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Increasing Automation in ATM and Airport Operations

Insights from the AEON and ARTIMATION projects

9th November 2022
ENAC ACHIL LAB

AEON

ARTIMATION

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Agenda

Time	Description
09:00 – 09:30	Welcome coffee and registration
09:30 – 09:50	Presentation of the Agenda, objectives of the event
09:50 – 10:20	***Keynote:*** *Artificial intelligence: application on ATM (Dr. Daniel Delahaye)*
10:20 – 11:10	Reduced Ground Emissions through Innovative Taxiing Techniques – **AEON project outcomes**: "A Concept of Operations integrating Autonomous and Non-Autonomous Taxiing Techniques".
11:10 – 11:30	**Q&A Session**
11:30 – 11:50	**Coffee break**
11:50 – 12:40	Transparent Artificial Intelligence and Automation to Air Traffic Management Systems – **ARTIMATION project outcomes**: "Conflict Detection and Resolution Visualisation and Delay Prediction results".
12:40 – 13:00	**Q&A Session**

Agenda

Time	Description
13:00-14:00	LUNCH
14:00 – 14:30	Introduction to DEMOS
14:30 – 16:30	**DEMOS** ● **AEON DEMO#** Tug Fleet Manager and Ground ATCOs working positions and the operations ● ARTIMATION DEMO#1 CD&R Validation setup ● ARTIMATION D EMO#2 Delay prediction ● ARTIMATION DEMO#3 MindTooth

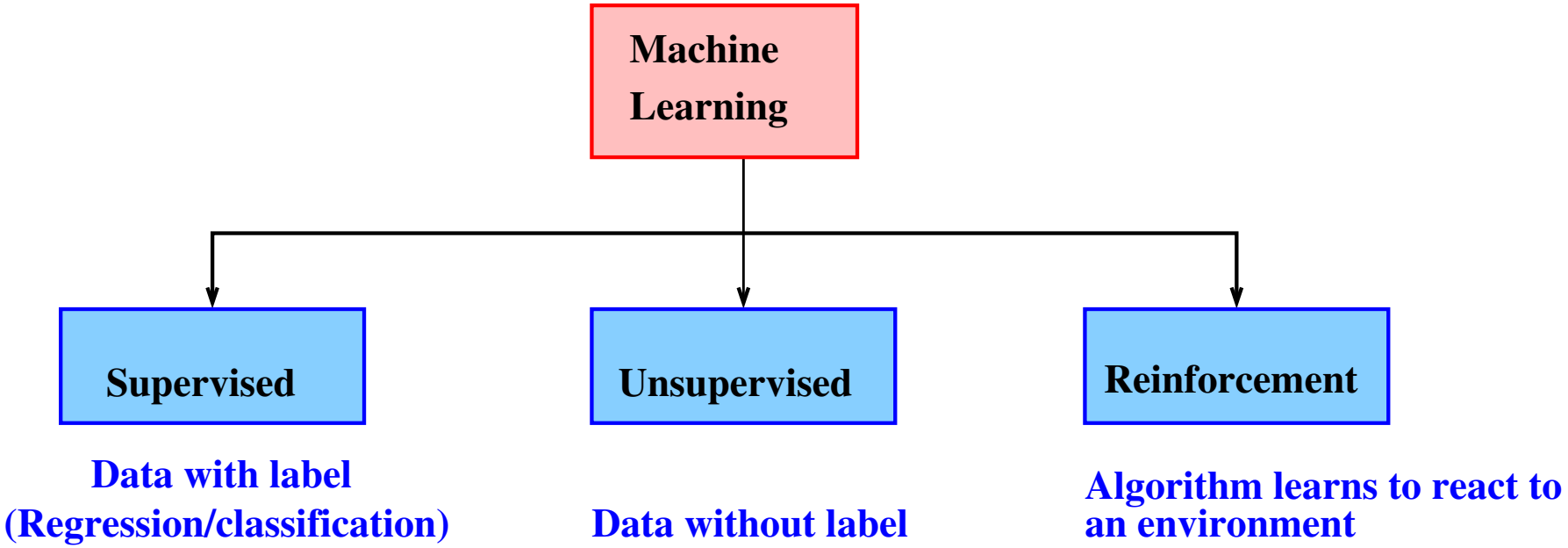
Artificial Intelligence : Application to ATM

Pr D. Delahaye

(OPTIM team) French Civil Aviation University
ANITI Research Chair (AI for ATM and UTM)
Toulouse France

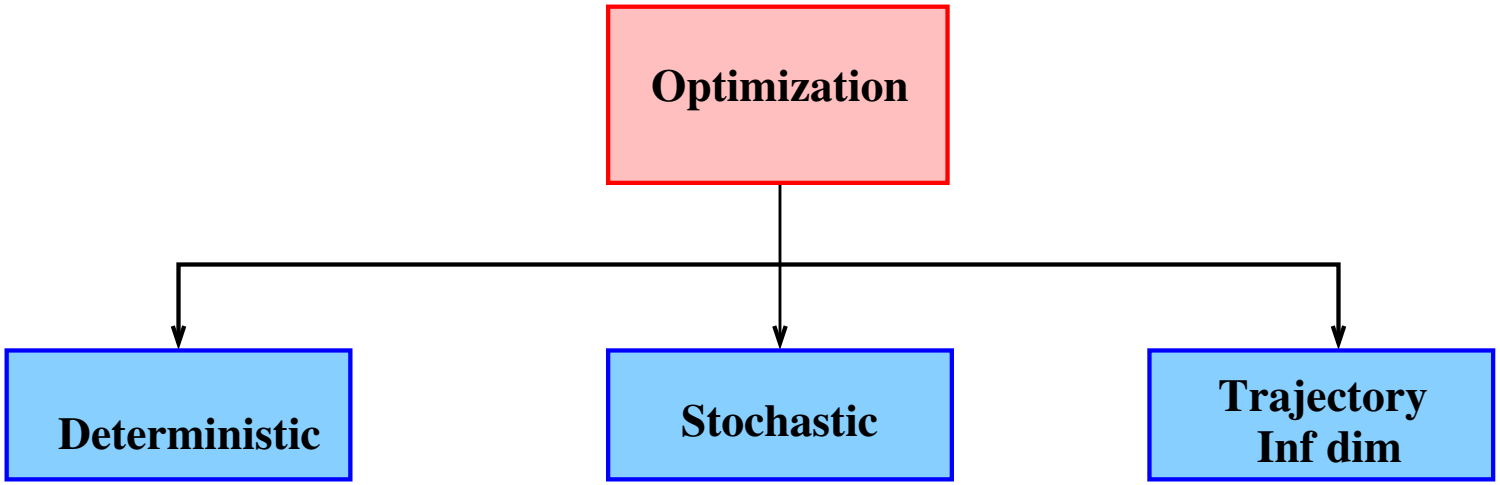
November, 9, 2022

ML Algorithms



- Neural Networks (CNN, LSTM, GNN, PINN, BNN, BPINN,...)
- Support Vector Machines
- Random Forests
- ...

Optimization Algorithms



Deterministic

- LP(1963)IP(1984)
- DFO (1960)1,2)
- Order 1 (1847)
- Order 2 (1697)BFGS(1987)
- Cont Def (1981)
- B&B(1960)
- Enum
- ...

Stochastic

- Monte Carlo(1980)
- B&prob B (1998)
- SA(1983)
- Taboo(1986)
- AE(1966)
- PSO(1995)
- Hyper−heuristics(2003)
- ...

Trajectory Inf dim

- DP(1950)
- FM (1994)
- Ord Upwind(1996)
- Opt Control(1956)
- Harmonic functions(1998)
- RRT,RRT*(1998)
- FMT,FMT*(2013)
- A*,D*(1991)
- Ant Col(1991)
- Dim Reduction (Spline, KL,...)
- ....

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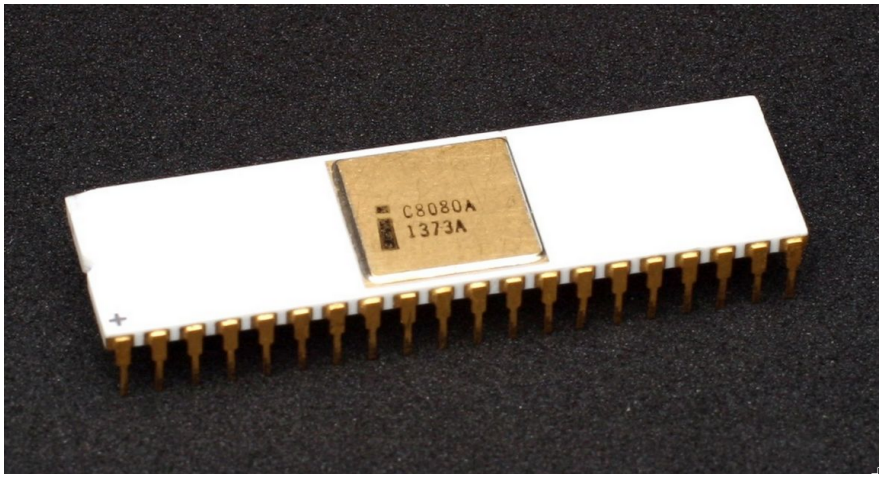
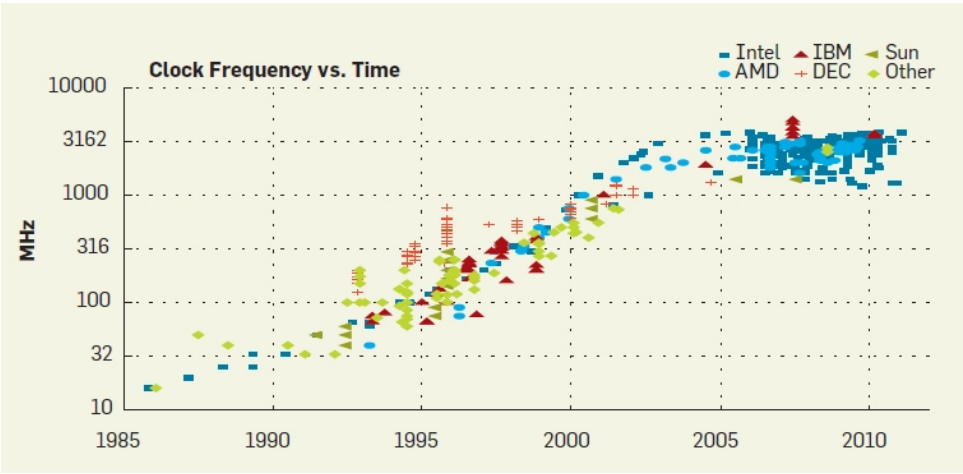
Why it works now ?

Nothing new under the sun but ...

CPU

In the eighties, popular micro-processors were the i8080, Z80, i8085, Motorola 6809, Motorola 6502 (8 bits , 1 or 2 Mhz, 64k memory, $\simeq$ 6000 transistors) then i8088, i8086, Motorola 68000, iAPX2-486, Pentium,(16 bits), ...





CPU clock frequency is stuck ....
$\Rightarrow$ GPU

GPU

Figure: Nvidia GeForce RTX 2080 Ti, CUDA Cores: 4352, $\simeq$ 30 TFLOPS ....

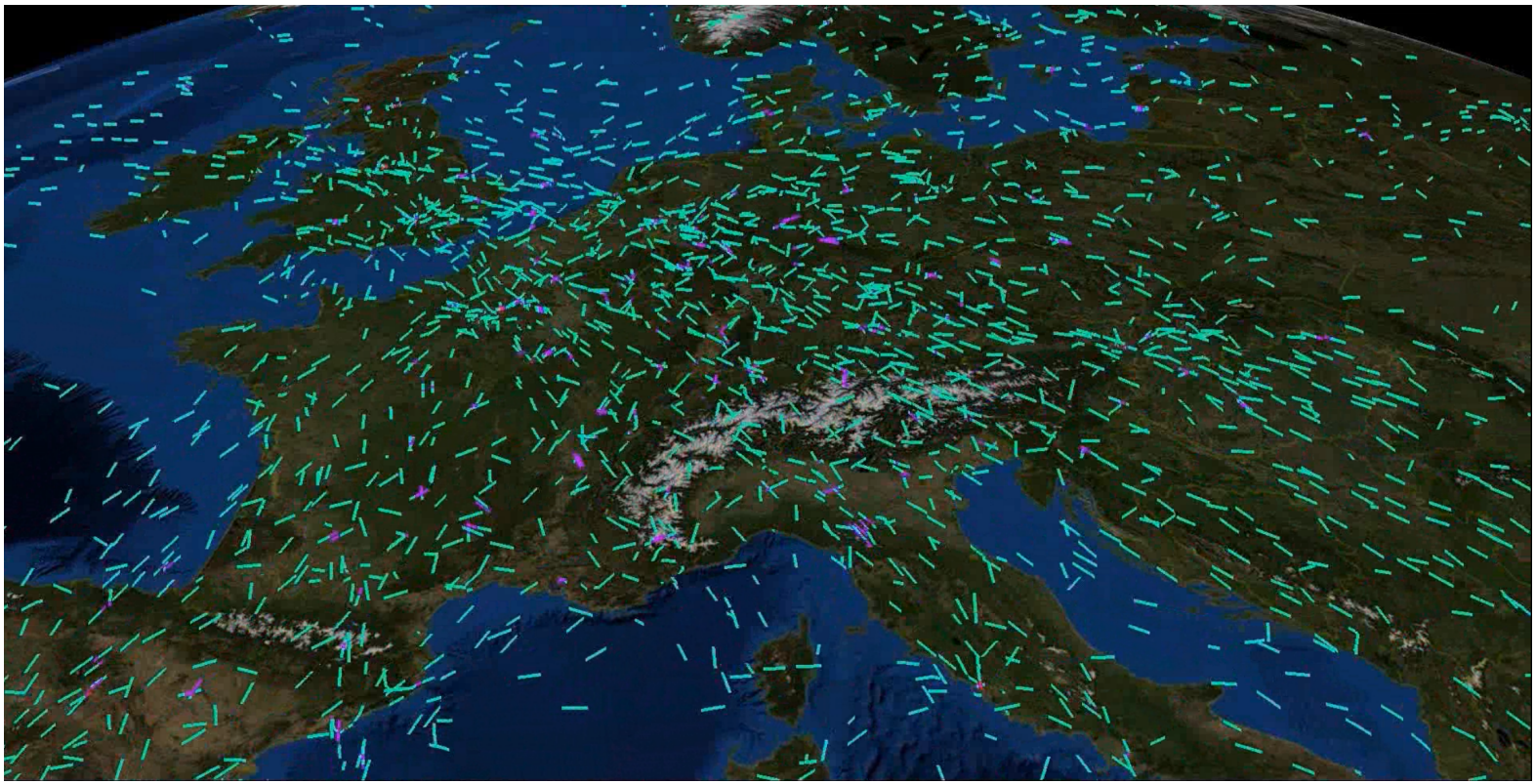
The i8080 with 6000 transistors could be integrated at the scale of a bacteria $\simeq 5\mu m$ ...

Examples of ATM Applications

Large Scale Trajectory Planing

Strategic Conflict Free Planning

4D bubbles separation by meta-heuristic algorithm (32000 flights)



Results Produced !

