-ops assessment (demand for Feb 20th 2017 crossing France)

• TCP example

With CASA algorithm (only delays):

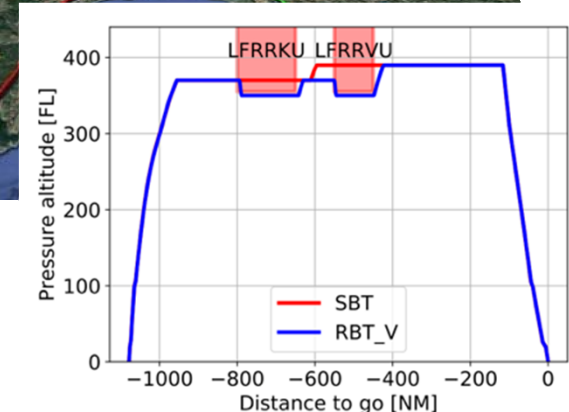
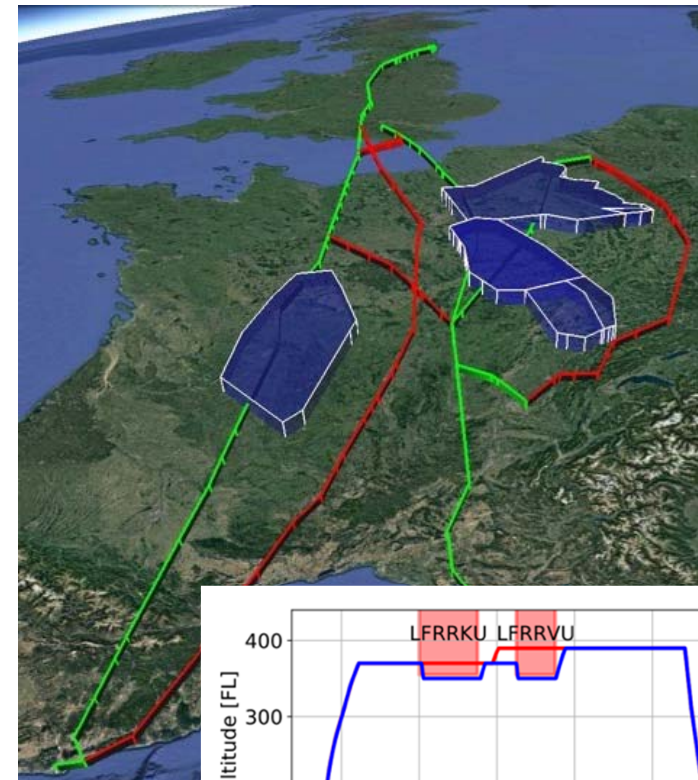
- 2, 510 aircraft delayed
- 406,042 min total delay
- 55min of average delay

With ADCB algorithm:

- 301 aircraft delayed
- 821 min total delay
- 0.11 min of average delay

ADVANCED DCB ALGORITHM RESULTS (FRENCH AIRSPACE)

	Original trajectory	Re-routing	Level capping	Total
Total flights	6,057	284	419	6,760
Delayed flights	227	20	54	301
Non Delayed flights	5,830	264	365	6,459



Conclusions



- ATM is progressively transitioning to a **performance based** system with many Key Performance Areas (KPA's).
- New tools and methods are needed to overcome current limitations in performance assessment to better capture:
 - **the impact** of new concepts and solutions; and
 - the complex **interdependencies** among KPAs.
- APACHE aims at filling some of existing gaps by providing a framework that combines **simulation, optimisation and performance assessment tools**.

<http://apache-sesar.barcelonatech-upc.eu/>

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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]



