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MODELLING AND EXPLAINABILITY

Session chair: **George Vouros**

University of Piraeus

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"Transparency & Explainability in higher levels of automation in the ATM domain"

María Florencia Lema Esposto

R&D Aeronautical Engineer | **CRIDA**

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Transparency & Explainability in higher levels of automation in the ATM domain

Maria Florencia Lema Esposto

TAPAS

Exploration of AI/ML transparency/explainability for automated systems to be acceptable and trustworthy by ATM operators

Identification of principles and criteria for AI/ML transparency/explainability in ATM domain scenarios

Selection and development of suitable and explainable AI/ML prototypes for two operational cases:

ATFCM & CD&R

TAPAS

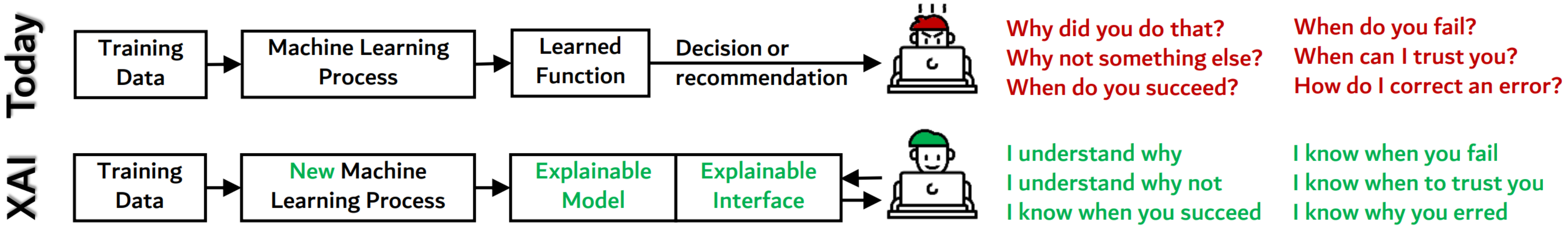
Degree of automation

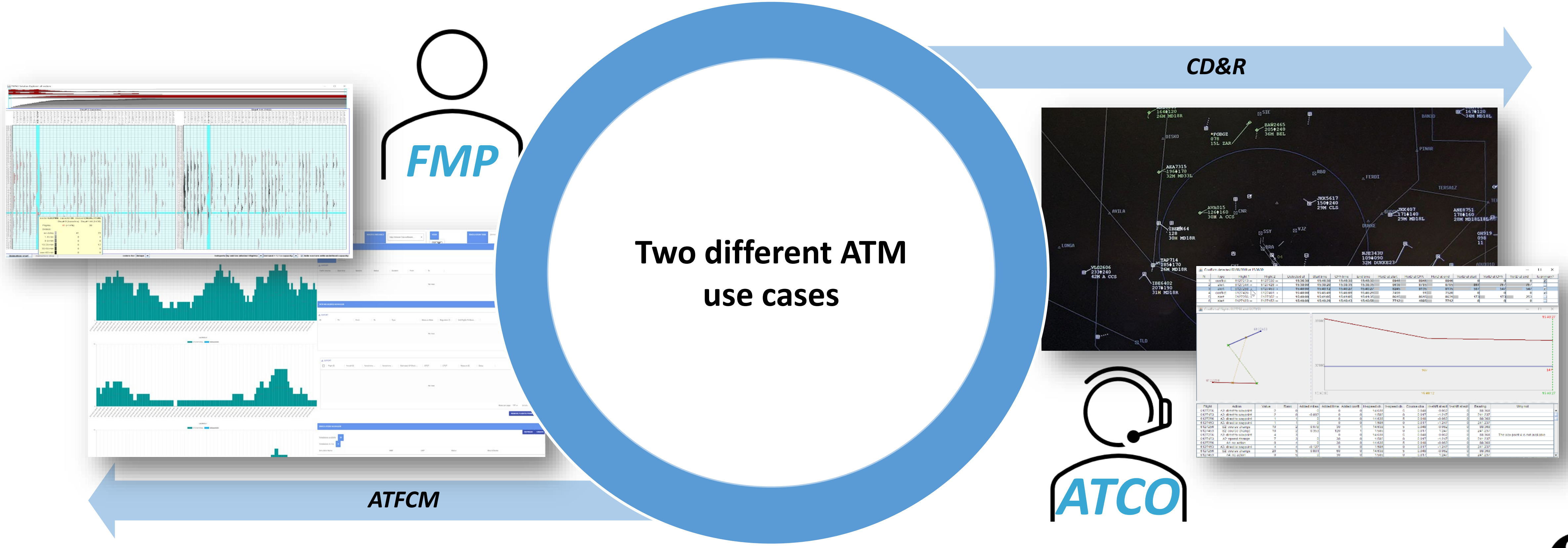
Higher automation

		Definition of level of automation per task					
		Information acquisition & exchange	Information analysis	Decision & action selection	Action implementation	Autonomy	
Action can only be initiated by human	**LEVEL 1** **DECISION SUPPORT** Automation supports human in information acquisition and exchange, information analysis and **action selection for some tasks/functions**						***Today's commonly spread operational concept***
Action can only be initiated by human	**LEVEL 2** **TASK EXECUTION SUPPORT** Automation supports human in information acquisition, exchange and analysis, **action** selection and **implementation** for **some tasks/functions**. Actions are always initiated by Human. Adaptable/adaptative automation supports optimal socio-technical system performance.						***System support*** ***Human Decision and implementation***
Action can be initiated by machine	**LEVEL 3** **CONDITIONAL AUTOMATION** Automation supports human in information acquisition, exchange and analysis, **action** selection and action **implementation** for **most tasks/functions**. Automation can initiate actions for some tasks. Adaptable/adaptative automation supports optimal socio-technical system performance.						***System decision and implementation*** ***Human monitor***

Transparency

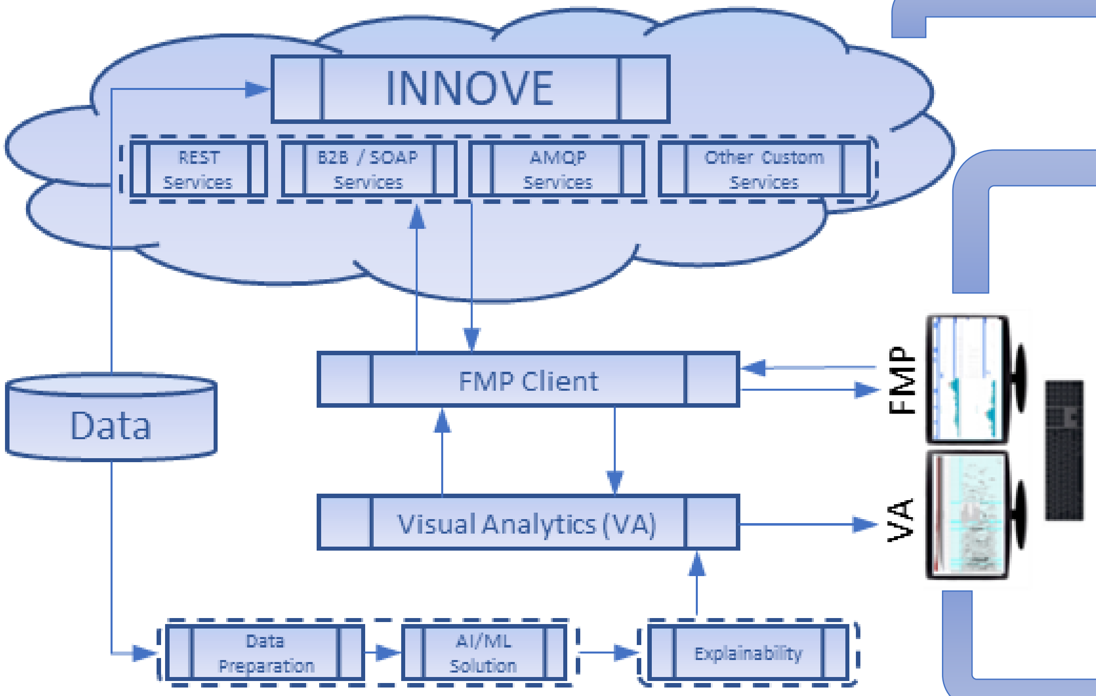
Explainability





TAPAS

ATFCM



INNOVE: where enviromental data is stored

Connected to

FMP Client: monitor TVs, declare/monitor hotspots, elaborate/implement demand measures, perform what-if scenarios

Connected to

VA component: XAI solutions and explanations are presented

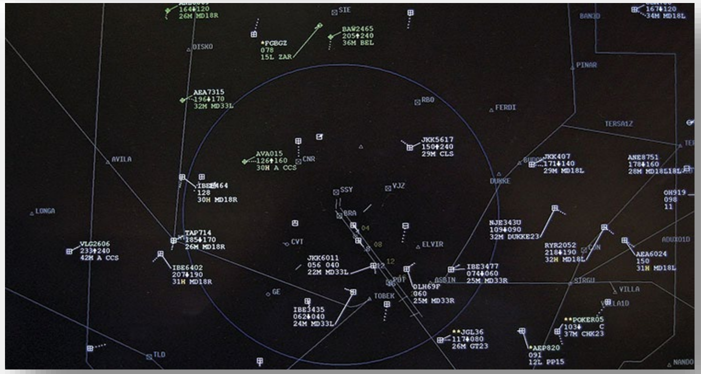
2019 Spanish data
Air traffic + airspace

DRL method using
Deep Q-Networks

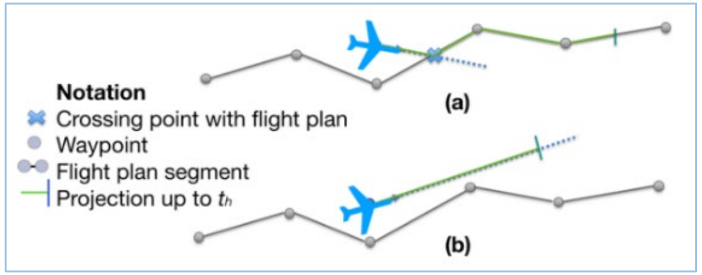
Stochastic Gradient Tree
mimicking the DQN