AMAN-SMAN-DMAN Integration
JI.MA PhD

Towards integrated approach

- Arrival Management Problem
- Landing sequencing
- Ensure proper separation

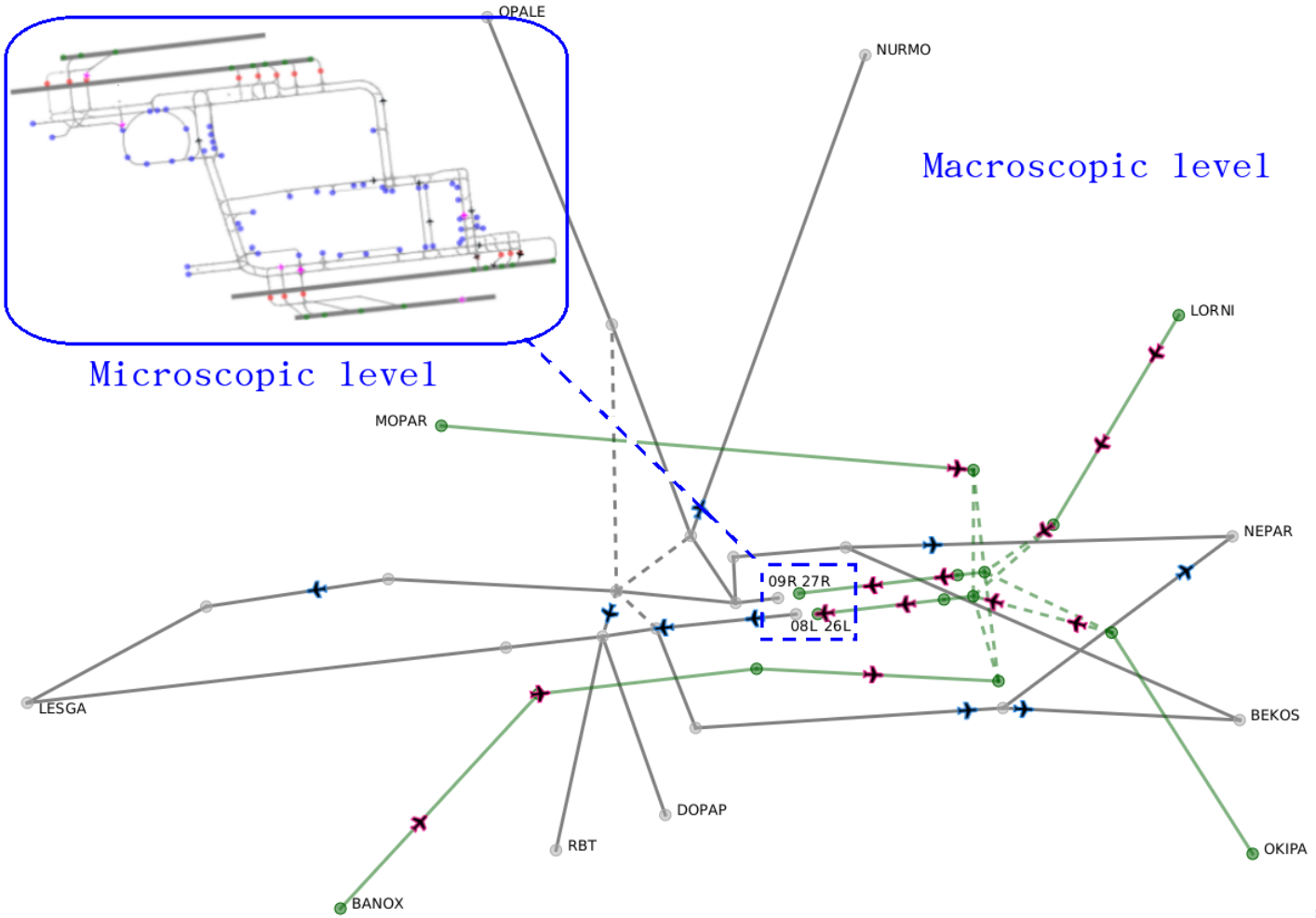
- Surface Management Problem
- Arriving aircraft taxi-in routes
- Departing aircraft taxi-out routes

- Departure Management Problem
- Take-off times and sequences for departing flights
- Ensure proper separation

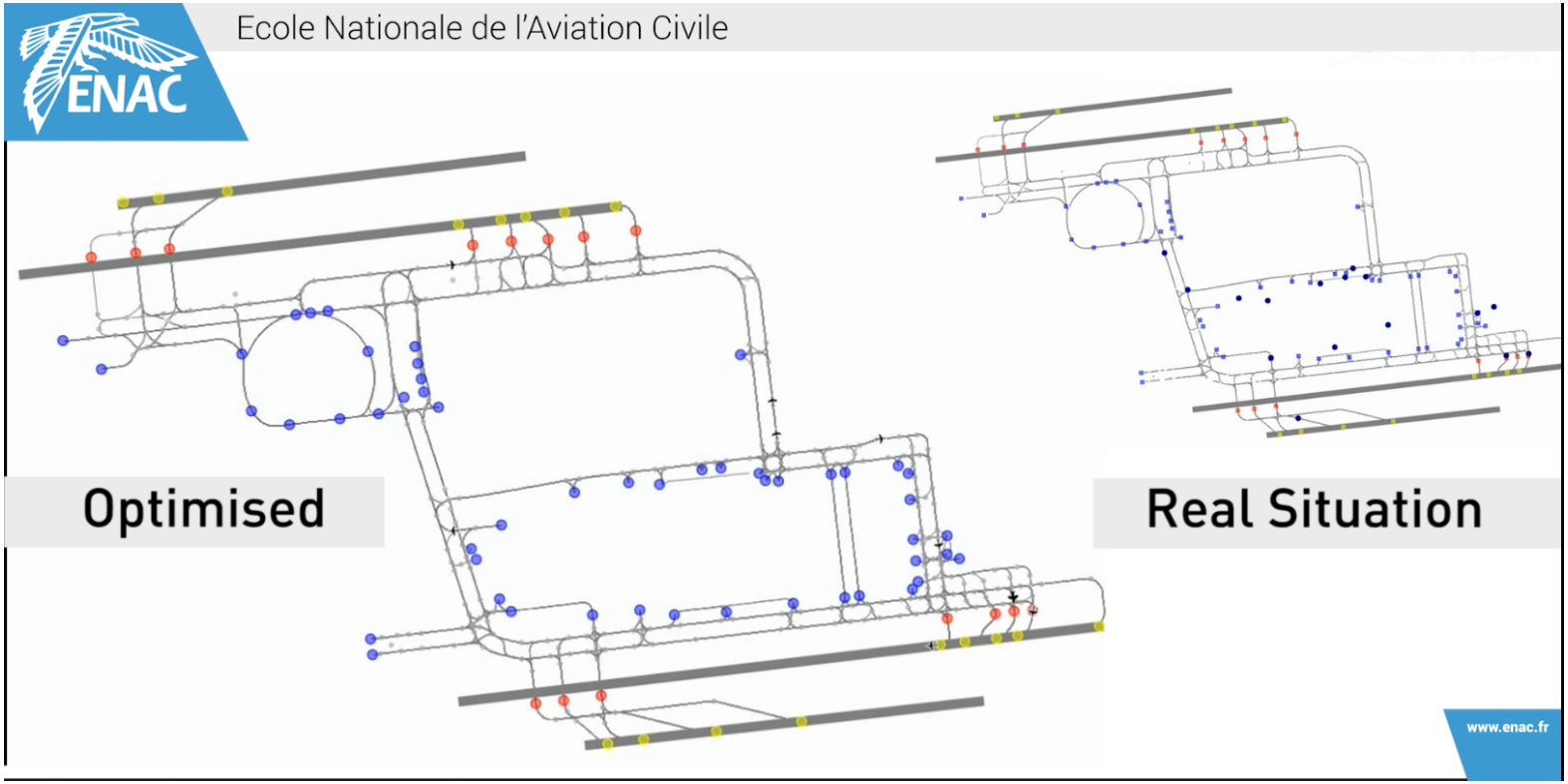
Integrated optimization of TMA and airport

The models are divided with regard to the temporal horizon of problem:

- Macroscopic model (long-term decision, 30 minutes in advance);
- Microscopic model (short-term decision, 5 minutes in advance).



Results on CDG

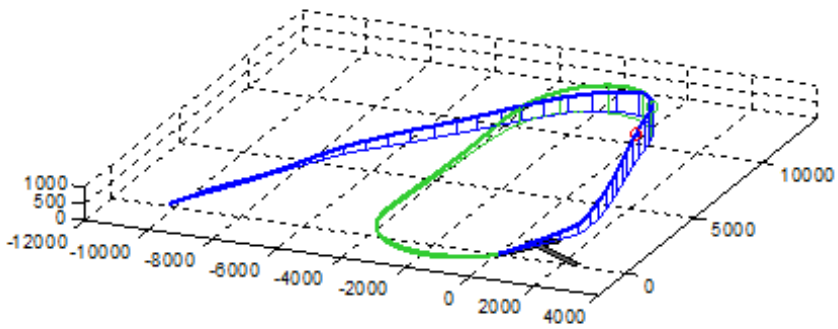


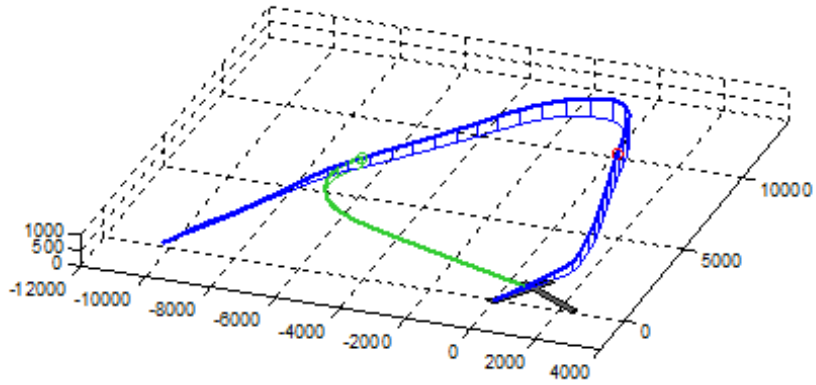
AMAN-SMAN-DMAN Video at CDG !