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Backup Slides



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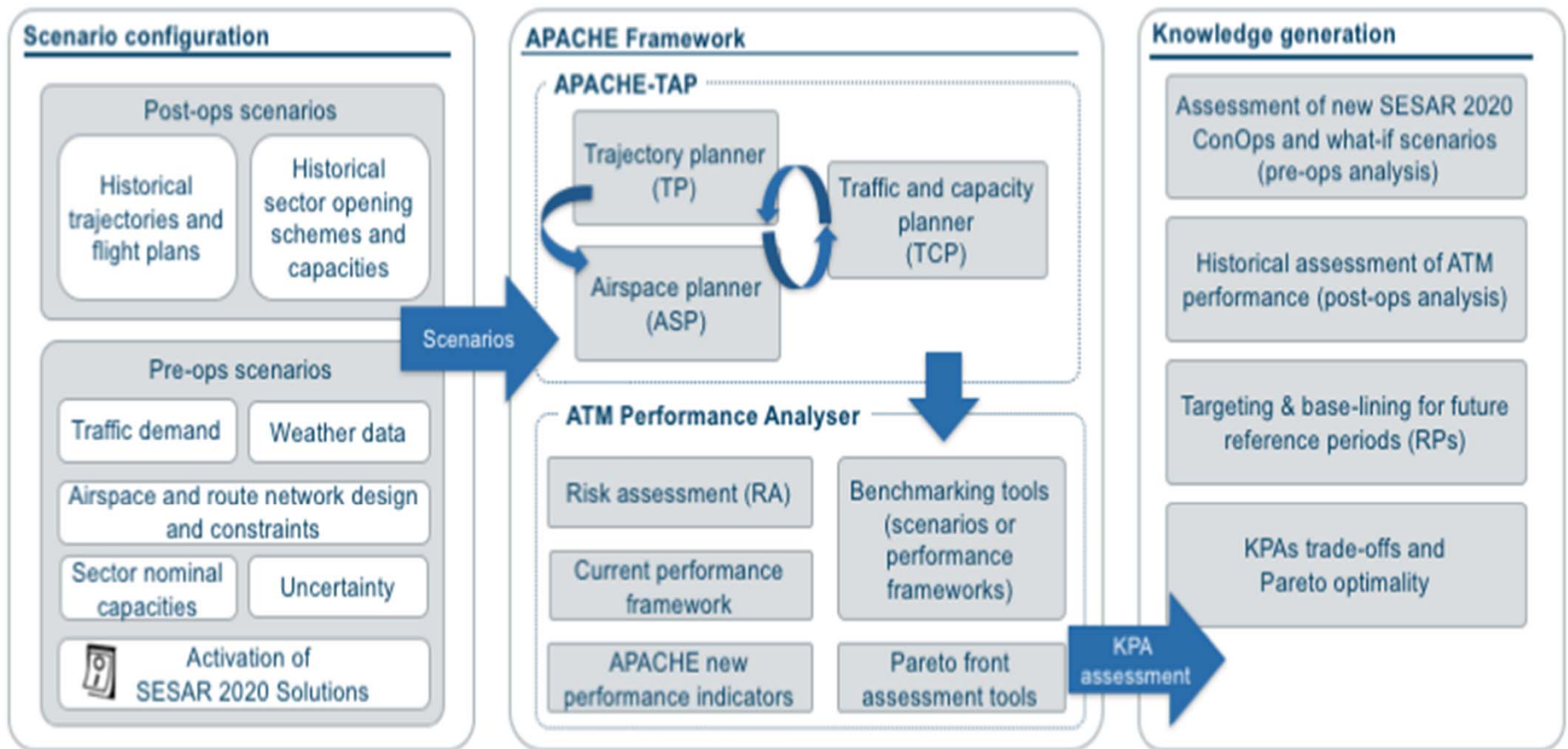
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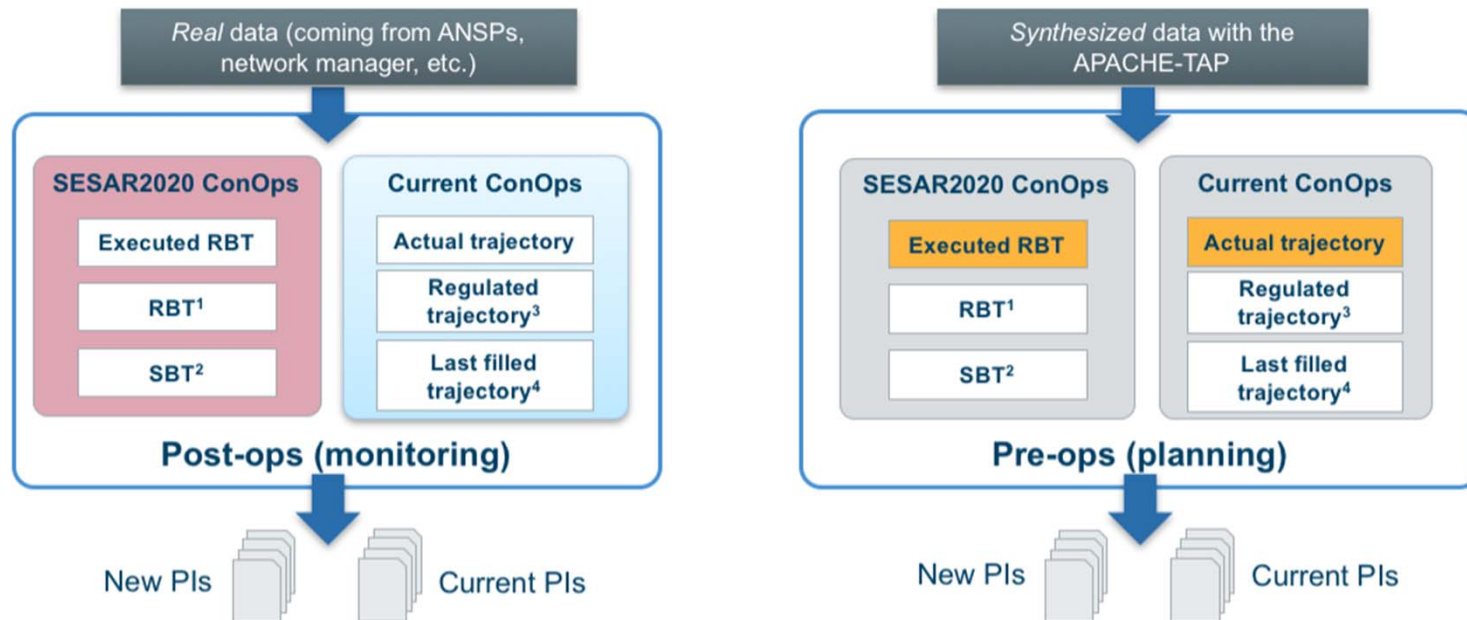
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Methodology and Approach