TAPAS

CD&R

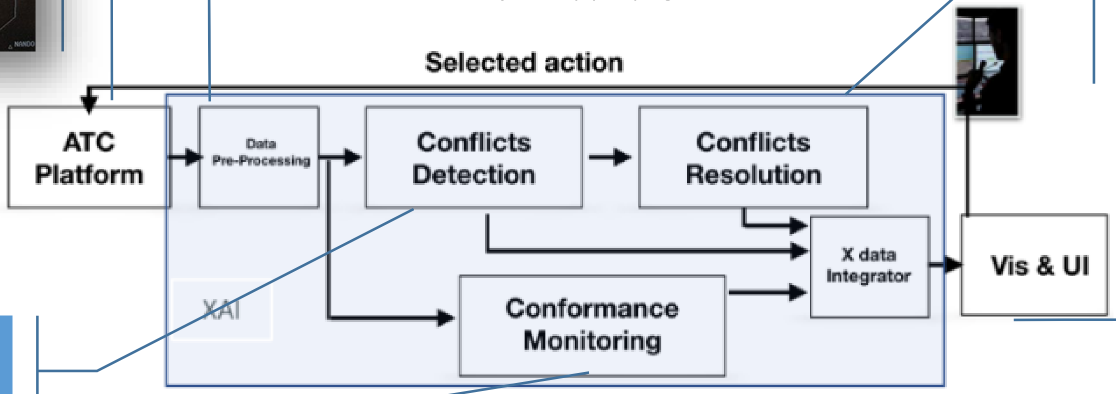


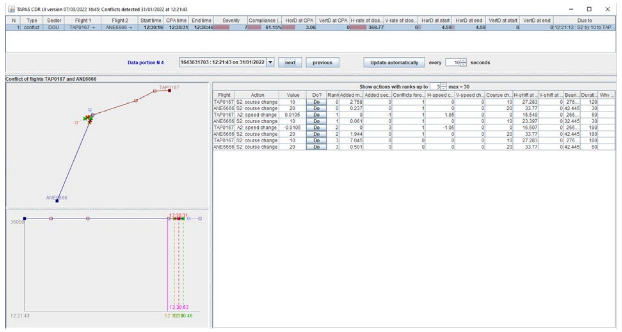
SACTA platform (radar display, traffic simulator)



Trajectory propagation

Change of altitude [±1 FL]
Course change [±20, ±10, 0]
Speed change [±7 knots]
Direct to a waypoint of the FPL





Conflicts and resolutions actions proposed by AI

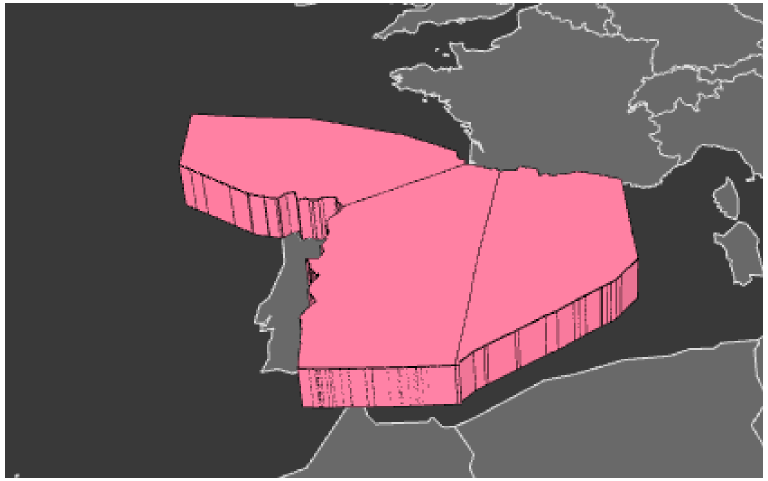
Separation infringements of less than 5NM/1000 ft
10 minutes ahead

Trained with Spanish operational data (ATCO events, radar tracks, FPLs)

Desired trajectory vs Actual trajectory
(oversees if an aircraft follows the resolution actions as prescribed by the AI/ML module)

TAPAS

ATFCM



3-day trials with FMP experts from the Spanish ANSP (ENAIRE)

CD&R

Two en-route sectors of Madrid ACC:

- Domingo upper (LECMDGU)
- Toledo upper (LECMTLU)

3-day trials with operational ATCOs and ATC instructors

TAPAS

Conclusions

- Trust prevails over explanations during real time operations
- Time horizon dictates level of explainability
- Traceability is key for transparency
- Accuracy comes before any means of transparency
- Complexity is a challenge to understanding

CRIDA I+D+i - ATM

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"Explainable Metamodels for ATM Performance Assessment"

Tatjana Bolic

Senior Research Fellow/ATM | **University of Westminster**

5-8 December 2022, Budapest

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Explainable Metamodels for ATM Performance Assessment

Tatjana Bolić, University of Westminster
SESAR Innovation Days
7 December 2022
Budapest, Hungary

Problem

- **Air traffic systems are hard to model**
- **Simulation approaches are a common modelling solution**
- **Such tools offer little room for understandability, transparency and interpretability (black-box)**
- **Simulation models can become computationally expensive**

Aims

- **Enhance explainability of simulation models and simulation-based studies**

- **Improve exploration of simulation models, reducing computational costs**

Solution

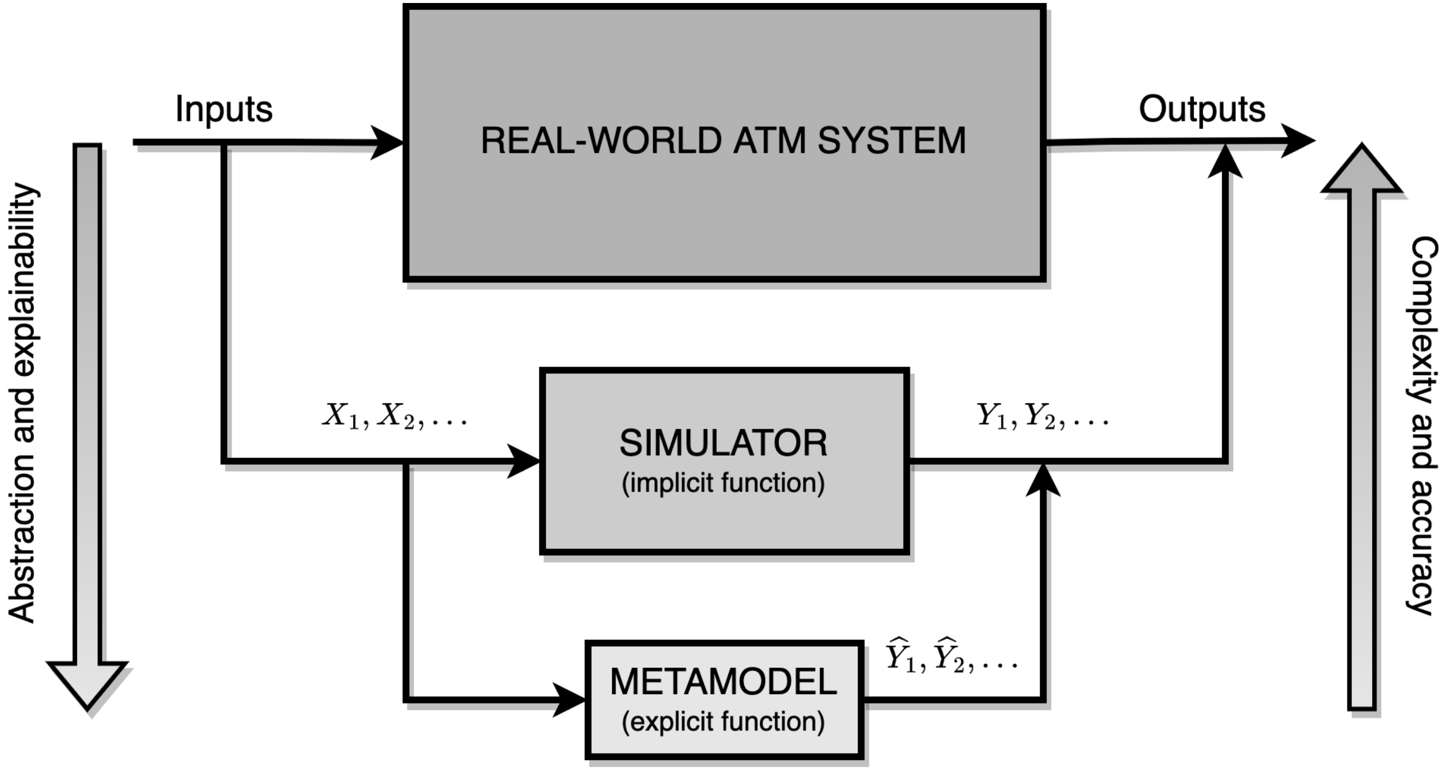
Combination of two techniques:

A. **Simulation metamodelling**

B. **SHAP values analysis**

A. Simulation Metamodelling

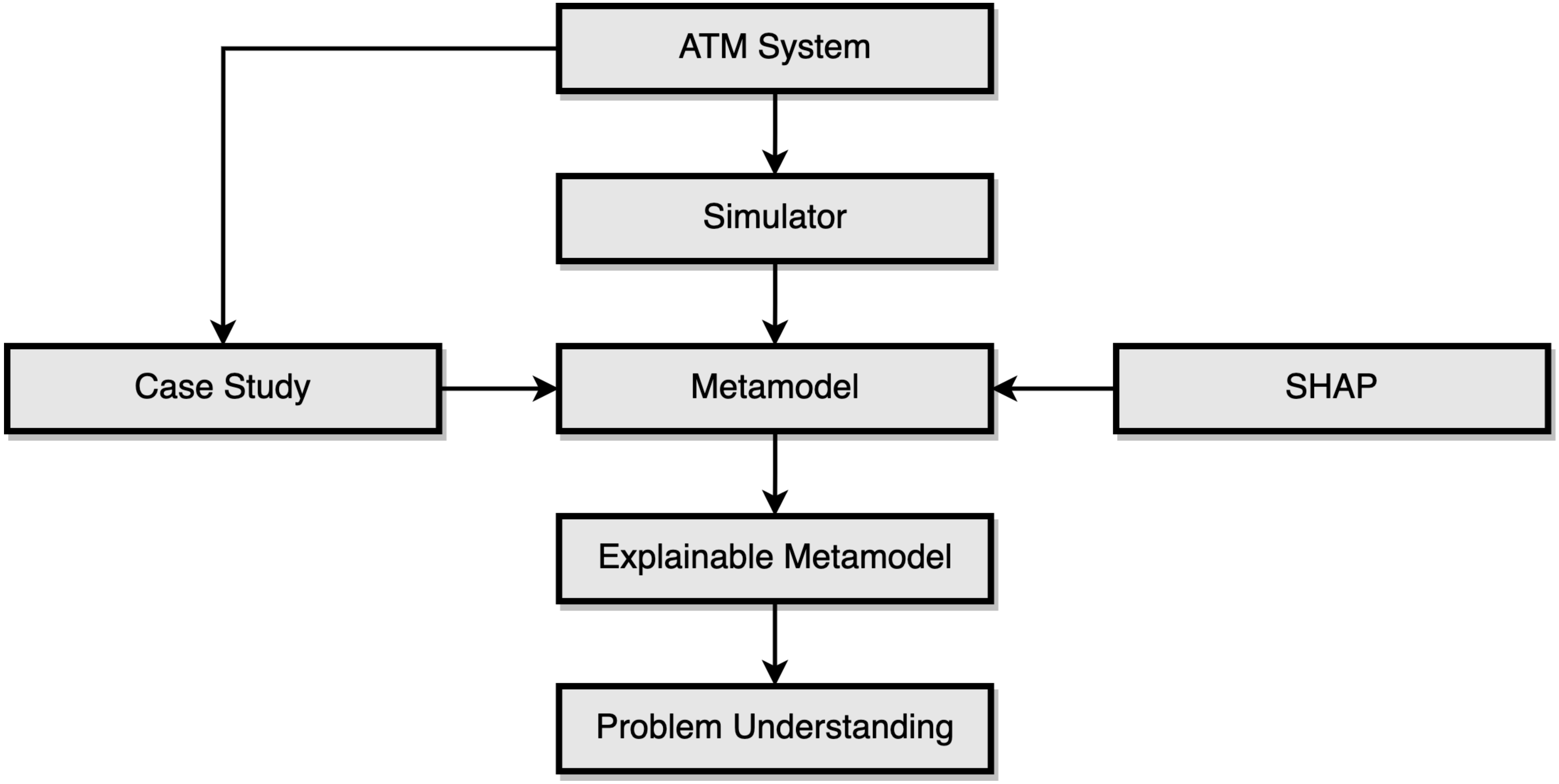
- **Explicit approximation of simulation models**