Emergency Trajectory Design

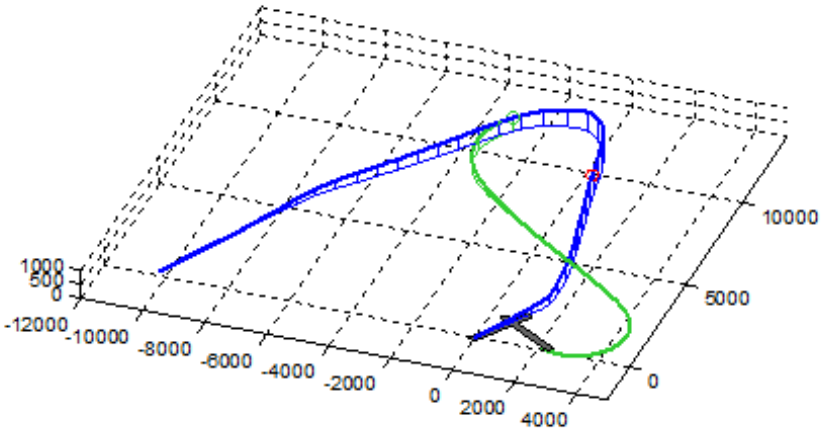
Test Case : US Air 1549

Runway 4

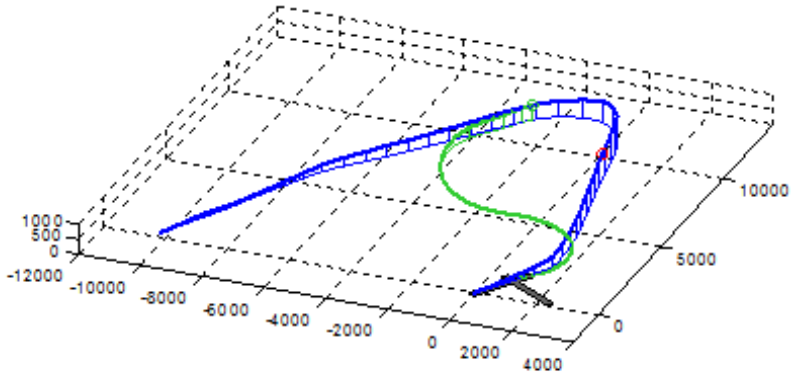




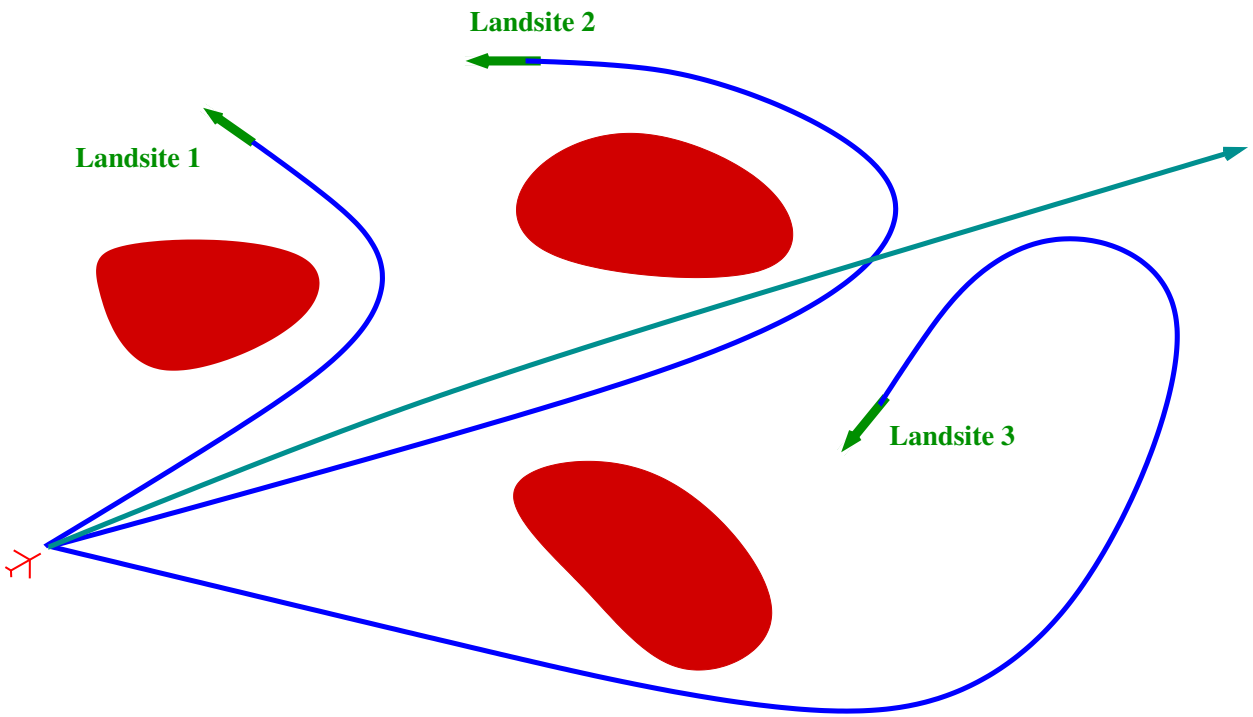
Runway 13



Runway 22

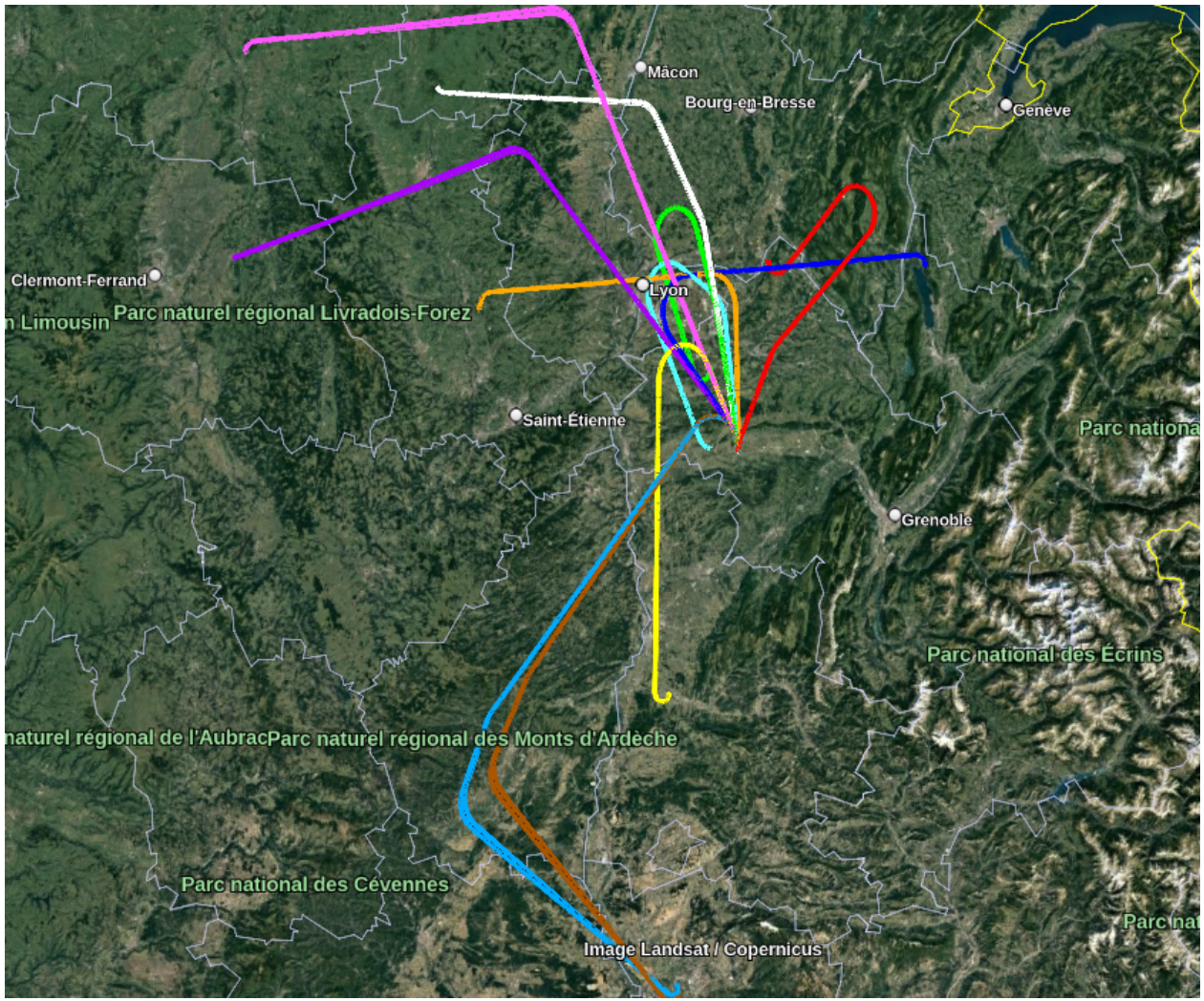


Principle

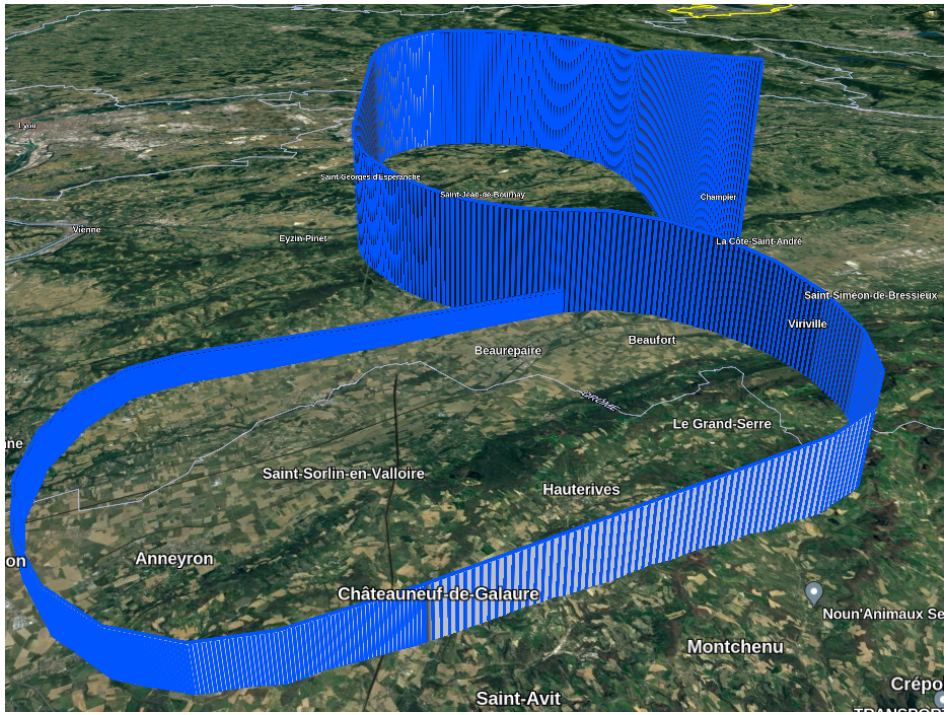


Extension with Safency project

FMT* algorithm (10 ms computation /traj...)



Extension with Safency project



A.Guitart, D.Delahaye and E.Feron. An Accelerated Dual Fast Marching Tree Applied to Emergency Geometric Trajectory Generation. Aerospace, March 2022.

L.Ligny, A.Guitart, D.Delahaye, and B.Sridhar. Aircraft Emergency Trajectory Design: A Fast Marching Method on a Triangular

Mesh. In 14th USA/Europe Air Traffic Management Research and Development Seminar, New-Orlean, United States,

September 2021.

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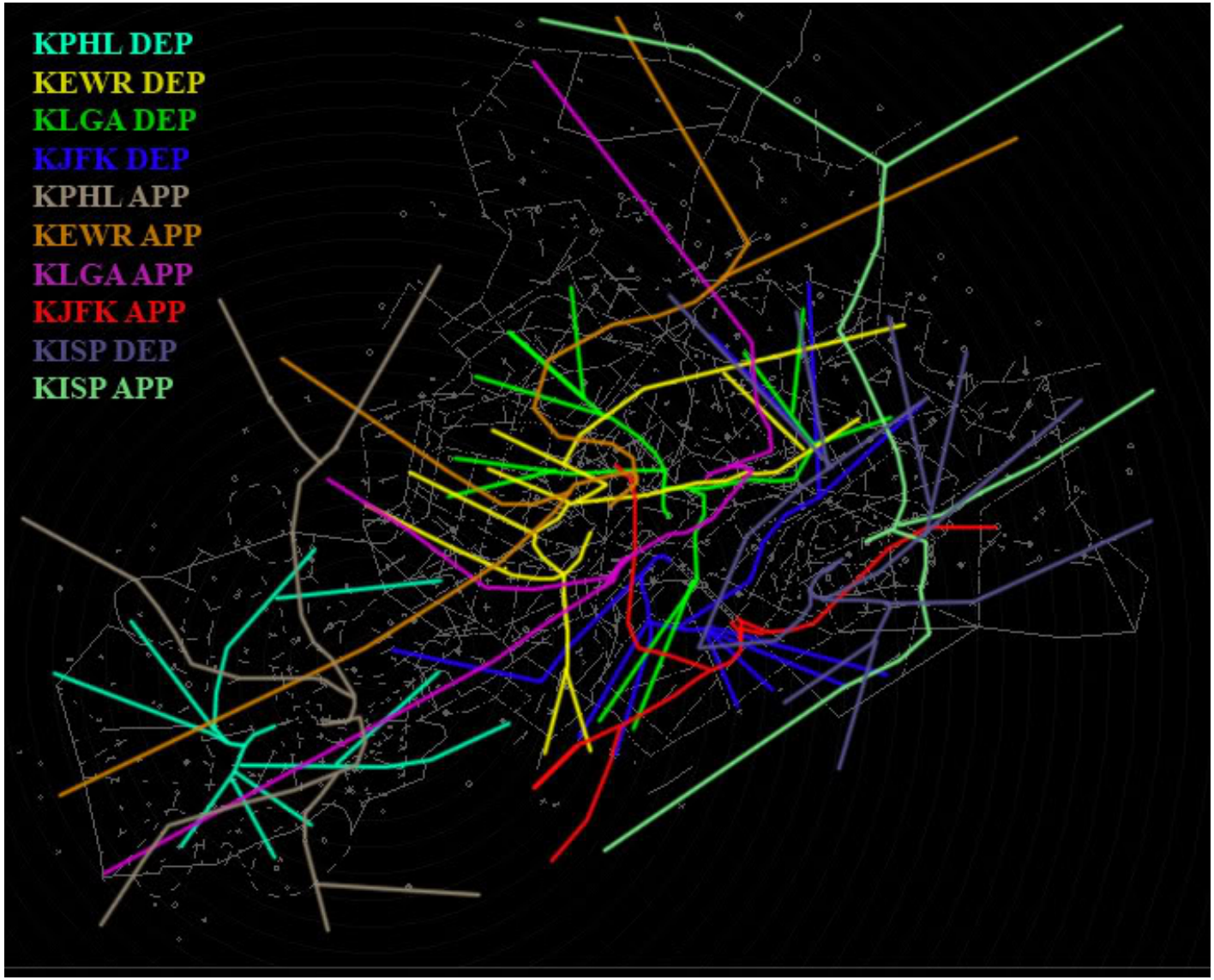
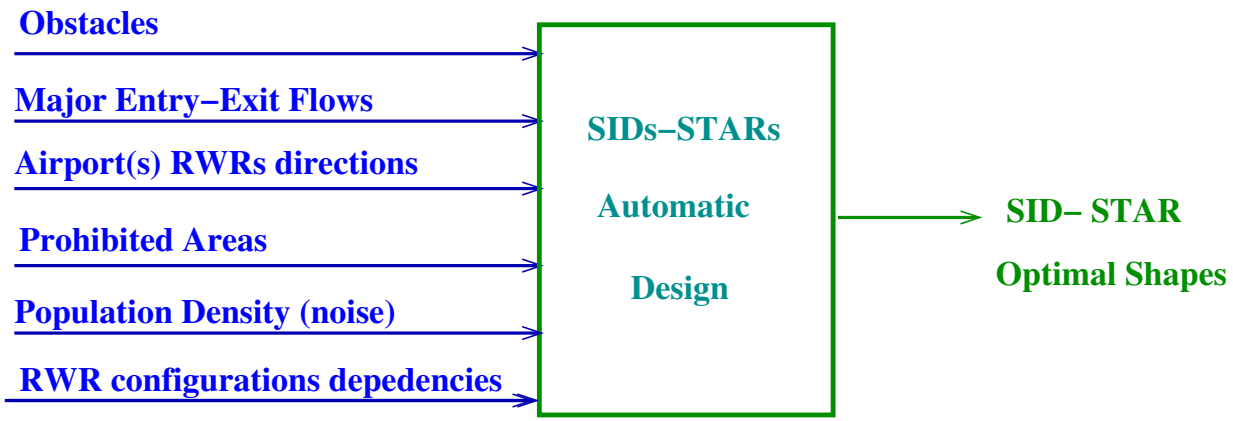
SID-STAR Design