TAP: Traffic and Airspace Planner

Scope of the research



Legend:



Out of scope of the APACHE Project because SESAR2020 ConOps is not yet deployed and real data is not available.



Done in the APACHE Project to demonstrate the utility of the APACHE system for post-ops analysis and to benchmark current PIs with new PIs in the current ConOps.



Out of scope of the APACHE Project because the tactical ATM layer is not modelled in the APACHE system. Therefore, the synthesized trajectories are only RBT or ATFM regulated trajectories.



Done in the APACHE Project to benchmark current ConOps with future ConOps (initial assessment of some SESAR2020 solutions and capturing ATM Pareto front) and to benchmark current PIs with new PIs when assessing SESAR2020 operations.

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 regulated flight plan, which includes ATFM re-routings and/or ATFM delays (if any).

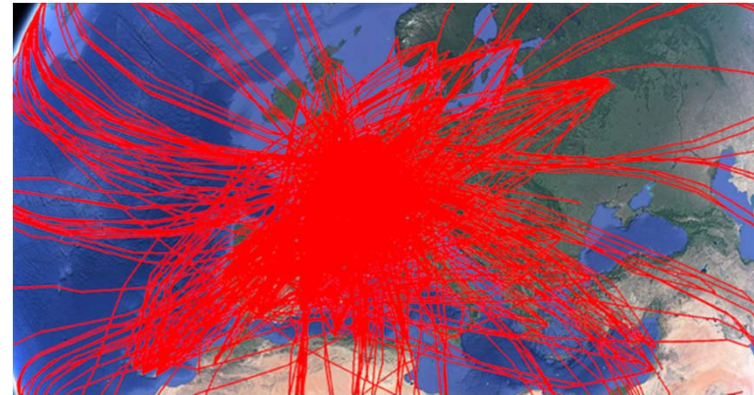
⁴ It comes from the last filled flight plan from the AU (without considering ATFM re-routings, if any).

APACHE trajectory and airspace planner (APACHE-TAP)