B. SHAP values

- **SHapley Additive exPlanations**
- **Traditionally used to address lack of explainability of ML/AI models**
- **Systematic framework for quantifying the individual contribution or impact that each input variable has on the output(s)**
- **Enhances the understanding of the associated interactions and, ultimately, the overall explainability of a given arbitrary model**

Proposed Methodology



Experimental Setup

- **ATM simulation model: Mercury**

- **Daily operations at Charles De Gaulle aiport**

- **Historical data from 12 September 2014: flights, origin-destination, routes,
  aircraft types, estimated cruise wind, distributions on climb
  and descent profiles, etc.**

Case studies and variables of interest

A. **UDPP (passenger arrival delay as KPI)**

B. **E-AMAN (planned absorbed delay as KPI)**

TABLE I. VARIABLES USED IN THE CASE STUDIES.

Variable	Description	Theoretical range	Practical range	Default
Fuel price	Price of one kg of fuel.	$[0, \infty)$	[0, 5]	1
Hotspot solver	Type of solver in the hotspot.	[GlobalOpt, NNBound, UDPP, ISTOP]	NA	ISTOP
Planning horizon	Distance horizon where the EAMA tries to optimize the arrival, in NM.	$(100, \infty)$	[100, 1000]	300
Cruise uncertainty	Deviation in the aircraft speed during cruise.	$[0, \infty)$	[0, 10]	1
Turn-around time scale	Scaler of mean of the distribution of turn-around times.	$[0, \infty)$	[0, 10]	1
Minimum connecting time scale	Scaler of mean of the distribution of passenger minimum connecting times.	$[0, \infty)$	[0, 10]	1
Claim rate	Proportion of passengers claiming compensation.	[0, 1]	[0, 1]	0.14

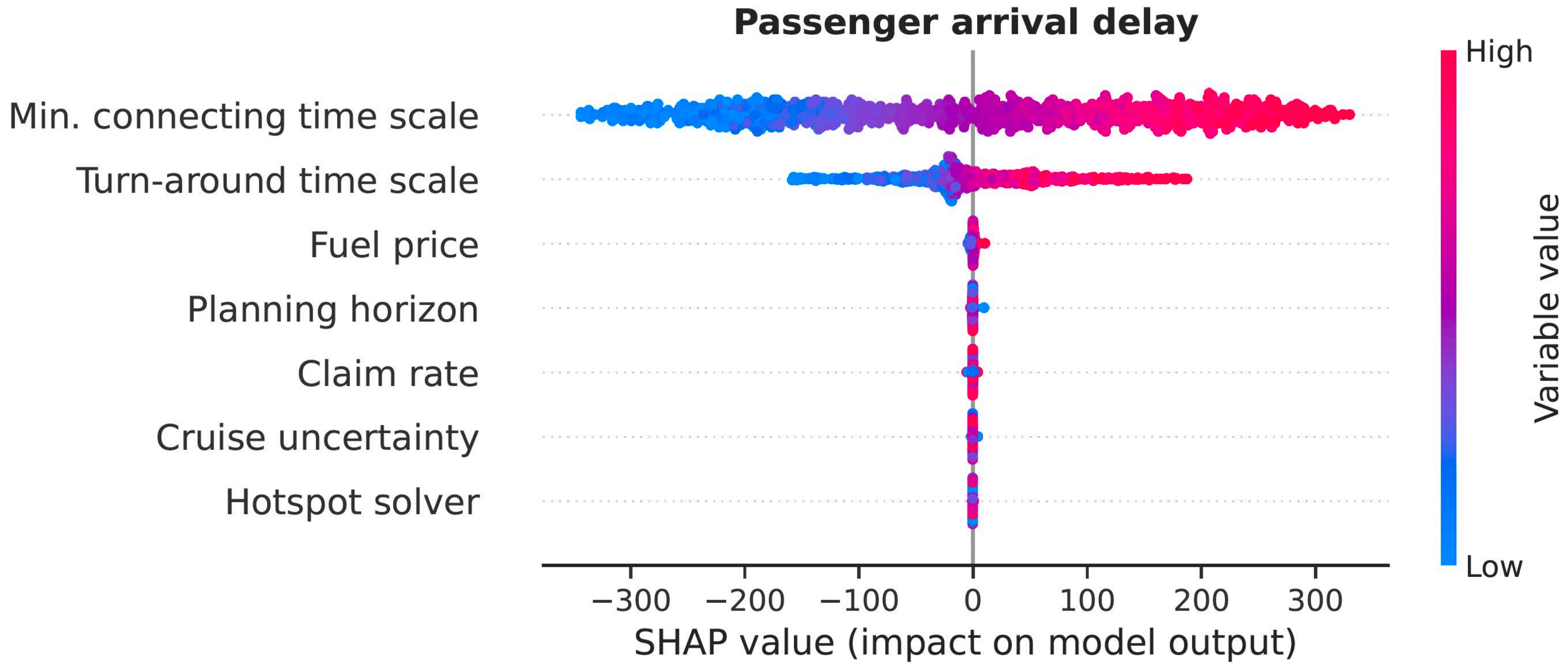
Optimizing the metamodel

- **XGBoost (Extreme Gradient Boosting) as metamodel**

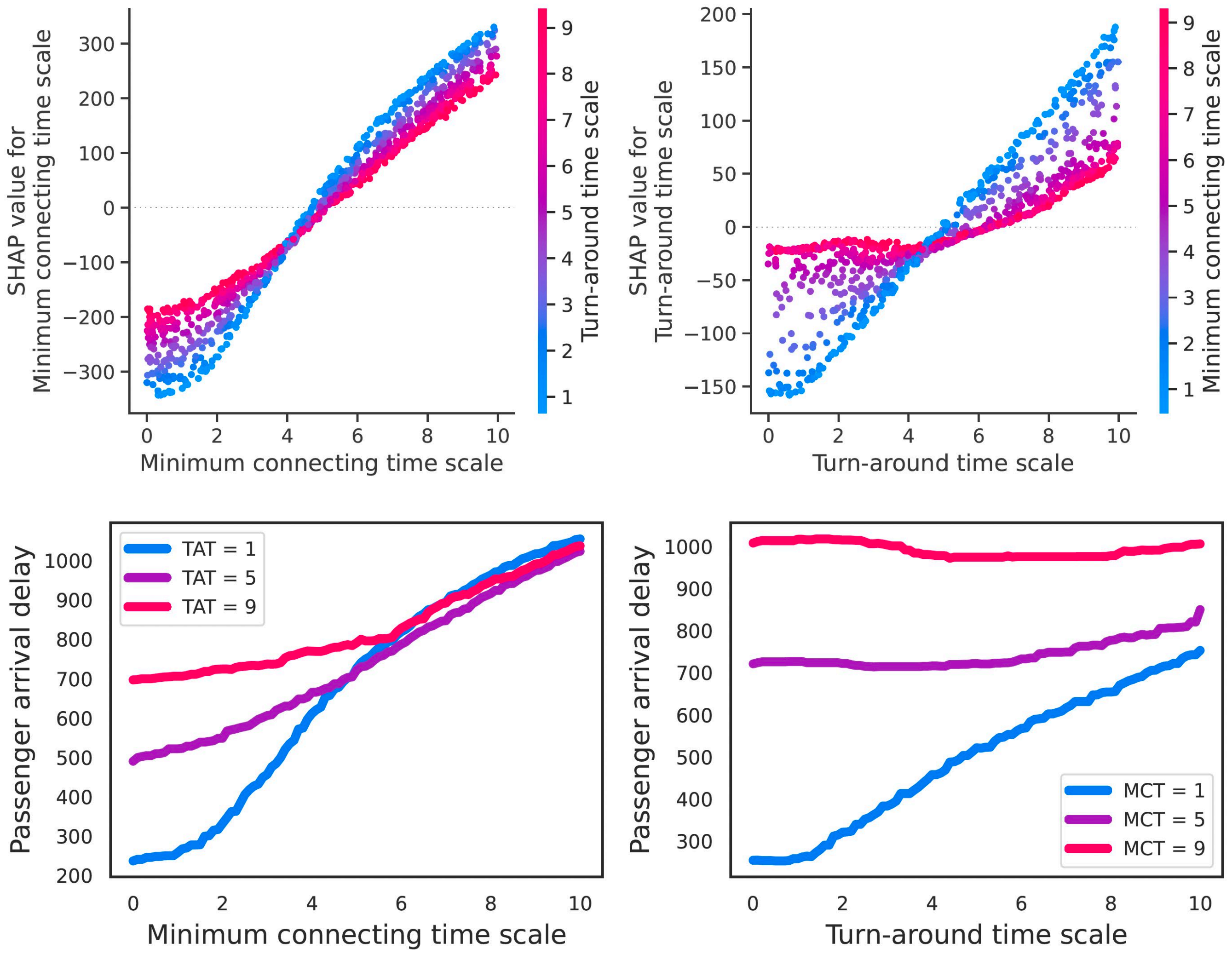
- **50k simulation points set for training**
- **10k simulation points for testing**