London TMA

New-York SID-STAR

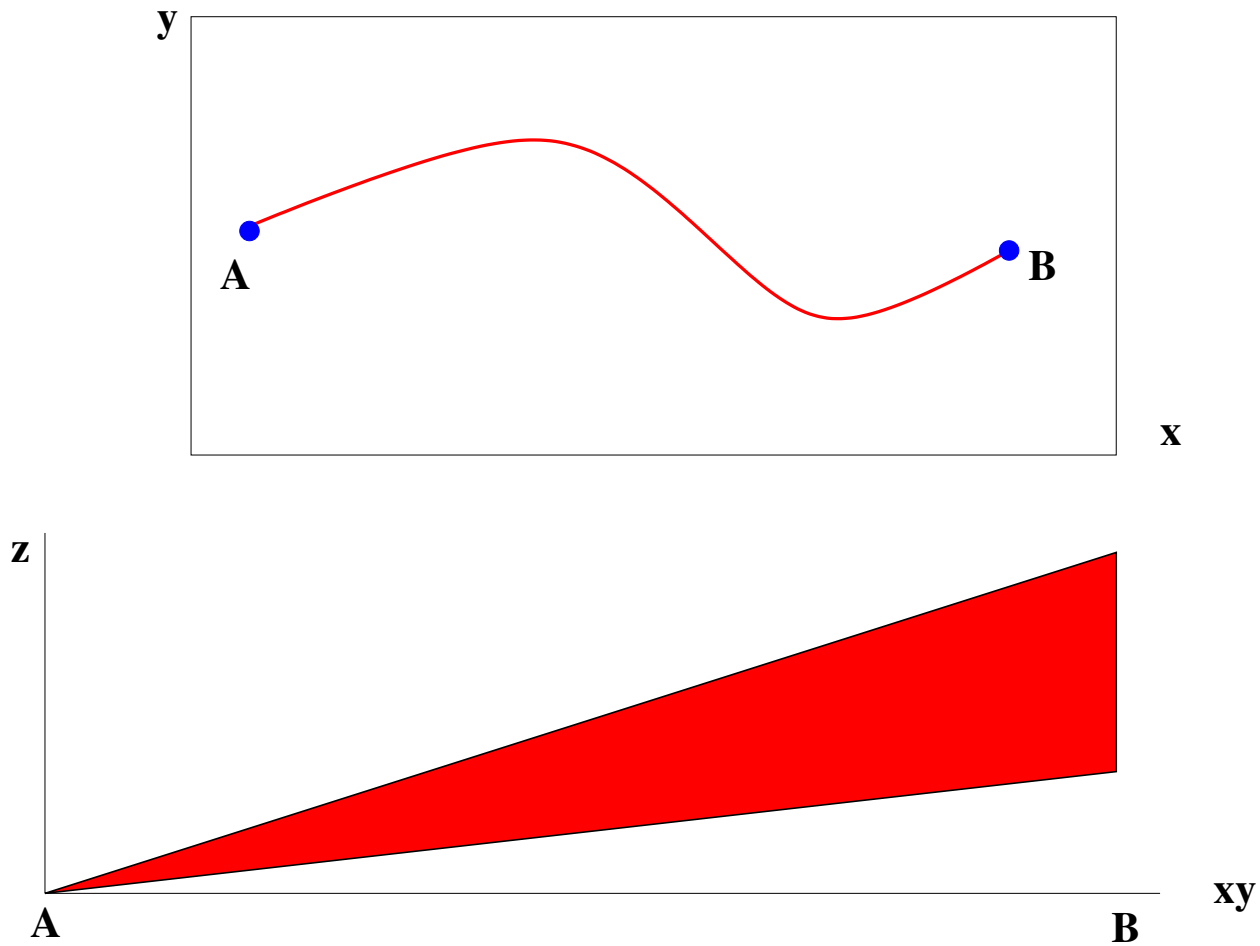


Automatic SID-STAR Design



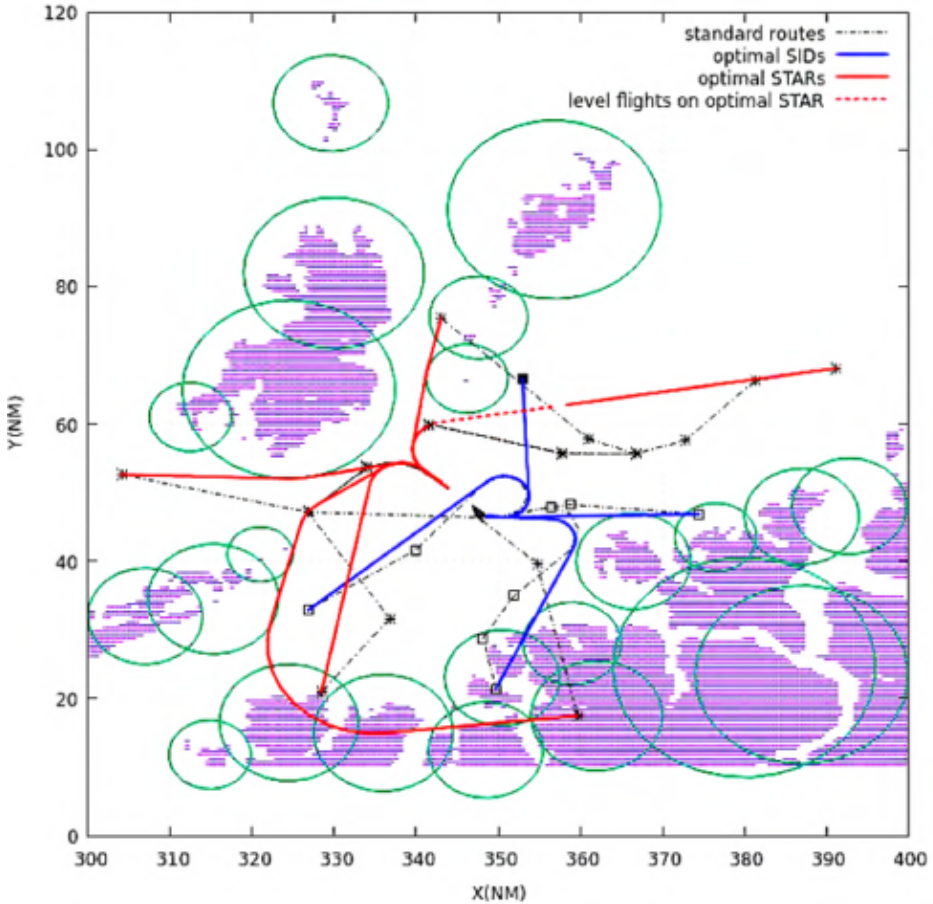
Principle

Shape optimization with vertical profile contraint



Example of application Zurich

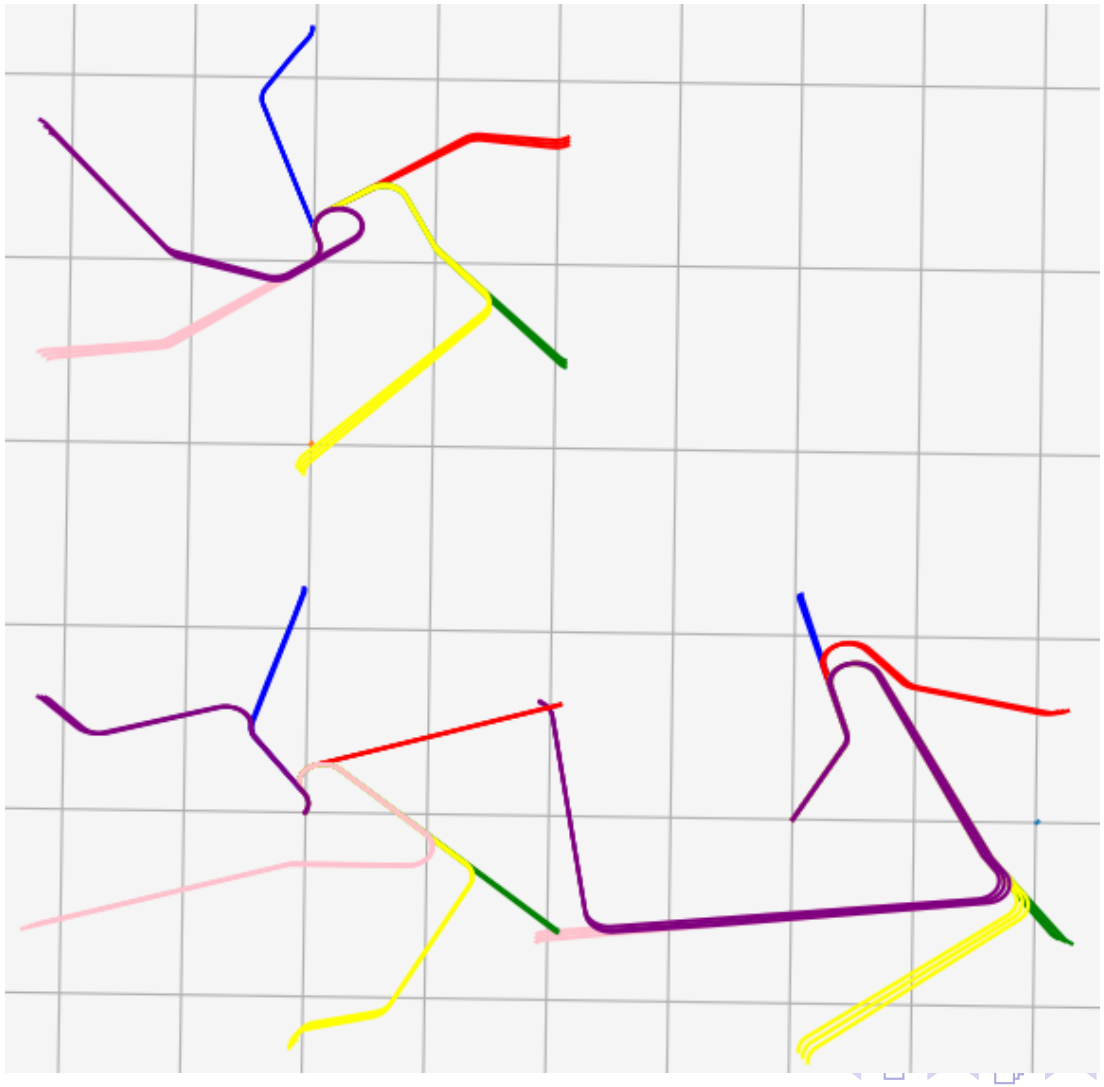
Meta-heuristic, B&B



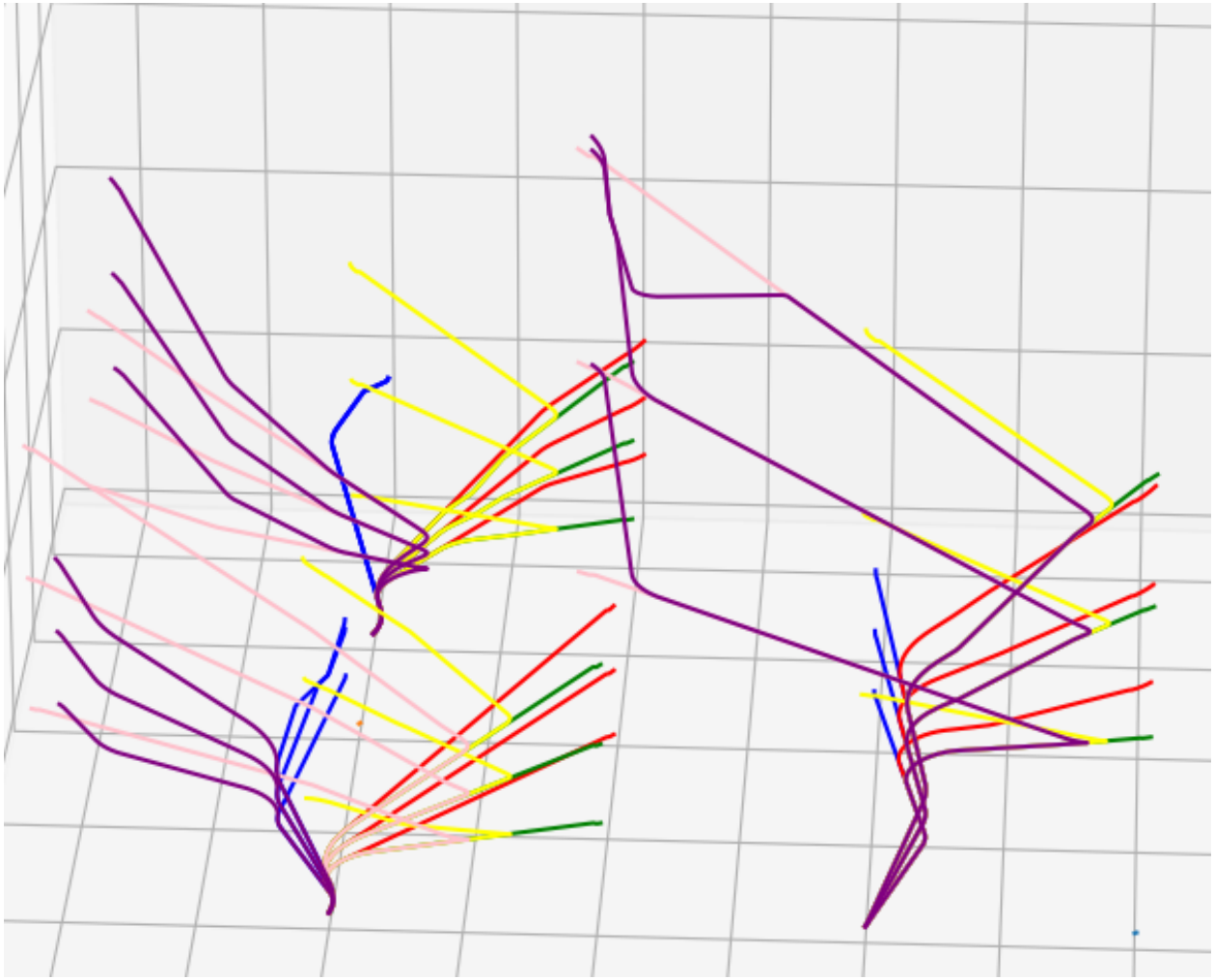
J.Zhou, S.Cafieri, D.Delahaye and M.Sbihi. Optimization-Based Design of Departure and Arrival Routes in Terminal Maneuvering Area . Journal of Guidance, Control, and Dynamics, 40(11):pp. 2889–2904., October 2017.