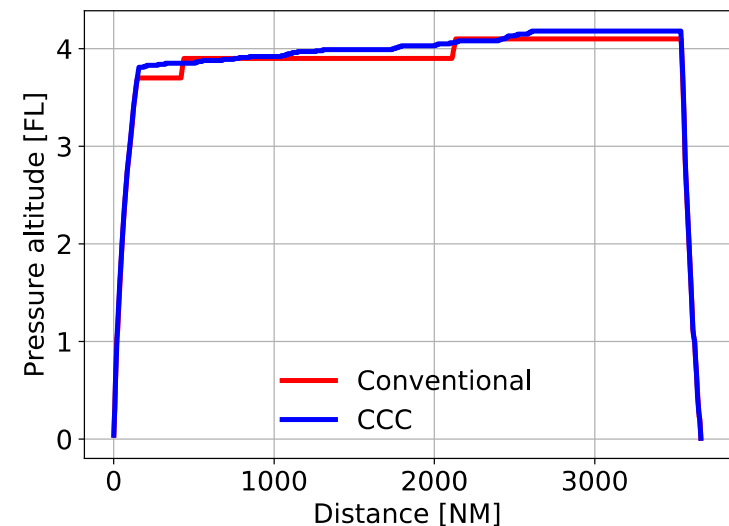
TP: Trajectory Planner



Current network + FRA

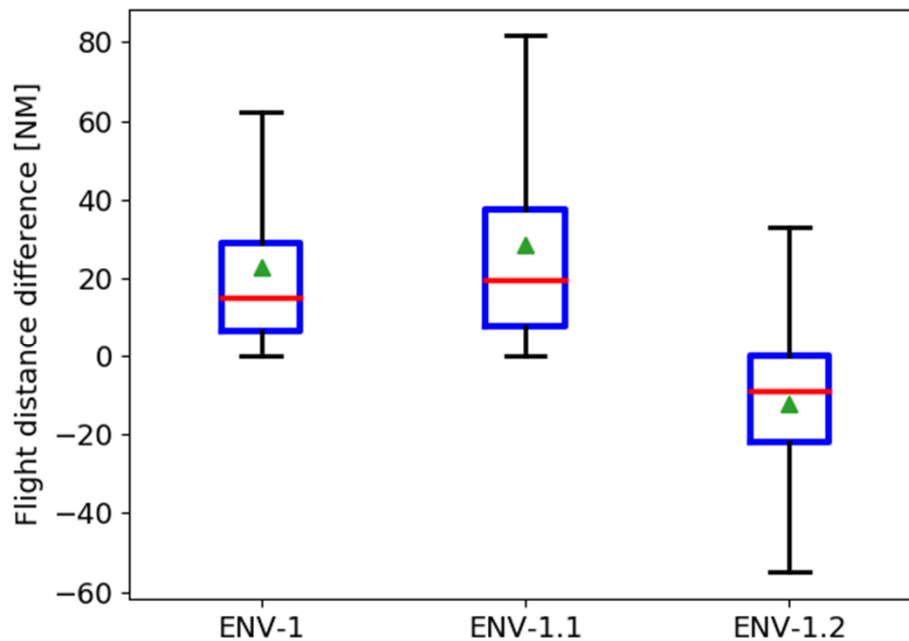


Full free-routing

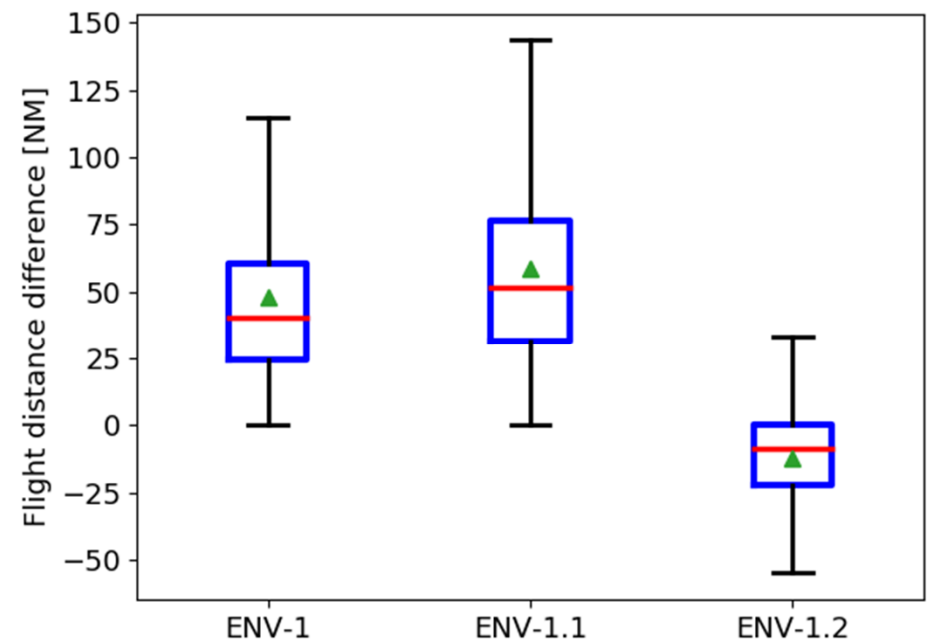


Post-ops results

Baseline trajectories: Current network



Baseline trajectories: Full Free-route



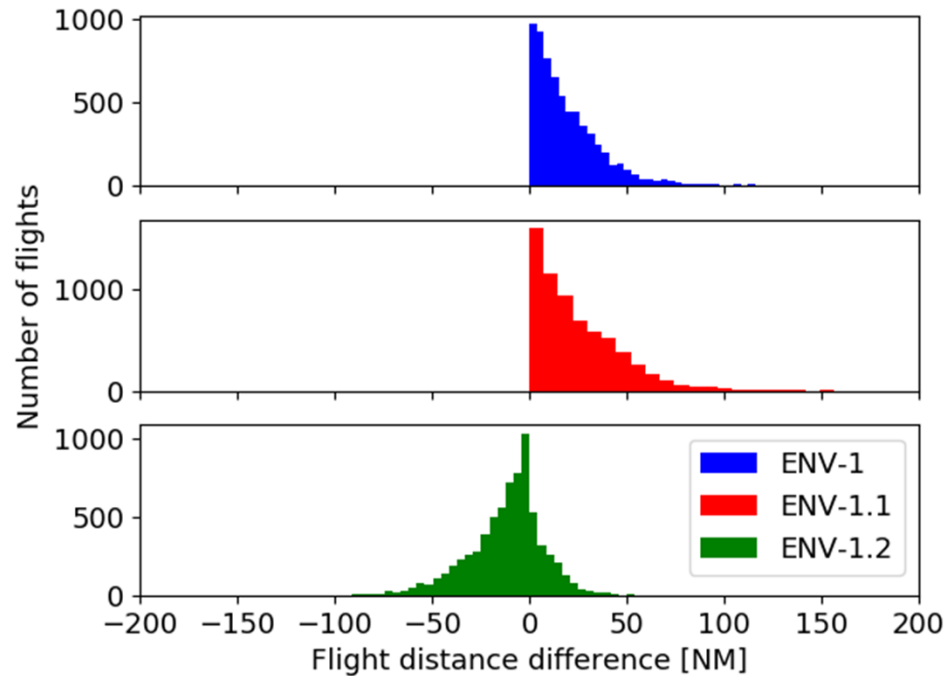
ENV-1: ATM inefficiency on the horizontal track (*using M3*)

ENV-1.1: **Strategic** ATM inefficiency on the horizontal track (*using M2*)