- **Hyperparameter tunning with grid search**

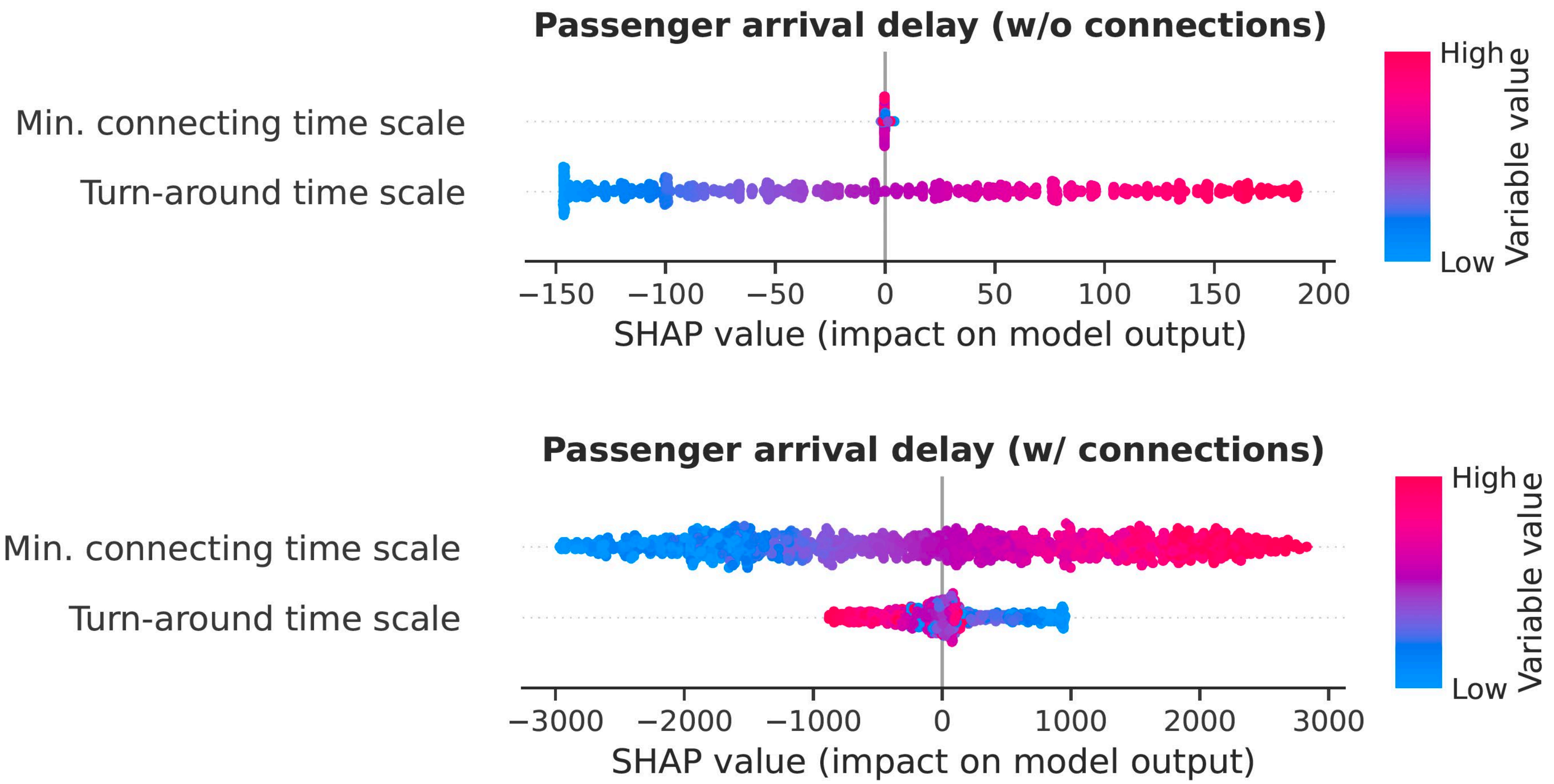
A. UDPP Case study



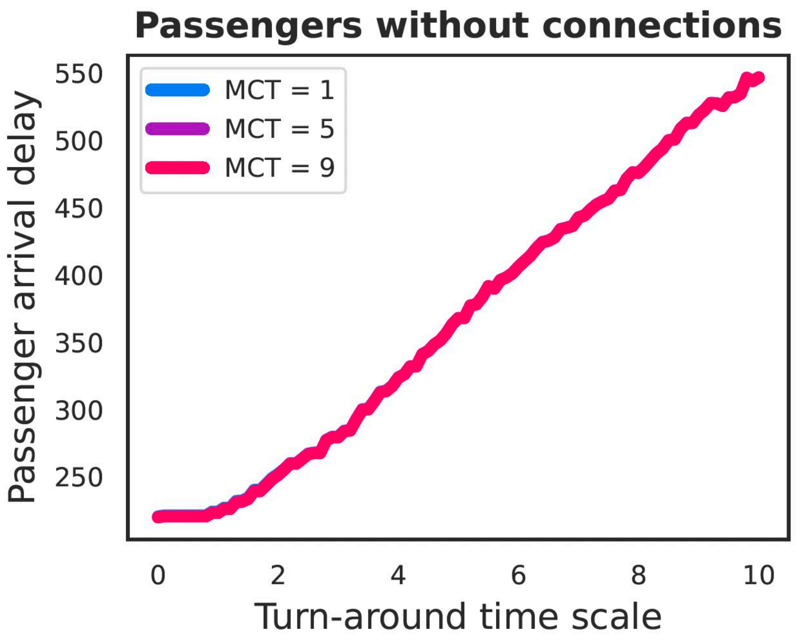
A. UDPP Case study

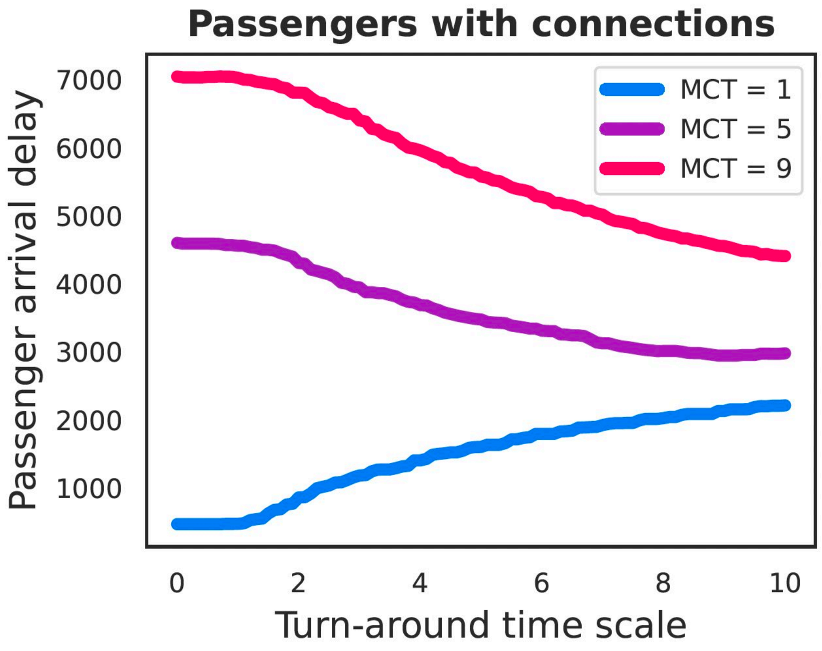


A. UDPP Case study

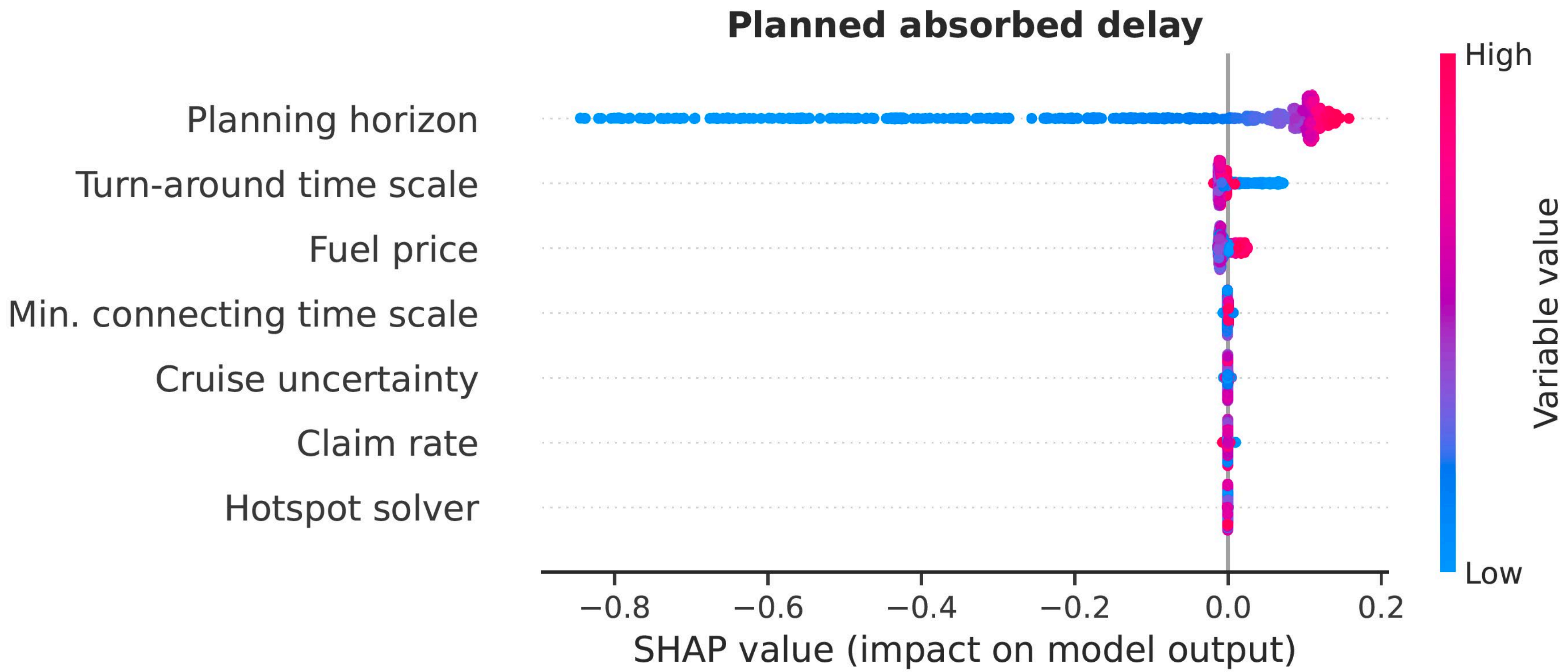


A. UDPP Case study

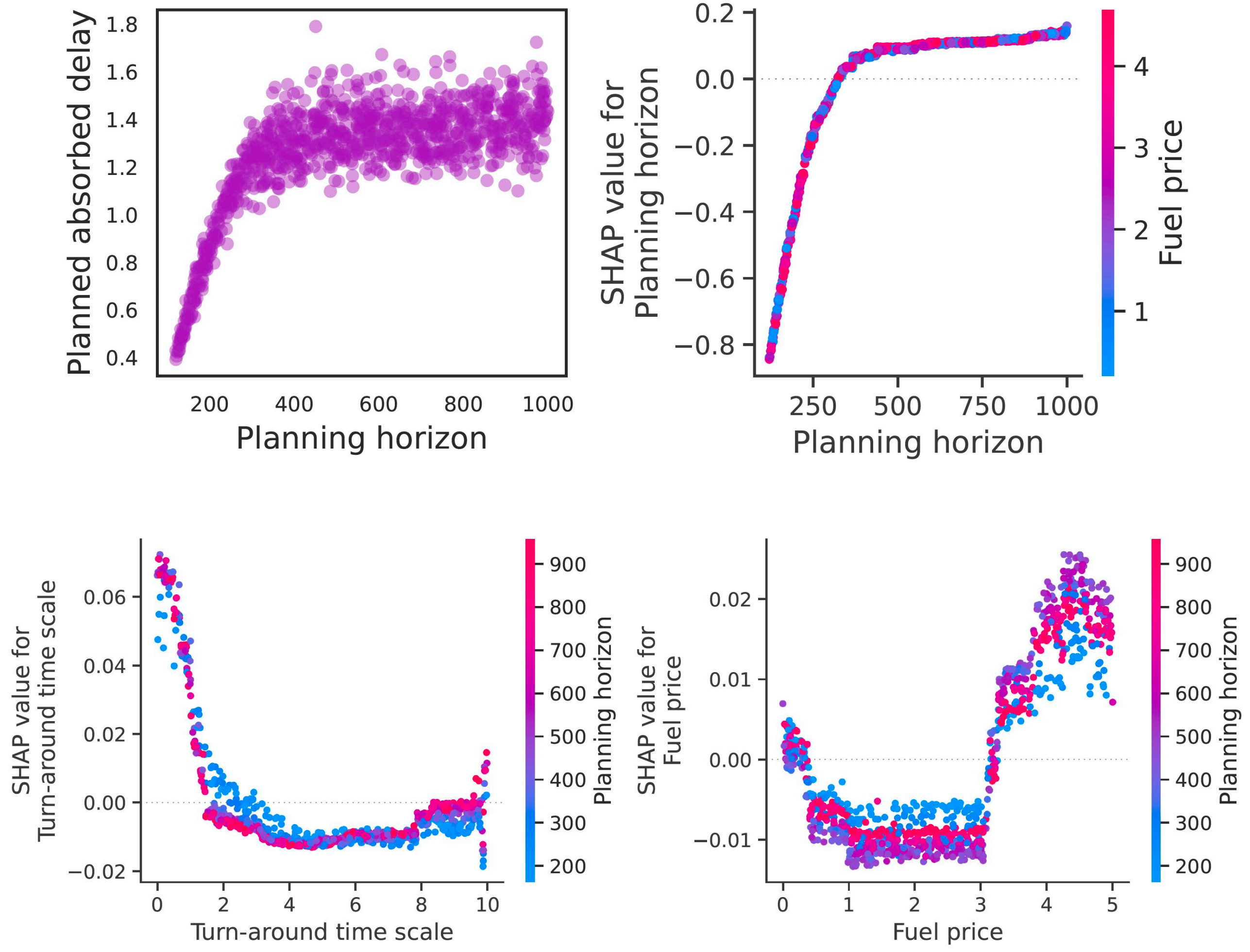




B. E-AMAN Case Study



B. E-AMAN Case Study



Conclusion and Future Work

- **Unified framework integrating SHAP values with simulation metamodels to create explainable metamodels**
- **Making simulation results more explainable, facilitating interpretation**
- **To be used as a complement to traditional simulation-based studies**
- **Enhancement of scenario-based and what-if analyses**
- **Plan to extend the current methodology to encompass active learning**

Acknowledgments

- **NOSTROMO (Next-generation Open-Source Tools for ATM PeRfOrmance Modelling and Optimisation)** project, framed in the scope of the SESAR 2020 Exploratory Research topic SESAR-ER4-26-2019, `ATM Validation for a Digitalised ATM,' with focus on the `Macro-modelling applied to Air Traffic Management' area and funded by SESAR Joint Undertaking through the European Union's Horizon 2020 research and innovation programme under grant agreement No 892517.

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"Active Learning Metamodelling for R-NEST"