Extension to Multiple Airports

Approach based Meta-heuristic+ RRT*
The merging locations are also optimized

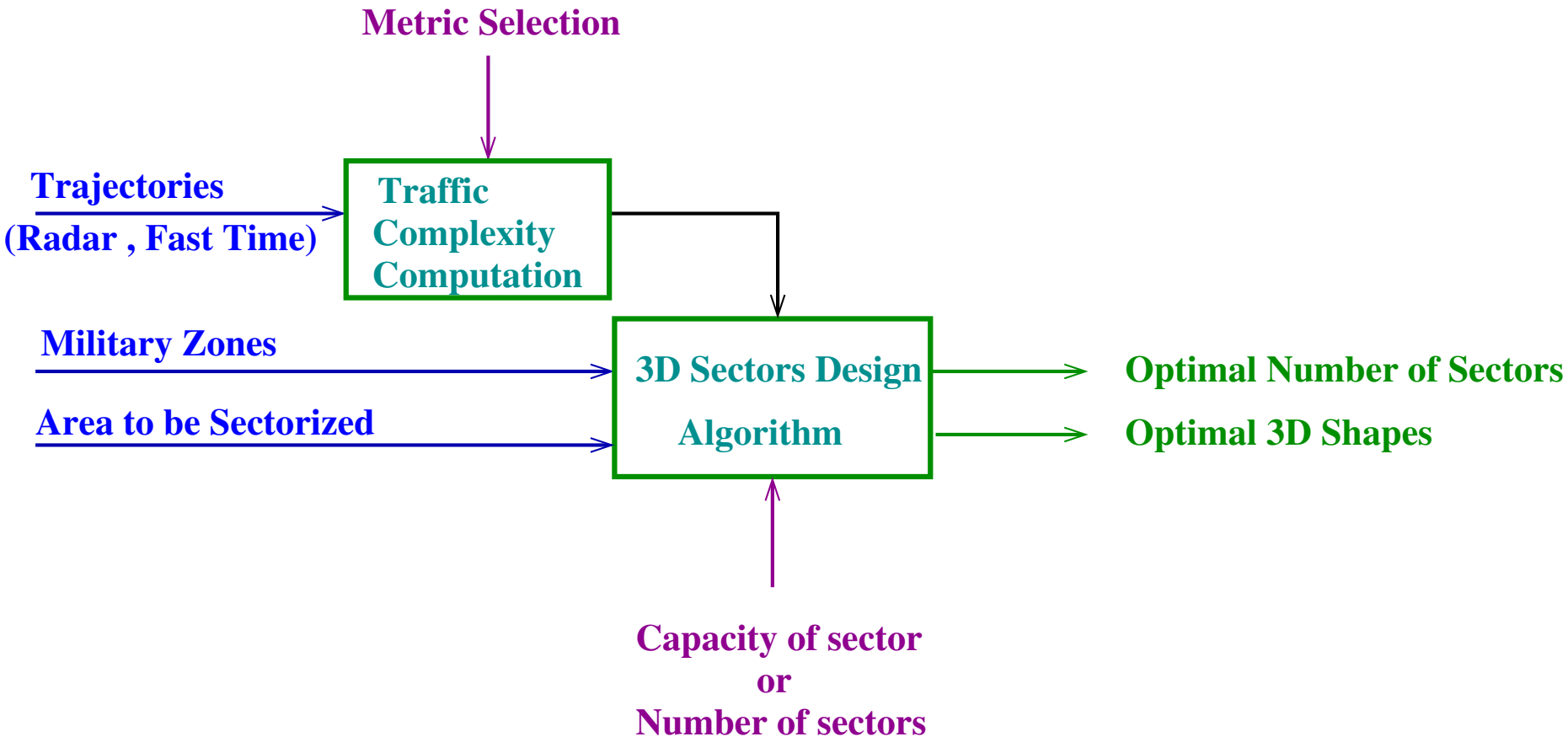


3D visualization

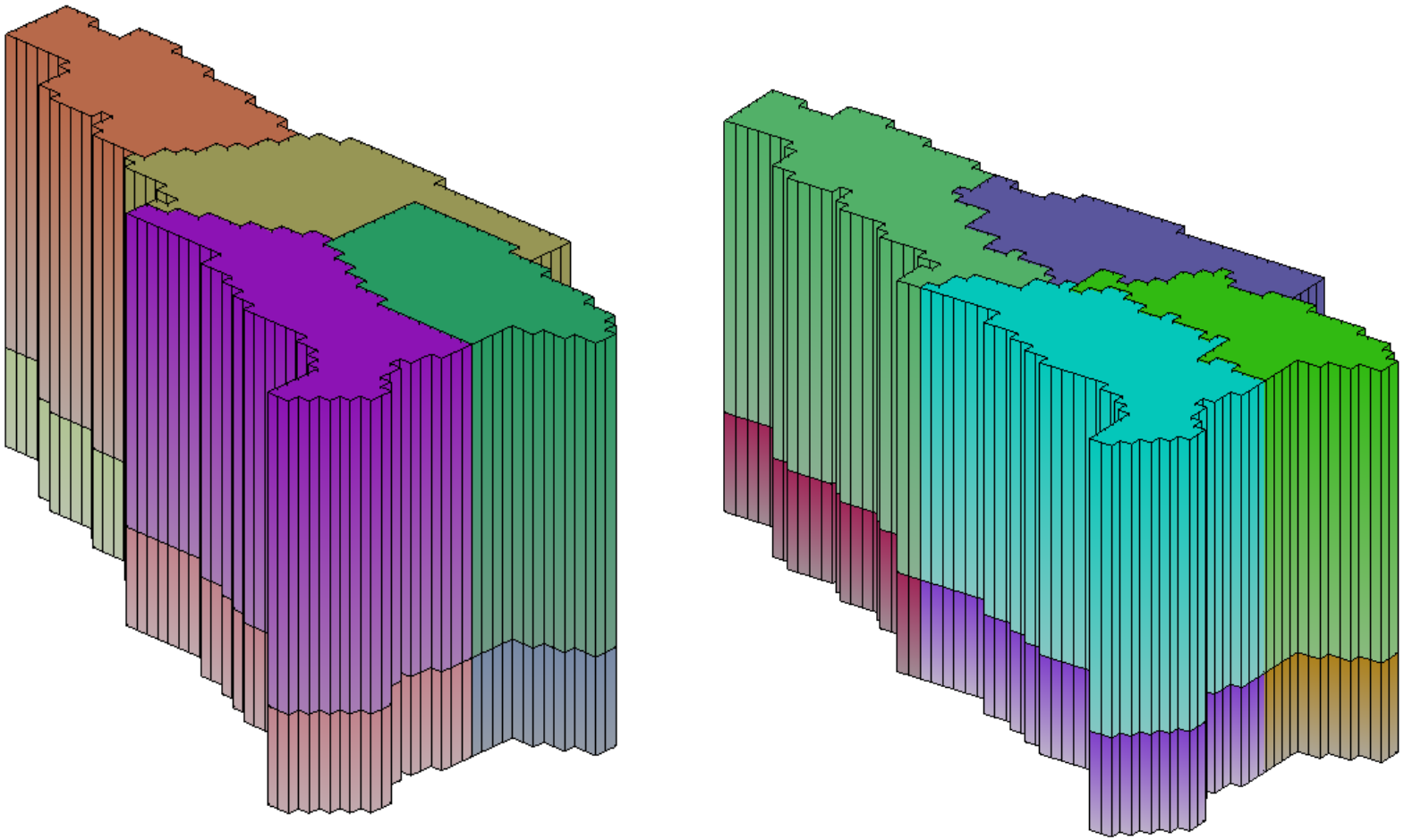


Automatic Sector Design

Automatic Sector Design Algorithm



Application to Reims ACC

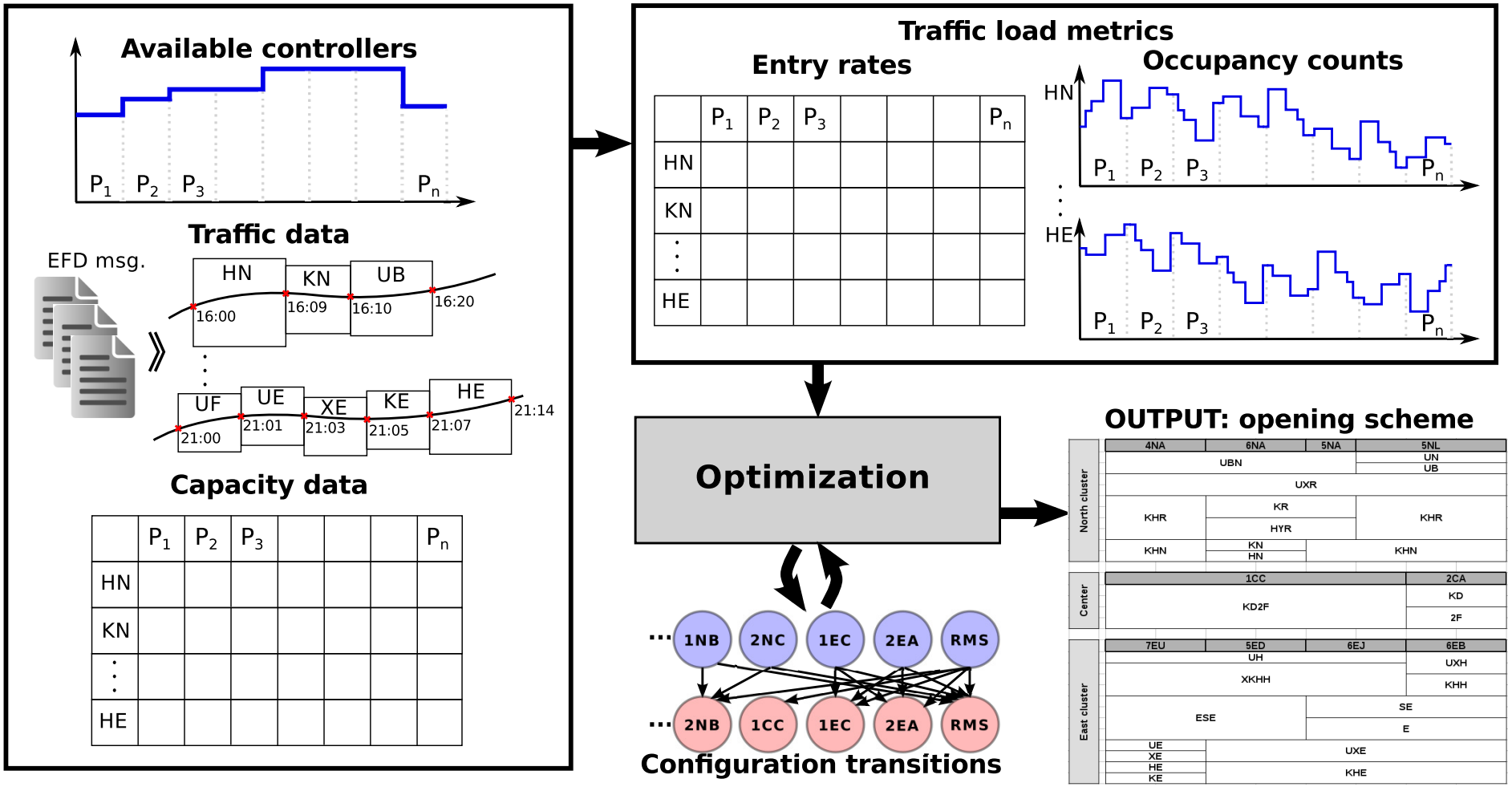


Real sectors on the left, sectors produced by the algorithm on the right

DST for ACC Configuration Optimization 4-CAST (implemented in all French ACC)

Dynamic assignment of sectors to controllers

Approach Based on Optimization (DP+ML)



Non Stabilized Approaches (NSA)

Non Stabilized Approaches (NSA)

Figure: Turkish Airlines Flight 1951 was a passenger flight that crashed during landing at Amsterdam Schiphol Airport, Netherlands, on 25 February 2009.

Video !

Algorithm Results

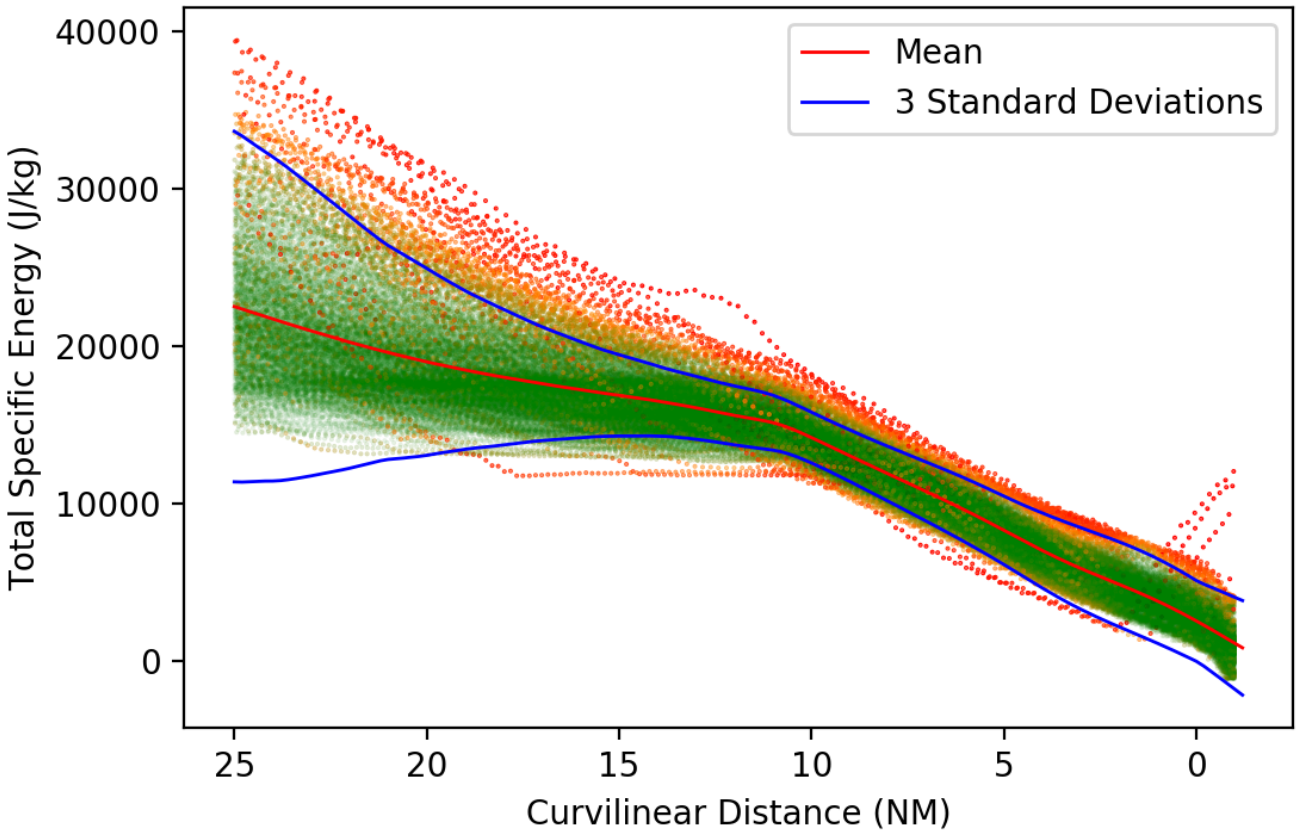
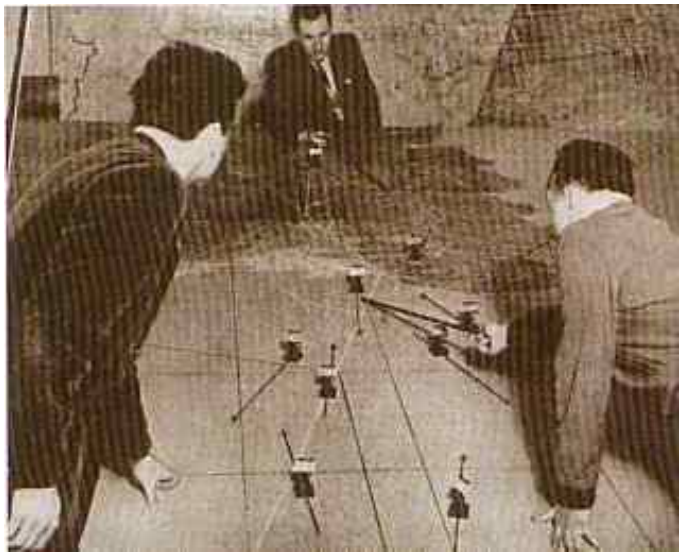


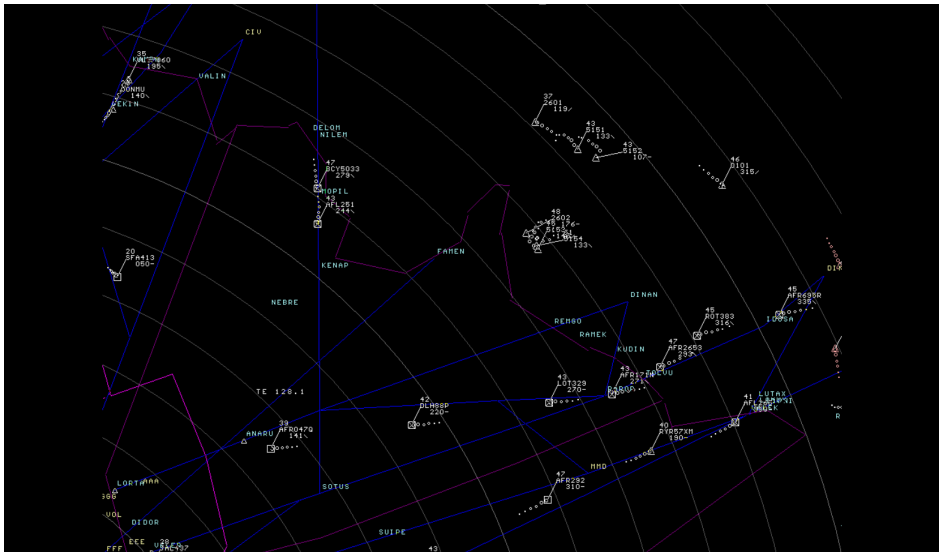
Figure: Algorithm results over the whole trajectories

What About Automation ?