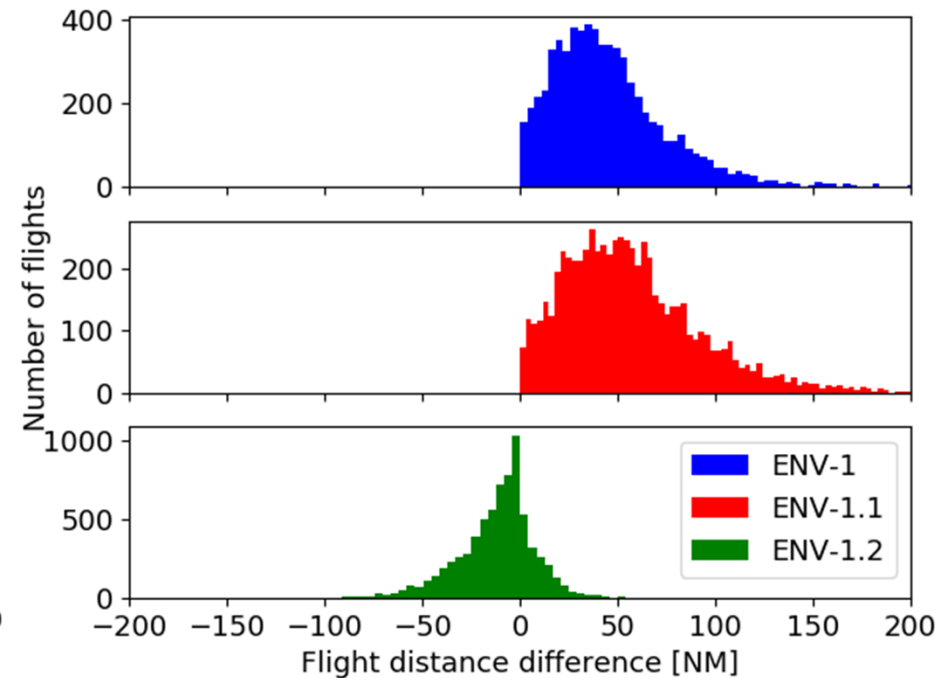
ENV-1.2: **Tactical** ATM inefficiency on the horizontal track

Post-ops results

Baseline trajectories: Current network



Baseline trajectories: Full Free-route



ENV-1: ATM inefficiency on the horizontal track (*using M3*)

ENV-1.1: **Strategic** ATM inefficiency on the horizontal track (*using M2*)

ENV-1.2: **Tactical** ATM inefficiency on the horizontal track