Raquel Sánchez

R&D Data Scientist | **Nommon**

5-8 December 2022, Budapest

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Active Learning Metamodelling for R-NEST

R. Sánchez-Cauce, C. Riis, F. Antunes, D. Mocholí,
O. G. Cantú Ros, F. Câmara Pereira, R. Herranz, C. Lima Azevedo

The problem

Microsimulation models are usually the only feasible and reliable way to assess the performance impact of new ATM concepts and solutions

When embedded with enough detail, computational cost is often a barrier for a comprehensive assessment of ATM solutions

- Simulations are necessarily restricted to a limited number of scenarios, often insufficient to obtain conclusive results
- There is an interest in picking only the most informative instances

An integrated approach combining **active learning** and **simulation metamodelling** to translate a complex simulation model into a metamodel

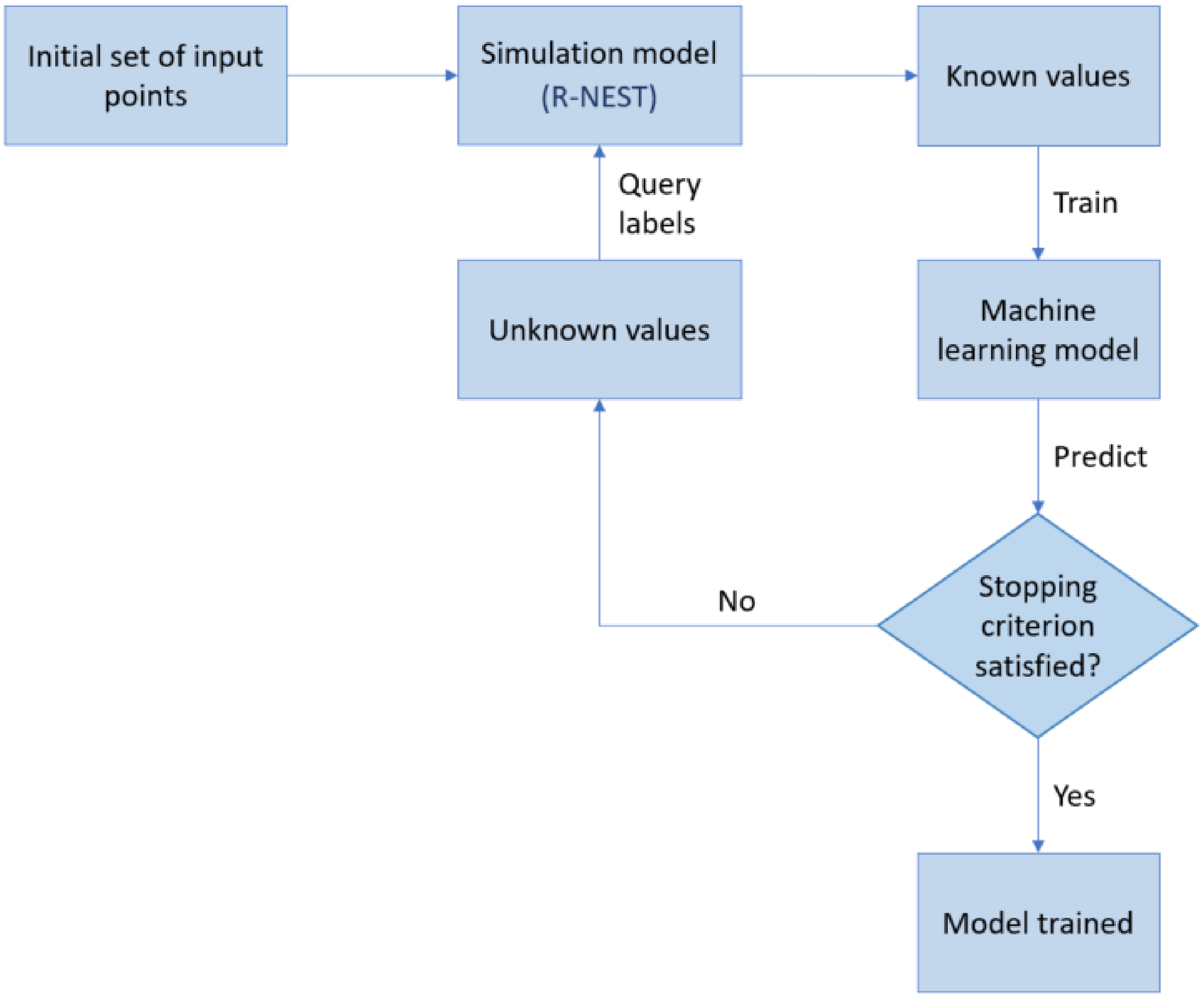
Active learning metamodelling

Simulation metamodel: simplified version that emulates the behavior of the original model, reducing the (expensive) simulation process

Training a metamodel usually requires running the simulation model many times. This task is quite inefficient in many cases

Active learning makes it possible to reduce the number of required model runs by **selecting the most informative** points