Evolution of the on-board system

Evolution of the ground system

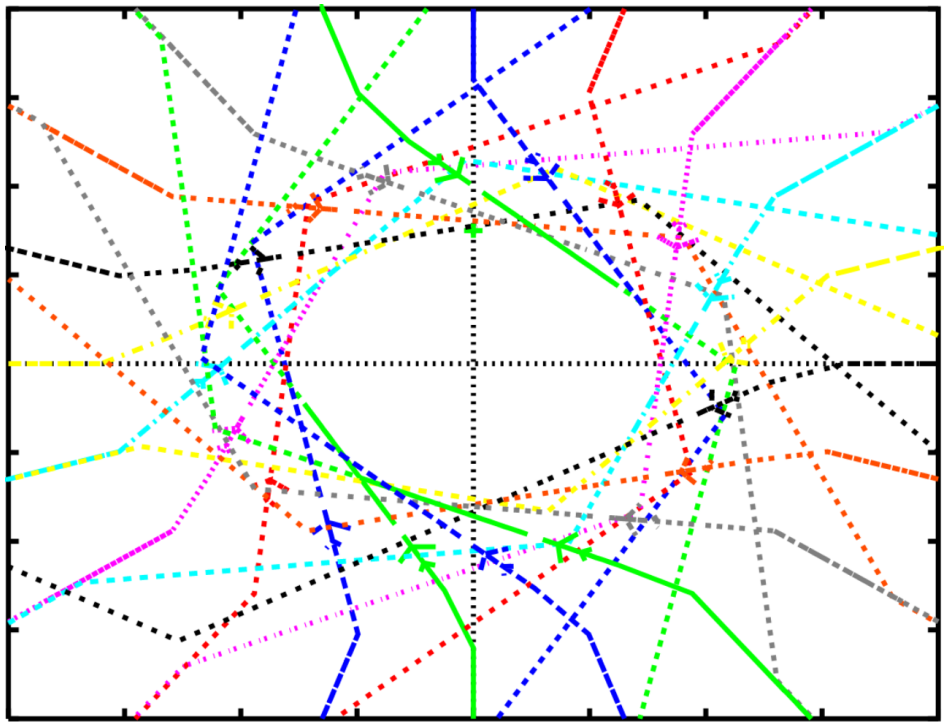




Examples of CDR Algorithms

Conflict Resolution DST based on GA

Complexity for n aircraft:
$2^{\frac{n(n+1)}{2}}$ linear programs with $\frac{n(n+1)}{2}$ constraints $\Rightarrow$ NP_Hard problem $\Rightarrow$ Meta-heuristics



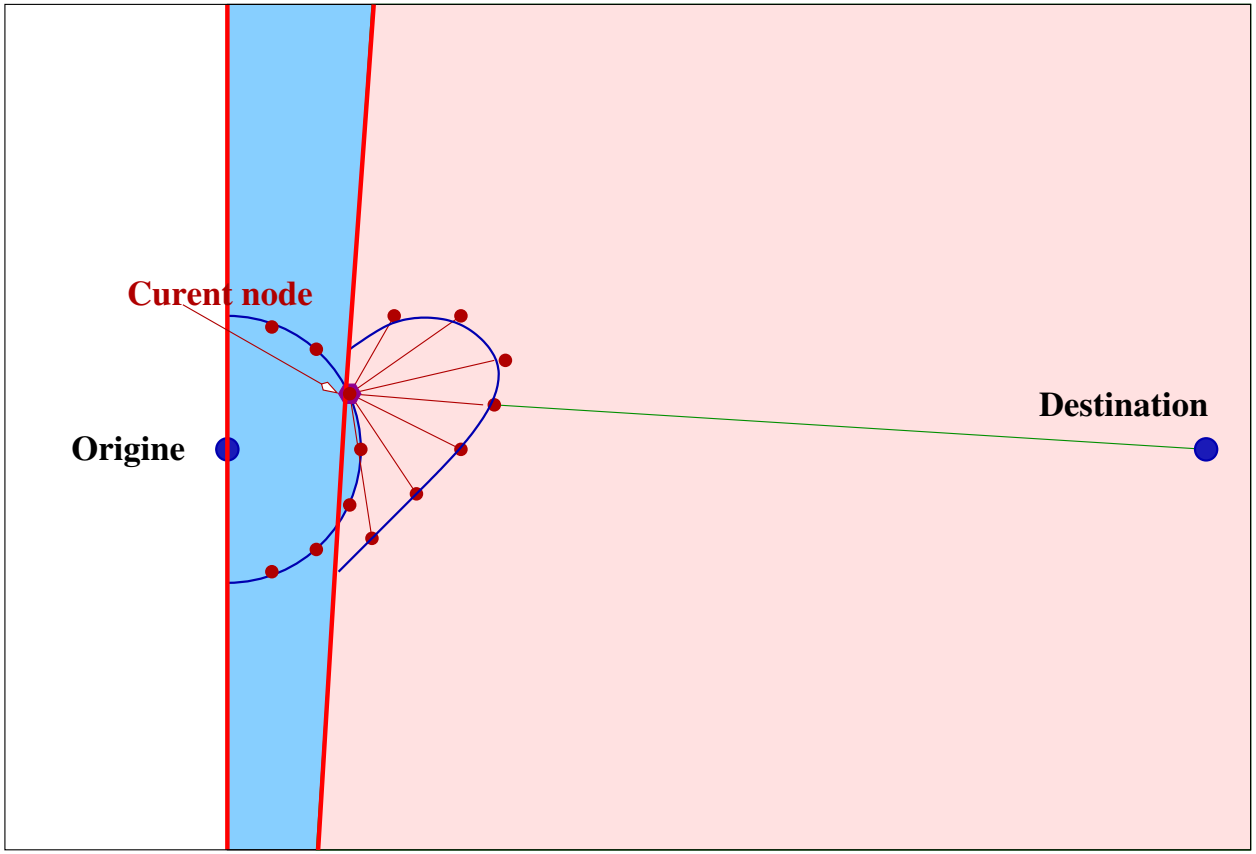
$1.64 \times 10^{63} \Rightarrow 5.321 \times 10^{46}$ Years (1 evaluation nano sec)

The light propagation method

The light propagation analogy

- Light follows Geodesic in time thereby avoiding areas of high index.
- Light propagation is controlled by the Descartes law.
- Trajectory planning can be achieved by computing wavefronts.

Principles of the light propagation method



Geodesic computation (A^* like algorithm or Triangle mesh algorithm)

Conflict Resolution for a full day of traffic

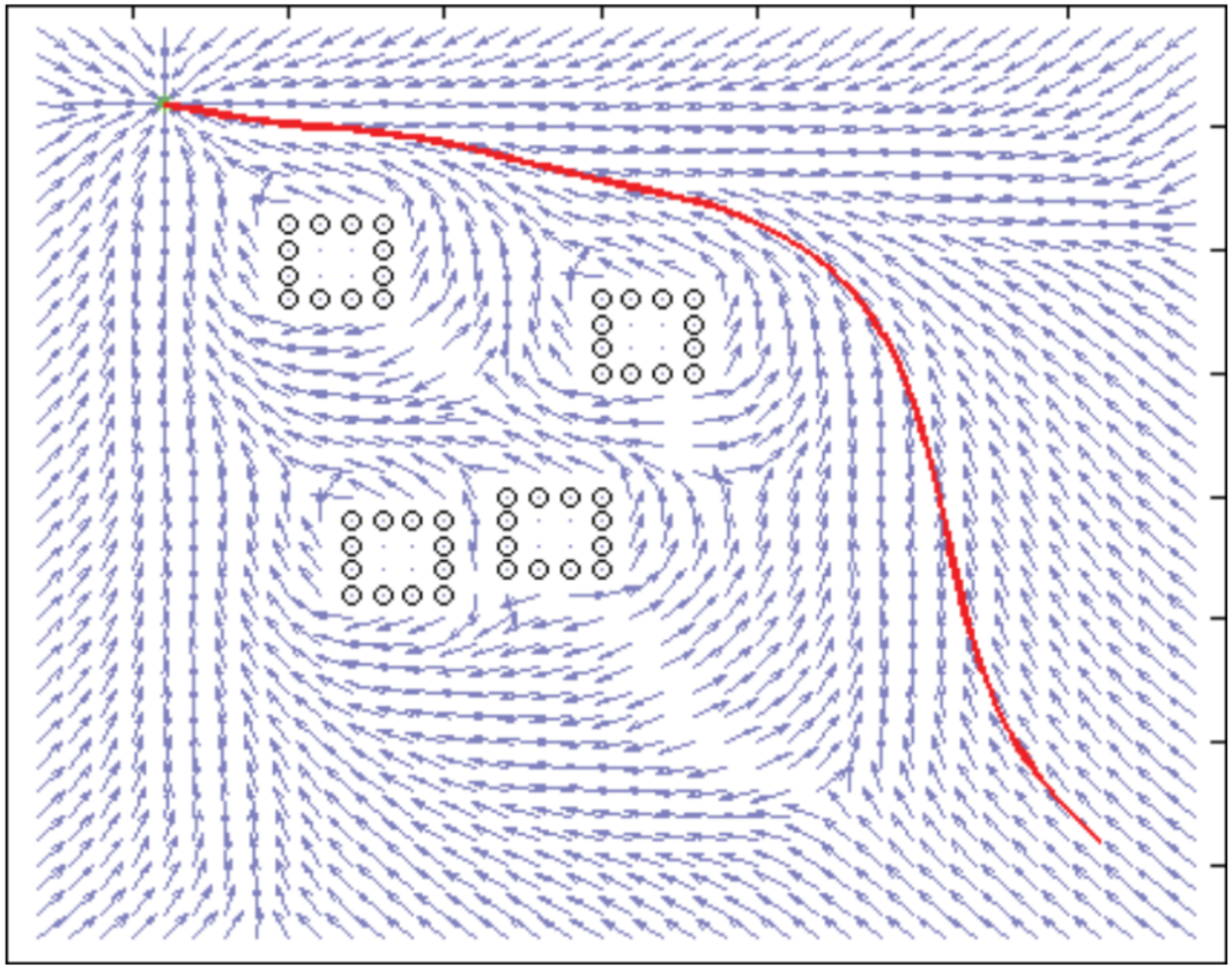
Numerical Results

The 8/12/2008 traffic day was tested with 8212 aircraft.

- 3344 clusters.
- 100% of clusters were resolved
- Number of modified trajectories is 1501.

Dougui, N and Delahaye, D and Puechmorel, S and Mongeau, M, *A Light-Propagation Model for Aircraft Trajectory Planning*,Journal Of Global Optimization, July 2013, V56

Biharmonic Navigation Functions



Biharmonic Navigation Functions

- Ensure conflict free trajectory design
- With mathematical proof
- With speed range constraint
- With curvature constraint
- May be used in tactical phase

L.Guys, S.Puechmorel. Automatic conflict solving using biharmonic navigation functions. EWGT 2012, 15th Meeting of the EURO Working Group on Transportation, Sep 2012, Paris

CDR Algorithms

ATM

- Centralized
- Done by humans
- Mainly on the ground

UTM

- Has to be de-centralized
- No human
- Done on board
- May be a nice framework to try algorithms which could be applied to ATM in the future....

Questions ?

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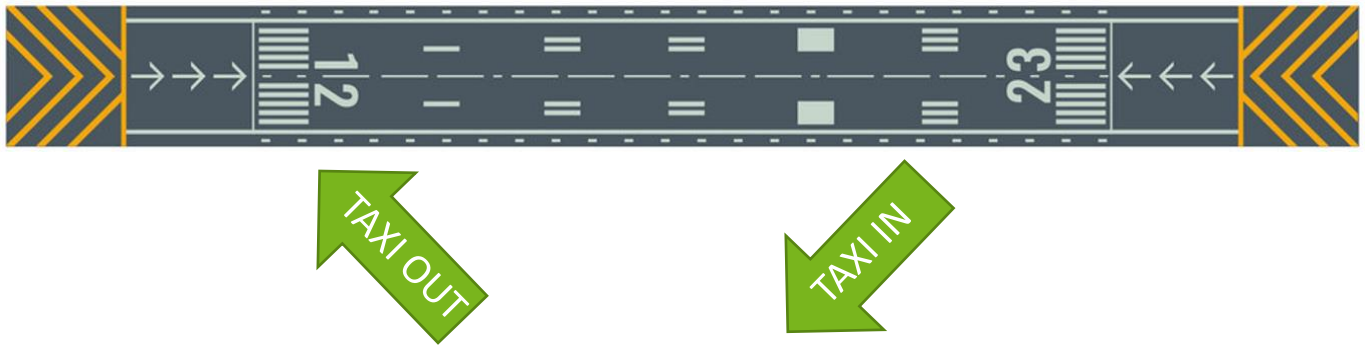
Advanced Engine-Off Navigation

EUROPEAN PARTNERSHIP

Co-funded by
the European Union

Advanced Engine Off Navigation

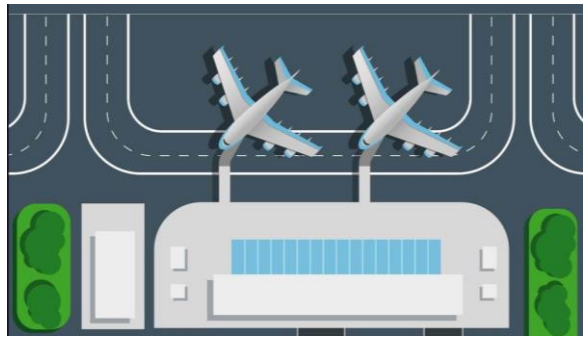


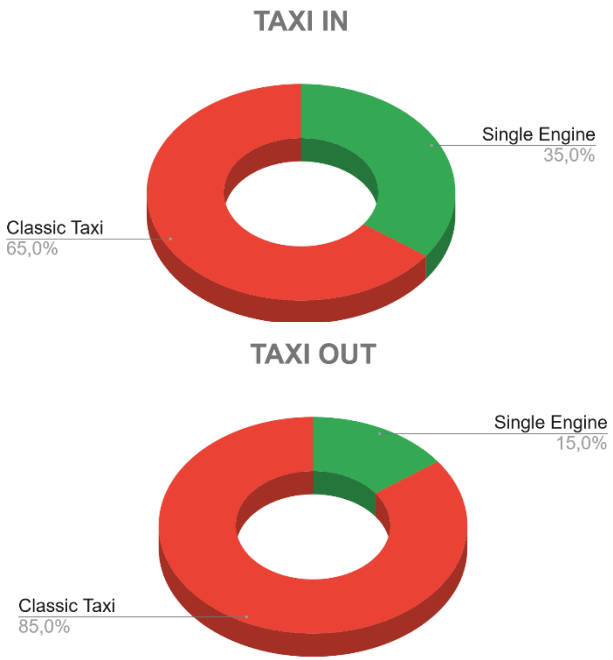
In air,
aircraft engines
are efficient

Not on ground,
where taxi fuel
consumption
represents up to
36% of LTO cycle

Advanced Engine Off Navigation

Today, the principal solution is Single Engine Taxiing





Advanced Engine Off Navigation

ER project funded by the SESAR JU (Nov 20 – Dec 22)

Goal: reducing the environmental impact of ground operations by supporting the use of engine off taxiing techniques

single engine taxiing

autonomous taxiing

non-autonomous taxiing

Advanced Engine Off Navigation

- Autonomous taxi:
  - Better manoeuvrability
  - Lower dynamic performances.
  - Additional weight on board.

- Non autonomous taxi:
  - More vehicles on ground.
  - Airport based system.

- All:
  - Engine start up management.
  - Collaboration between ground operators.
  - Faster turnaround (no deconnection time)

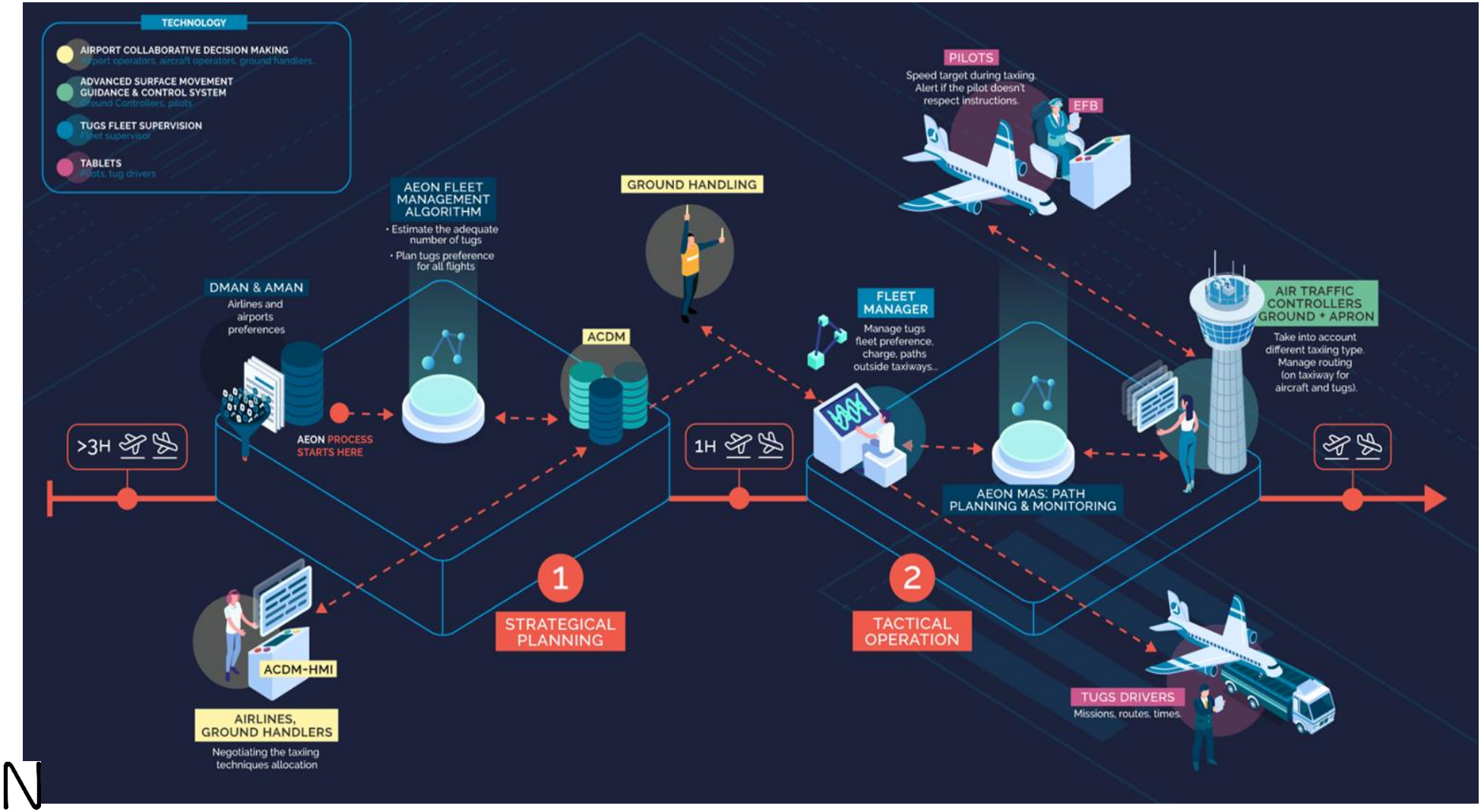
Approach

Development of **supporting algorithms** to help operators manage the tug fleet.

Creation of **a collaborative tool** to help airline and airport implement the solution.

Introduction of **a new concept of engine-off taxiing operations** for the aviation sector.

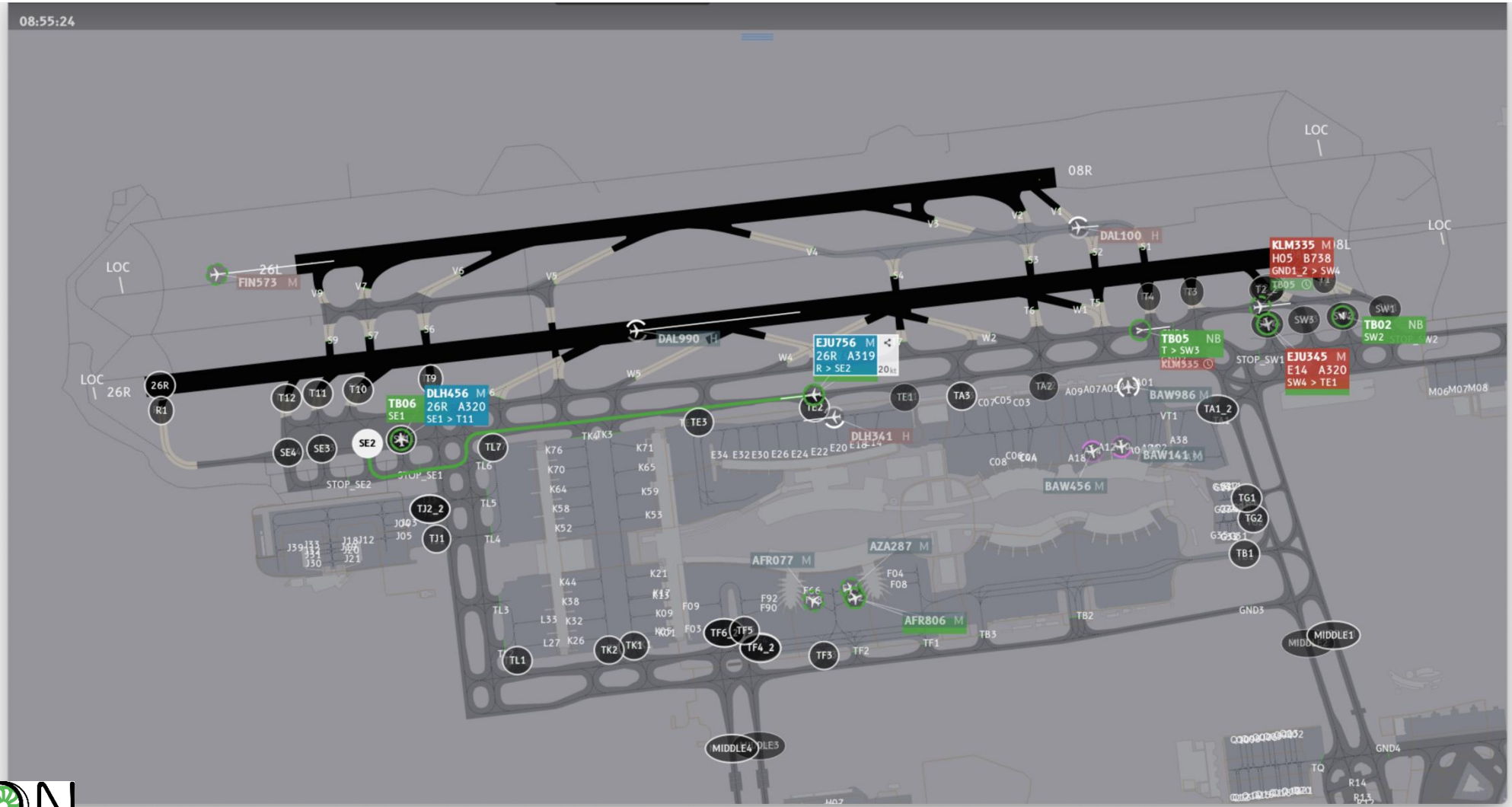
Overall Concept



Advanced Engine Off Navigation

- A-CDM taxiing technique definition
- A-SMGCS increased situational awareness
- ATM Solution: Management of non-autonomous engine-off taxiing operations by Tug Fleet Manager:
  - ✓ Prepare ATCO work
  - ✓ Communicate with tug drivers / airline operations
- Technological Solution: Ecological routing with speed profiles
  - ✓ ATC side computation
  - ✓ Conflict free routing

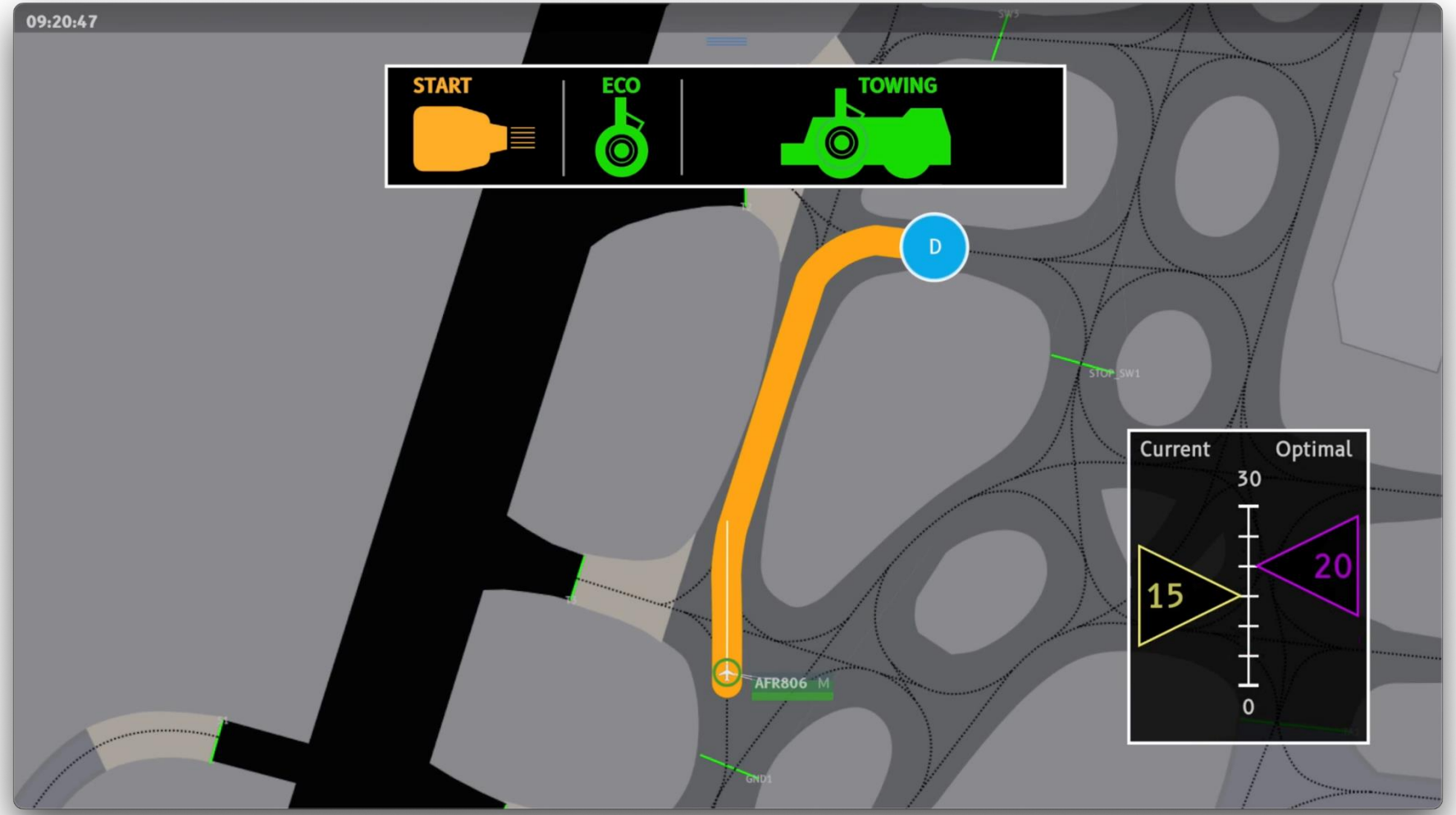
A-SMGCS : situationnal awareness



AEON

Fleet Manager Working Position

Cockpit view



Validation Sessions

- Intermediate validation sessions on site at Roissy CDG and Amsterdam Schiphol

- Final Human in the loop simulations in ACHIL lab

Validation Sessions

- 2 weeks beginning of July
- 3 pairs of ATCO played alternatively Ground Control and Fleet Manager roles
- 1h representative of average traffic at Roissy CDG
- Each pair played the scenario twice

Validation Sessions

- Objective data recording
- Subjective feedbacks from interviews
- Input for the solution assessment reports:
  - ✓ Human performance
  - ✓ Safety

Validation Set Up

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Validation activities and results

Paola Lanzi, Samuele Gottofredi, Elisa Spiller | Deep Blue

EUROPEAN PARTNERSHIP

Co-funded by the European Union

THE AEON VALIDATION APPROACH AND TIMELINE

VALIDATION APPROACH

PARTICIPATIVE

ITERATIVE

MULTIDIMENSIONAL

INTEGRATED

THE ADVISORY BOARD INVOLVED IN VALIDATION

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Schiphol Amsterdam Airport

DSNA

PARIS AÉROPORT

EUROCONTROL

SAFRAN AEROSPACE · DEFENCE · SECURITY

to70

KLM

AIRBUS

SAS SMART AIRPORT SYSTEMS

3-STEP ITERATIVE VALIDATION PROCESS

INITIAL VALIDATION SESSION

What: Focus Group

When - Sept 2021

Who – Advisory Board

Why - Input to Initial CONOPS

INTERMEDIATE VALIDATION SESSION

What: Demo Sessions

When – April/May 2022

Who – End users (AB)

Why – Use cases and HMI

FINAL VALIDATION SESSION

What: Real-Time Simulation

When - July 2022

Who – End users (DSNA)