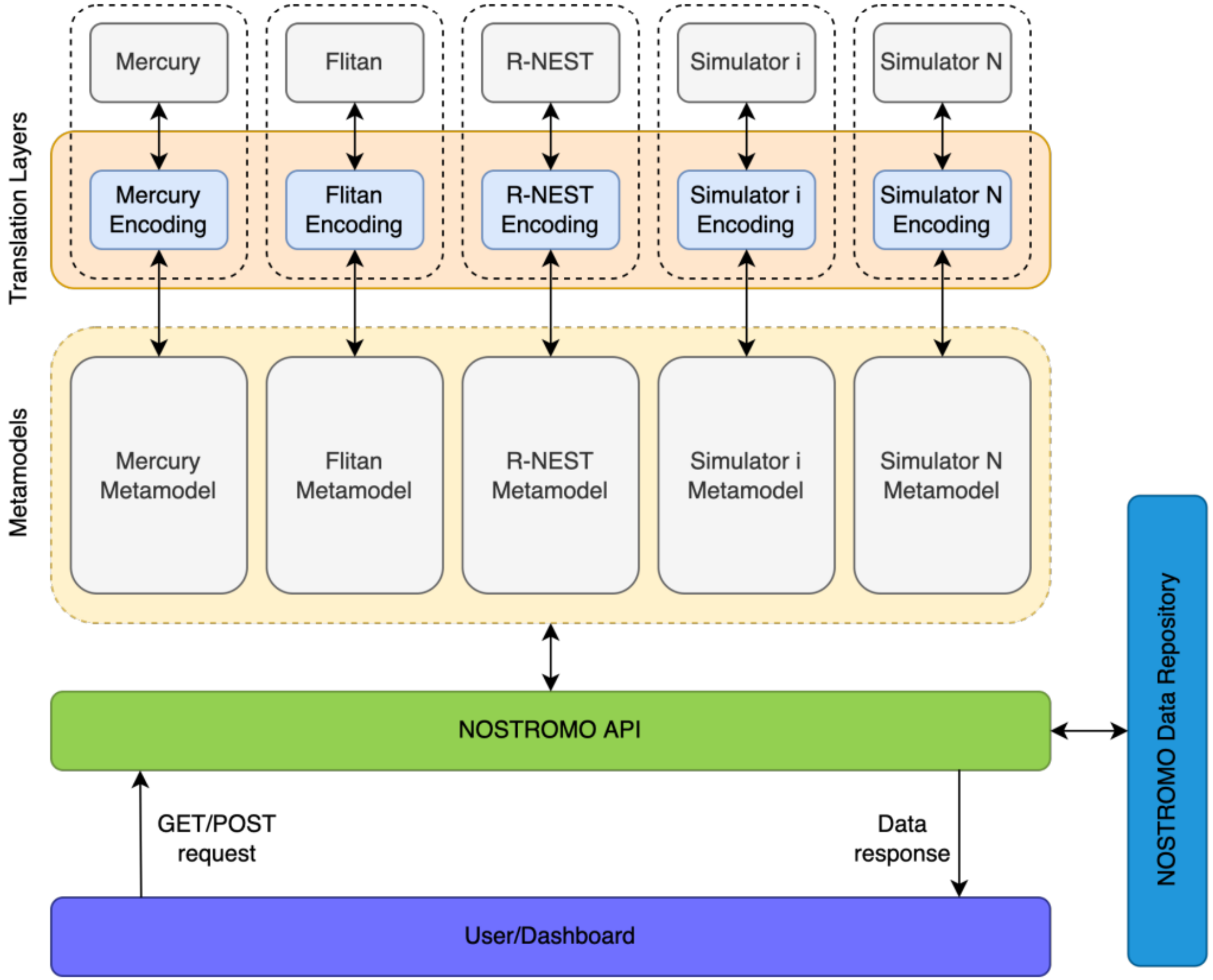
Active learning process



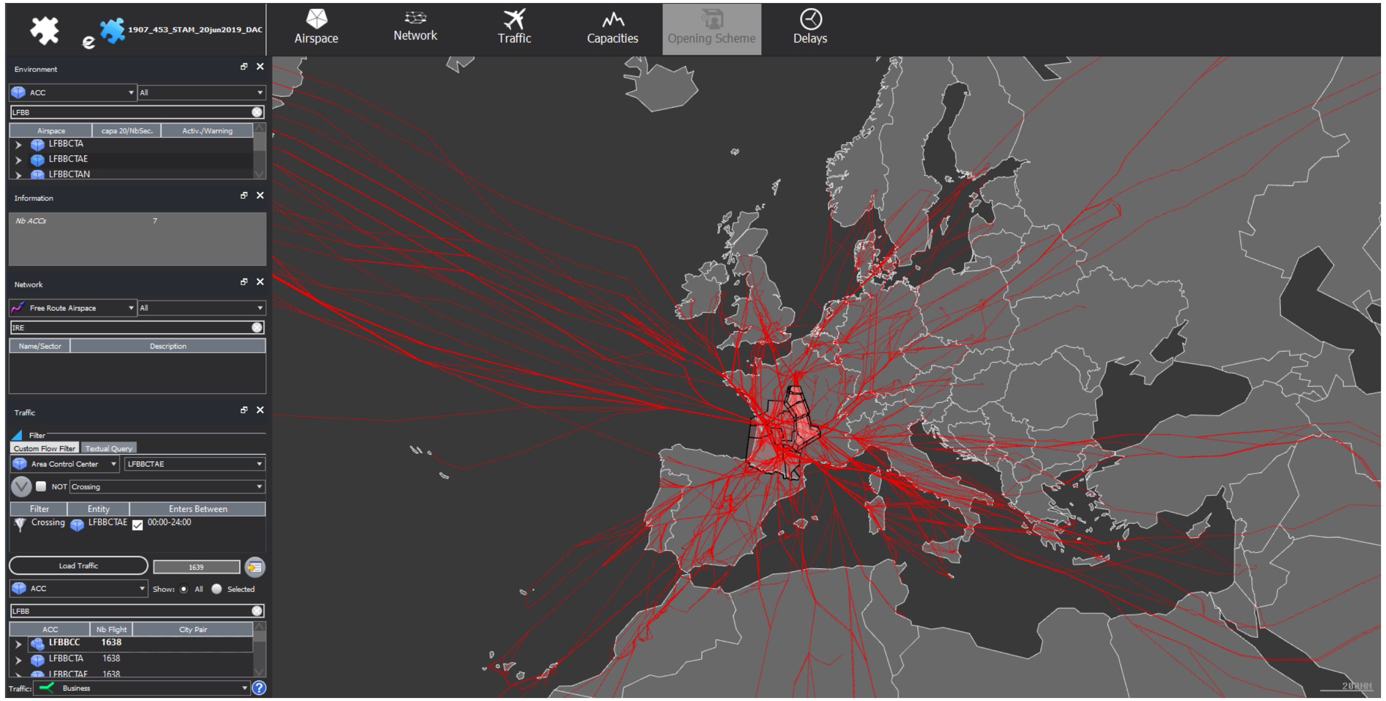
Implementation

- Metamodels for the **R-NEST** simulation tool
- Tested with the **Demand and Capacity Balancing (DCB)** SESAR solution:
  - Dynamic Airspace Configuration (DAC) + Short Term ATM Measures (STAM)
  - **DAC**: increase the granularity and flexibility in the airspace configurations that can be used by ANSPs
  - **STAM** measures: smooth ATCo workload by reducing traffic complexity and peaks through the short-term application of minor ground delays and horizontal and vertical re-routings
- Two use cases:
  - One-day R-NEST metamodel
  - AIRAC cycle R-NEST metamodel

NOSTROMO metamodelling framework



R-NEST

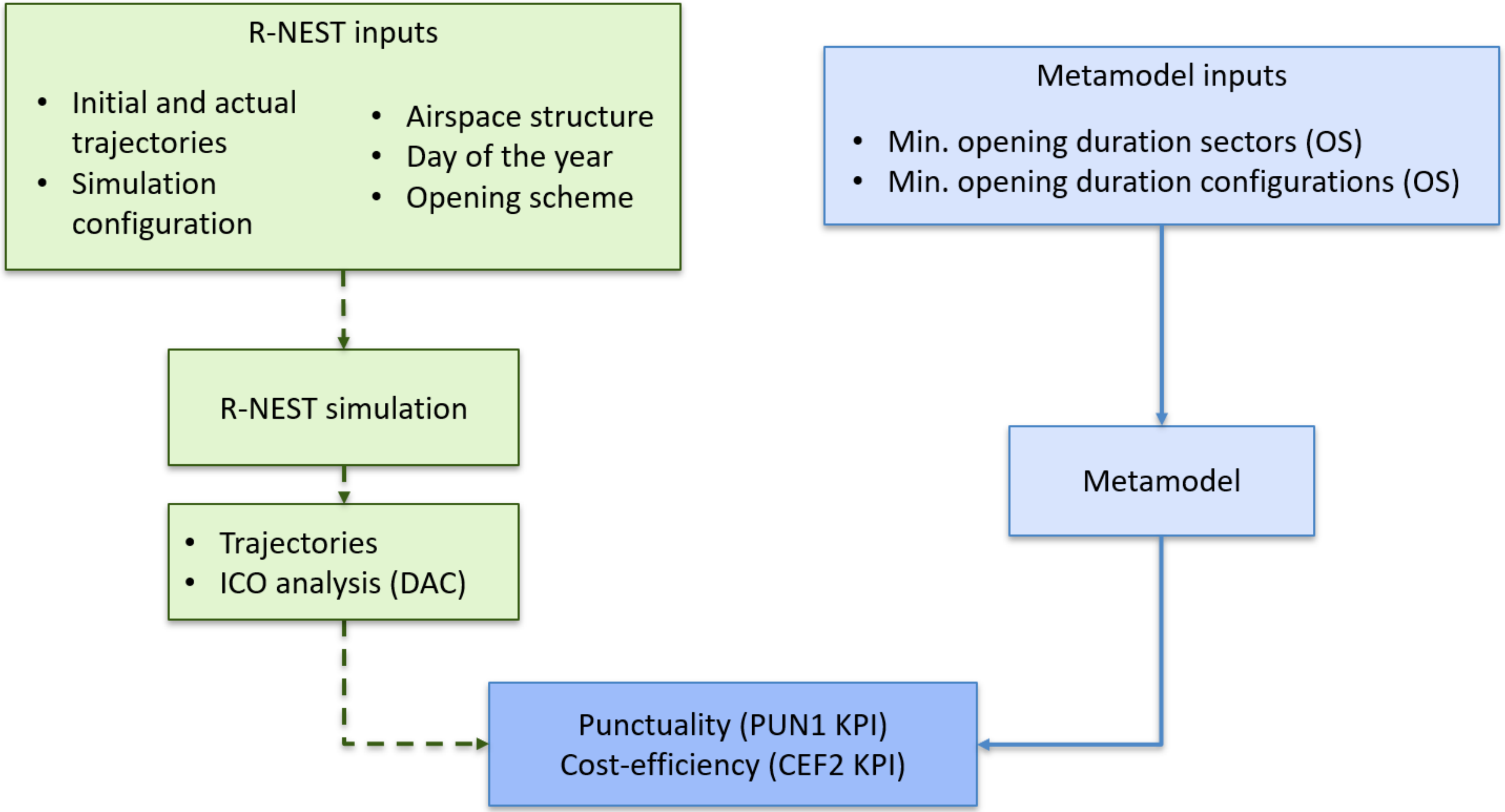


- EUROCONTROL research simulation tool
- Performance assessment of advanced ATM concepts
- Dynamic simulation of network operations and prediction of different types of delays

One-day R-NEST metamodel

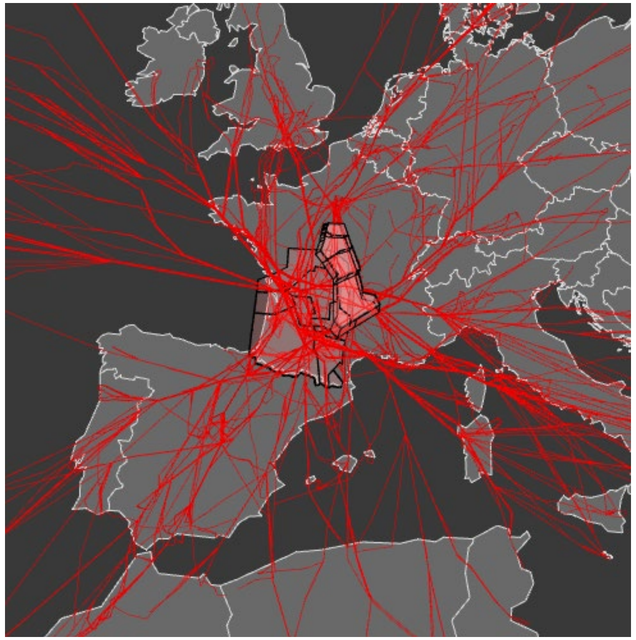
- Inputs:
  - minimum opening duration of the configurations for the opening scheme (OS)
  - minimum opening duration of the sectors for the OS
- Outputs:
  - Network punctuality: average departure delay per flight (**PUN1 KPI**)
  - Cost-efficiency: number of flights per ATCO-Hour on duty (**CEF2 KPI**)

Day R-NEST metamodel



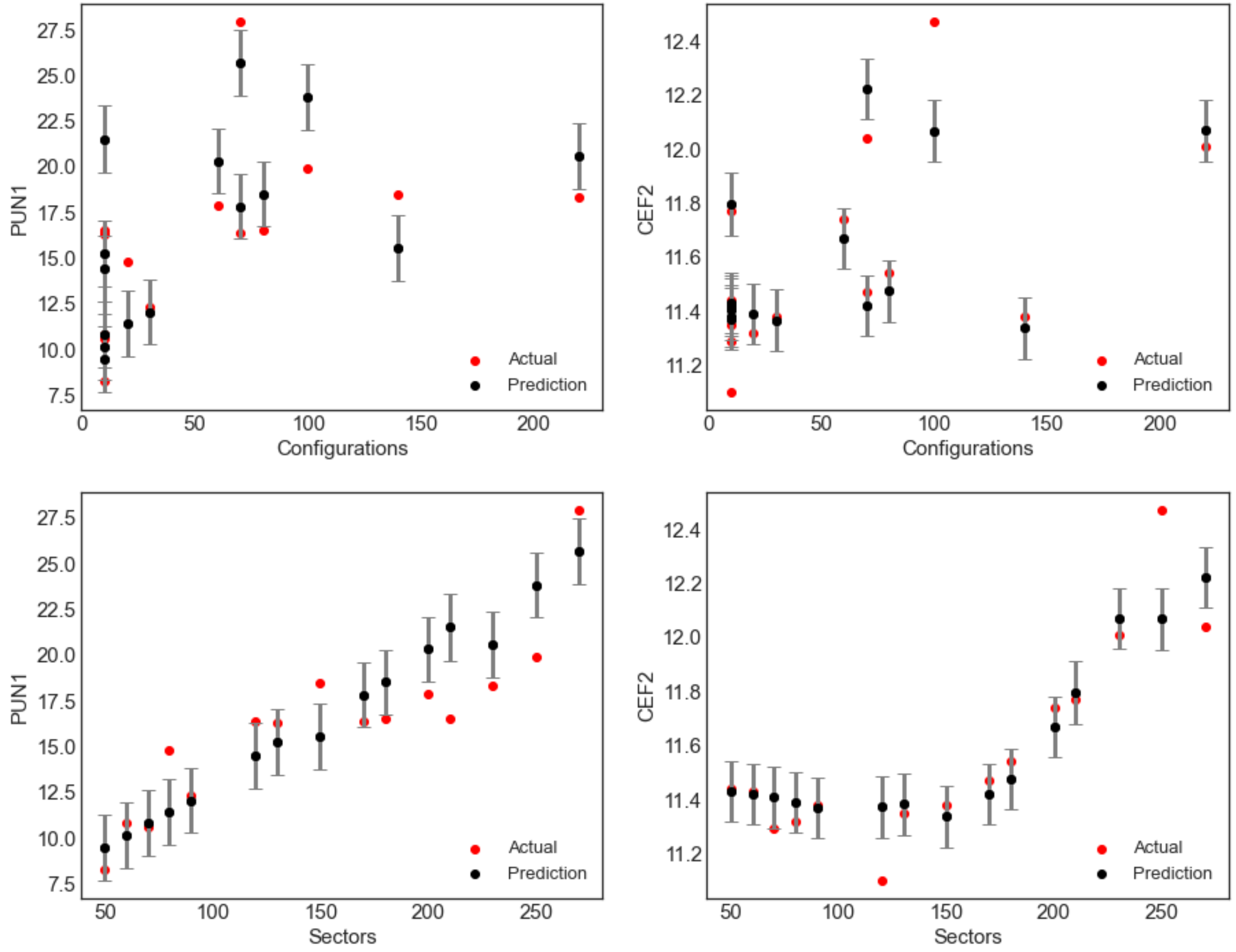
Metamodel implementation

- The metamodel is defined for the **5th July 2019**
- The lower and east cluster of **Bordeaux ACC** is selected
- DCB implementation:
  1. DAC: Define the OS (configurations and sectors):
     i. Configurations (minutes): [10, 300] in 10-steps
     ii. Sectors (minutes): [10, 300] in 10-steps (restriction sectors ≥ configurations)
  2. STAM: Once the OS is defined, perform the STAM simulation



Results – One-day R-NEST metamodel

45 points were used to train this metamodel (**9.66%**)



	PUN1	CEF2
RMSE	2.45	0.14
MAPE	0.125	0.008

AIRAC-cycle R-NEST metamodel

- Extend the R-NEST metamodel to the whole 7th AIRAC
- Using AIRAC representative days* and the metamodelling methodology:
  - Identify the different traffic patterns in a region
  - For each pattern observed, select a set of representative days
  - Train the metamodel with the set of representative days

*using the methodology developed in:

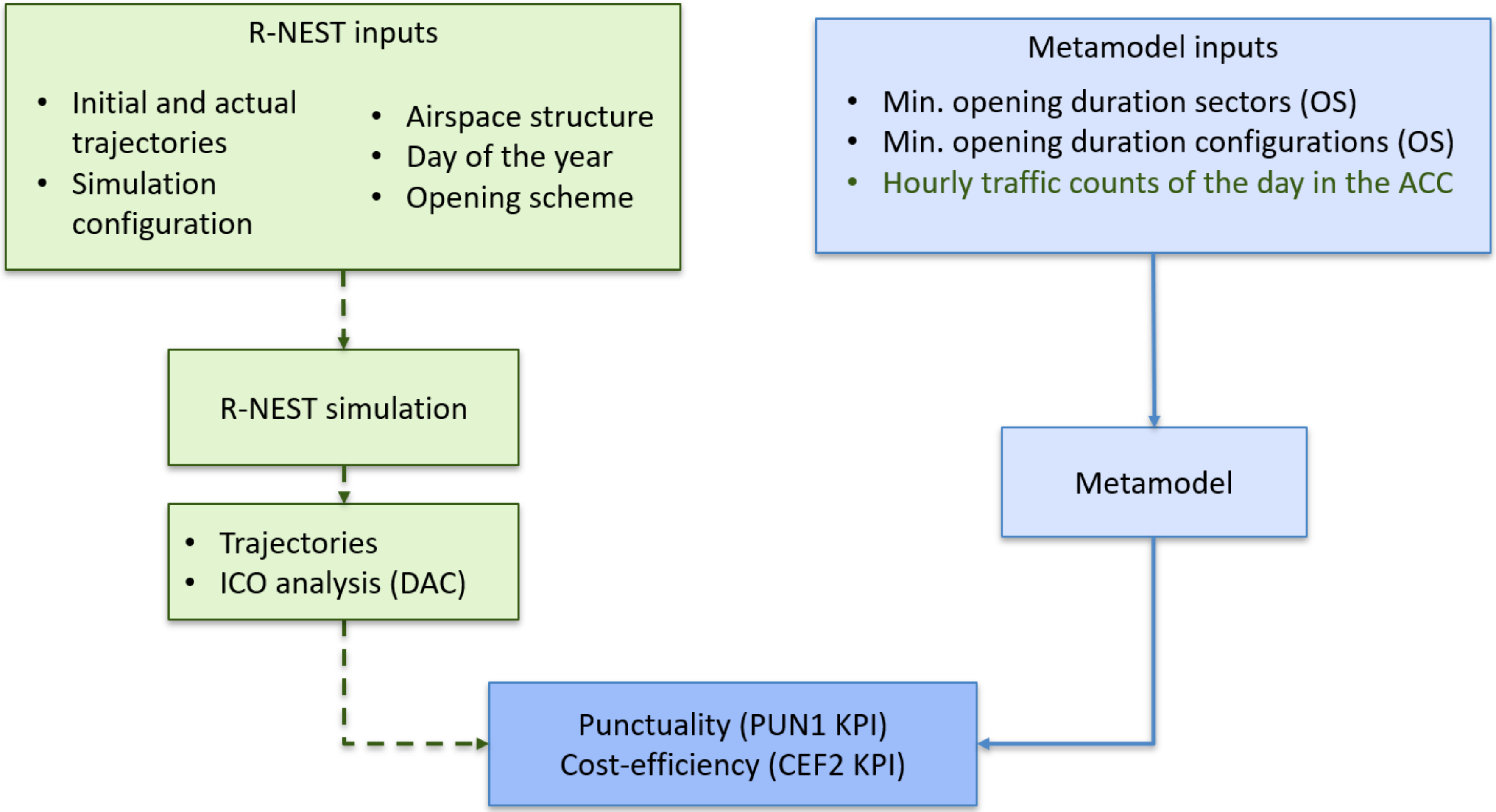
Sánchez-Cauce, R., Mocholí, D., Cantú Ros, O. G., Herranz, R., Rodríguez, R., Tello, F., & Fabio, A. (2022). Identification of Traffic Patterns and Selection of Representative Traffic Samples for the Assessment of ATM Performance Problems. In 12th SESAR Innovation Days (SIDs)

Extended R-NEST metamodel

	10/07/2019	30/06/2019	29/06/2019	15/07/2019	20/06/2019	02/07/2019
Temporal period	Summer days	Winter days (Jan., Feb, Mar.)	Summer weekends	Winter working days	No temporal pattern	Summer working days
Efficiency	Medium values	The lowest values	Low values	Medium values	The highest values	Very high values
Predictability	Low values	The lowest values	Low values	The highest values	High values	Very high values
Regulations	Large delays due to non-ANS	No delays due to MET & non-ANS	Large delays due to ANS	No MET regulations		Very large delays due to ANS & MET

- Train the metamodel for the representative days of the Bordeaux ACC
- Add the hourly traffic counts of the day in the Bordeaux ACC as inputs of the metamodel

Extended R-NEST metamodel concept

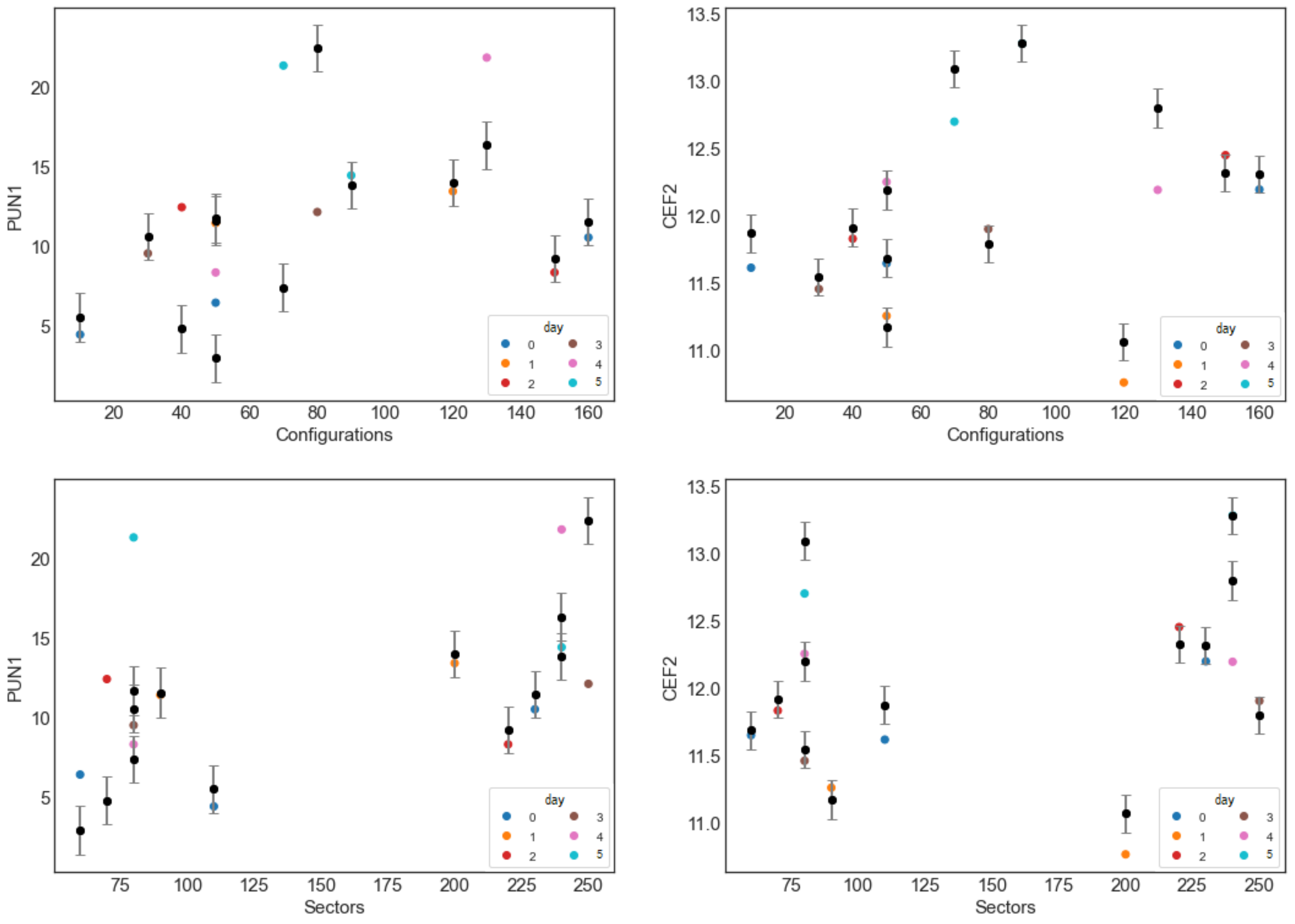


Results – AIRAC R-NEST metamodel

65 points were used to train this metamodel (**2.36%**)

Predictive performance assessment on the validation set with the representative days:

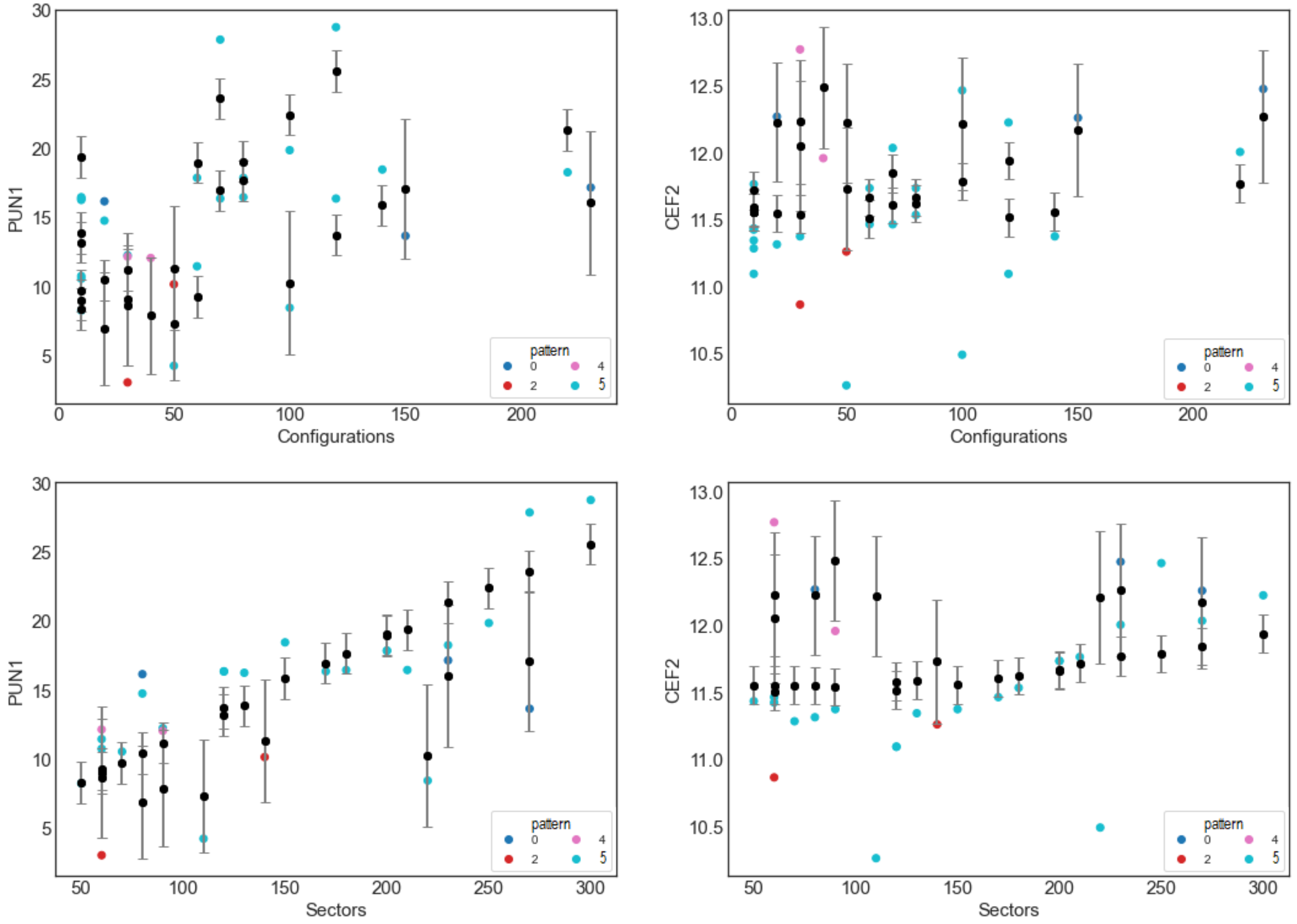
	PUN1	CEF2
RMSE	5.66	0.24
MAPE	0.306	0.015



Results – AIRAC R-NEST metamodel

Predictive performance assessment on the validation set with other days of the AIRAC cycle:

	PUN1	CEF2
RMSE	3.23	0.61
MAPE	0.247	0.035



Conclusions

- The **one-day R-NEST metamodel has good predictive performance**

- The **AIRAC cycle R-NEST** metamodel reaches **good predictive results for the CEF2** variable in the validation set with the representative days. For the PUN1 variable, the results are worse

- The results of the AIRAC cycle R-NEST metamodel for the validation set with different days are worse
  - ➢ The metamodel **has not enough information to accurately generalize**

- The results obtained show the **potential of the proposed methodology**

Future work

- To improve the performance of the AIRAC cycle R-NEST metamodel and further demonstrate the presented metamodelling approach:
  - enlarge the training set with more points
  - take more representative days (the days of the AIRAC with the lowest silhouette score per cluster)
- Extend the metamodel for the whole year
- Explore the applications of active learning metamodelling: e.g., optimal scenario discovery

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for your attention!

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