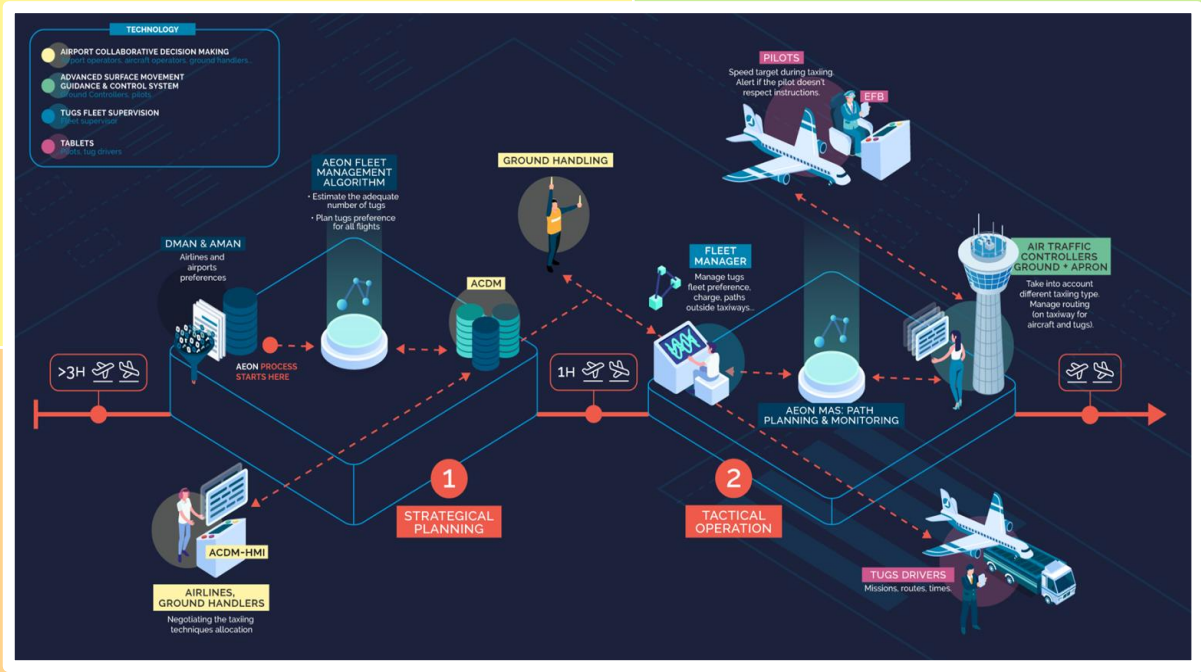
Why – CONOPS and HMI validation

1 → 2 → 3

MULTIDIMENSIONAL VALIDATION APPROACH

HUMAN PERFORMANCE

SAFETY



LIABILITY

COST-BENEFIT

INTEGRATED VALIDATION STRATEGY & PLAN

1. PREPARATION PHASE

COMMON VALIDATION STRATEGY AND PLAN

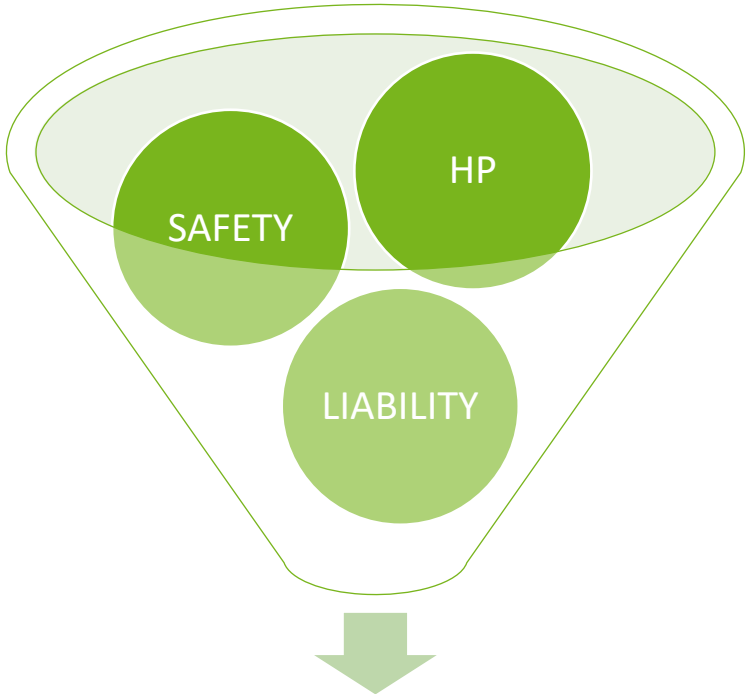
- Assumptions
- Validation objectives
- Data collection methods
- Use cases / scenarios

2. EXECUTION PHASE

COMMON DATA COLLECTION SESSIONS

- observations
- focus groups
- debriefings
- questionnaire

3. ANALYSIS & REPORTING PHASE

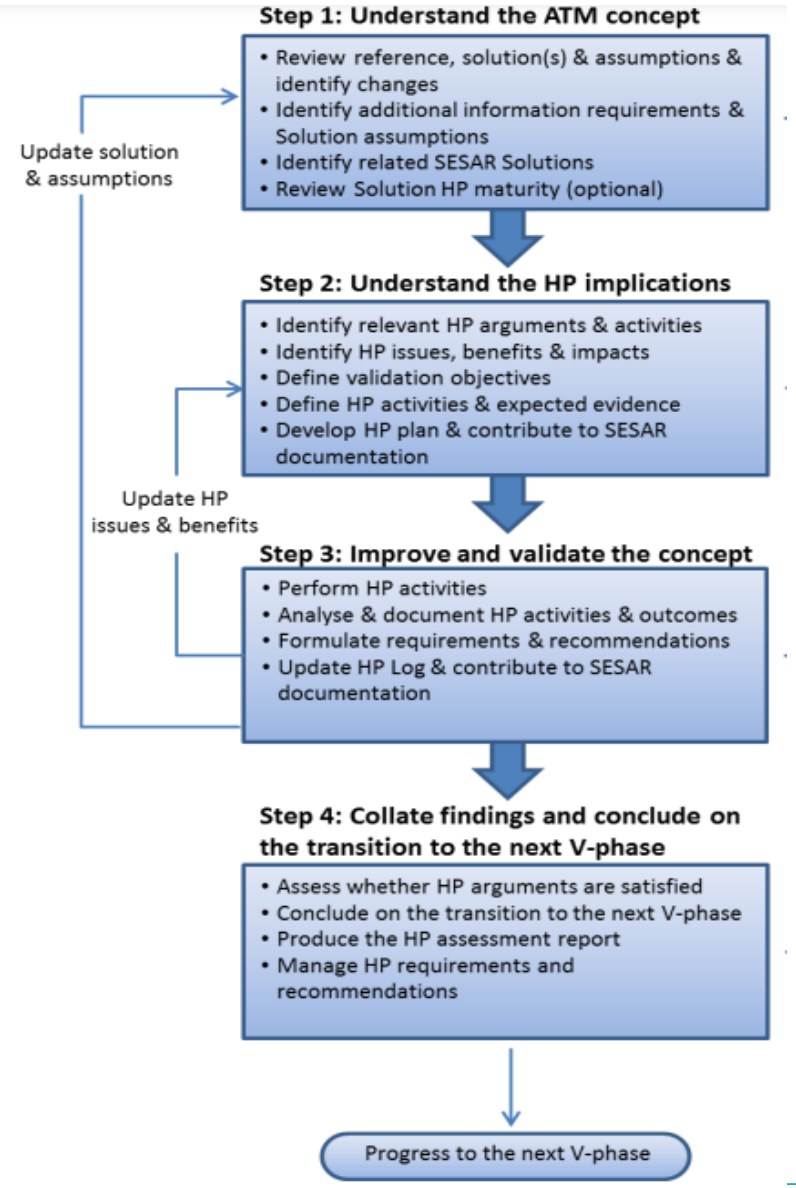


RECOMMENDATIONS

FOR CONOPS CONSOLIDATION

THE AEON HP AND LIABILITY VALIDATION RESULTS

INTEGRATED HP AND LIABILITY ASSESSMENT



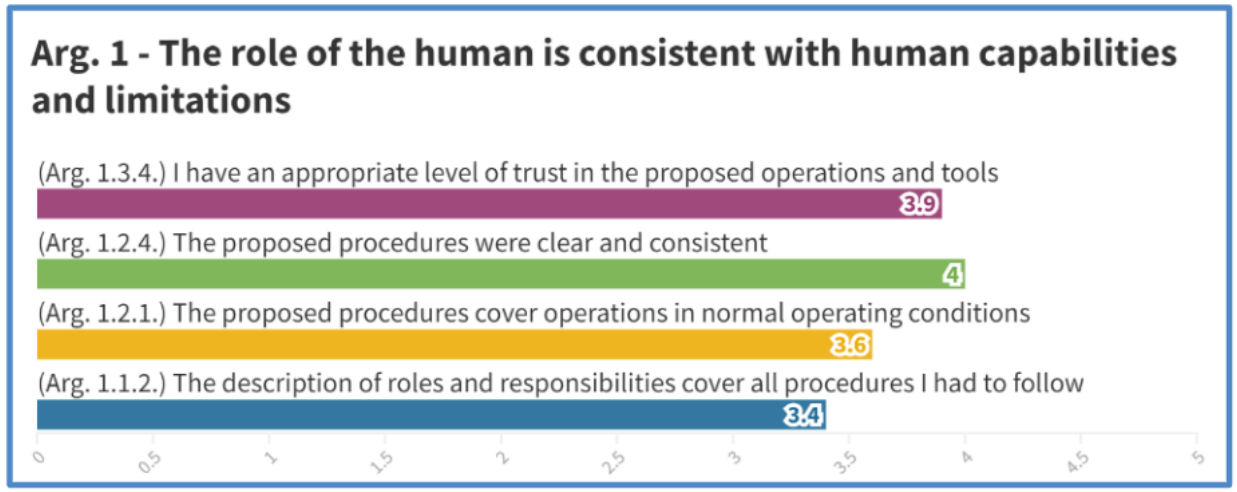
The **SESAR HP Assessment process** for V1 and the **Legal Case method** were jointly used during the validation activities

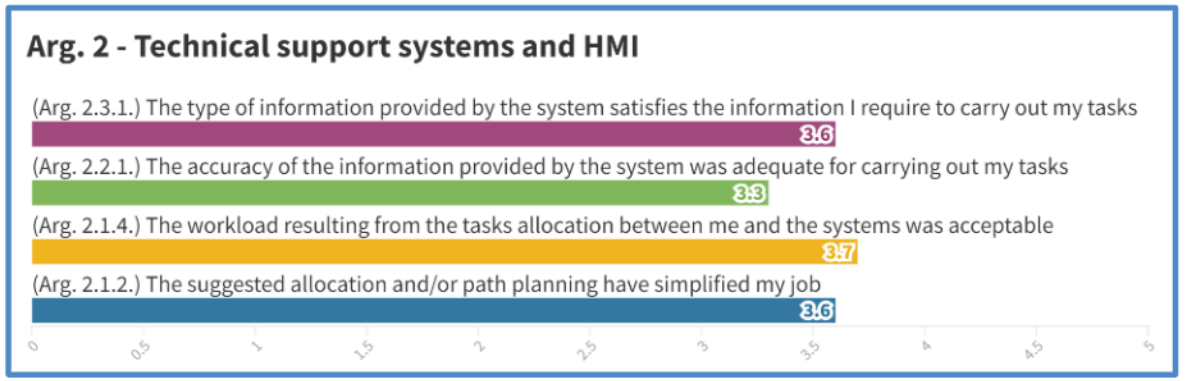
From the methodological perspective this was one of the novelties introduced by the project

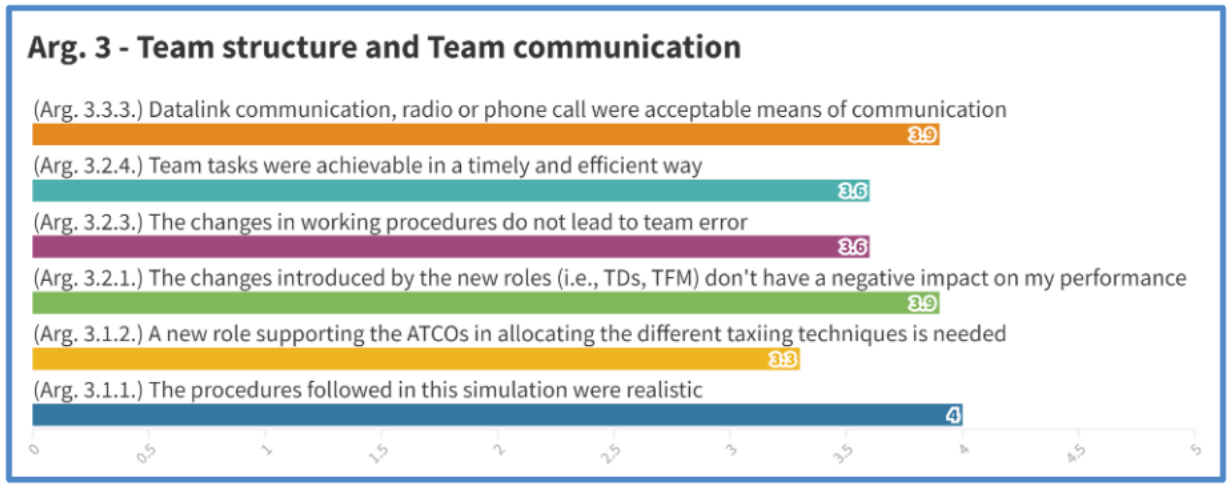
OVERALL POSITIVE RESULTS

- Overall, the results of the validation activities are positive.
- The foundations of the AEON solution (concept, algorithms and systems) seem to be acceptable and promising from the HP perspective, coherent with the current regulatory framework and associated to acceptable liability risks for the actors involved.
- The AEON solution is worth being further addressed, explored and exploited in the SESAR innovation pipeline, considering both the current version of the concept and a more advanced version of it based on higher levels of automation.

FROM THE QUESTIONNAIRES







One aspect of the AEON solution was the cause of the uncertancy reported by the air traffic controllers:

the tug fleet manager role

THE TUG FLEET MANAGER ROLE

Shall the tug fleet manager be an air traffic controller?

2 divergent working styles

- it was evident that the new key role of the AEON proposed solution, namely the TFM, had been defined in a too vague way in the initial operational concept.

- two working styles emerged, quite divergent from one another.

- they highlighted a need for a clearer and more precise definition of this role and of the associated working methods and tasks, in order to reduce the variability of the human performance while playing the role.

Not equal from the HP and liability perspective

- The combined HP/liability assessment revealed that **both styles could be applicable** (none of the two implied blocking issues and/or showstoppers), but the first one (TFM as a flight dispatcher) could be more problematic and riskier to adopt in daily operations than the second one (TFM as a simile-ATCO)

- The first option (TFM as a flight dispatcher), although apparently might be perceived as simpler and more straightforward to adopt than the second one TFM as a simile-ATCO), in reality could be risky for the Ground ATCO

- From the HP perspective, this could be due to the different background of the two roles that may imply possible problems of collaboration, effective support and mutual and shared situational awareness. On the same page, from the liability perspective, the different qualifications and backgrounds may aggravate the accountability position of Ground ATCO.

As a consequnce…..

- common recommendation to consider the TFM as a simile-ATCO role in future stages of the project, rather than as a kind of flight dispatcher.
- need for further detailing the working methods and tasks of this role in this perspective, as well as to opportunely consider this nature of the role while redesign the HMI of the various supporting tools and the communication means and channel used with the other concerned actors.
- some initial considerations about the implications in terms of new ATCO skills, licencing and staffing can be formulated in order to take into account the introduction of this simile-ATCO role.

Overall conclusions and recommendations

- Methodological considerations about the integrate HP/liability assessement
- Need for an overall revision of the TFM role and associated working methods, tasks and tools
- Need for detailed design of communication flows and associated channels/tools
- What operational scenario for towing vehicles: taxiways or service roads?
- The impact of the introduction of higher levels of automation is not in the scope of this validation activity and shall eventually be considered in further research initiatives

sesar
JOINT UNDERTAKING

THANK YOU FOR YOUR ATTENTION!

EUROPEAN PARTNERSHIP

Co-funded by the European Union

ARTIMATION project outcomes: “Conflict Resolution Visualisation and Delay Prediction ”

Mobyen Uddin Ahmed, MDU
Augustin DEGAS, ENAC
Shaibal Barua, MDU

This project has received founding from the SESAR Joint Undertaking grant agreement No. 699381 under European Union’s Horizon 2020 research and innovation programme

SESAR-ER4-01-2019

Content

- Overview of Artimation

- Conflict Detection and Resolution Visualisation

- Delay Prediction results

Content

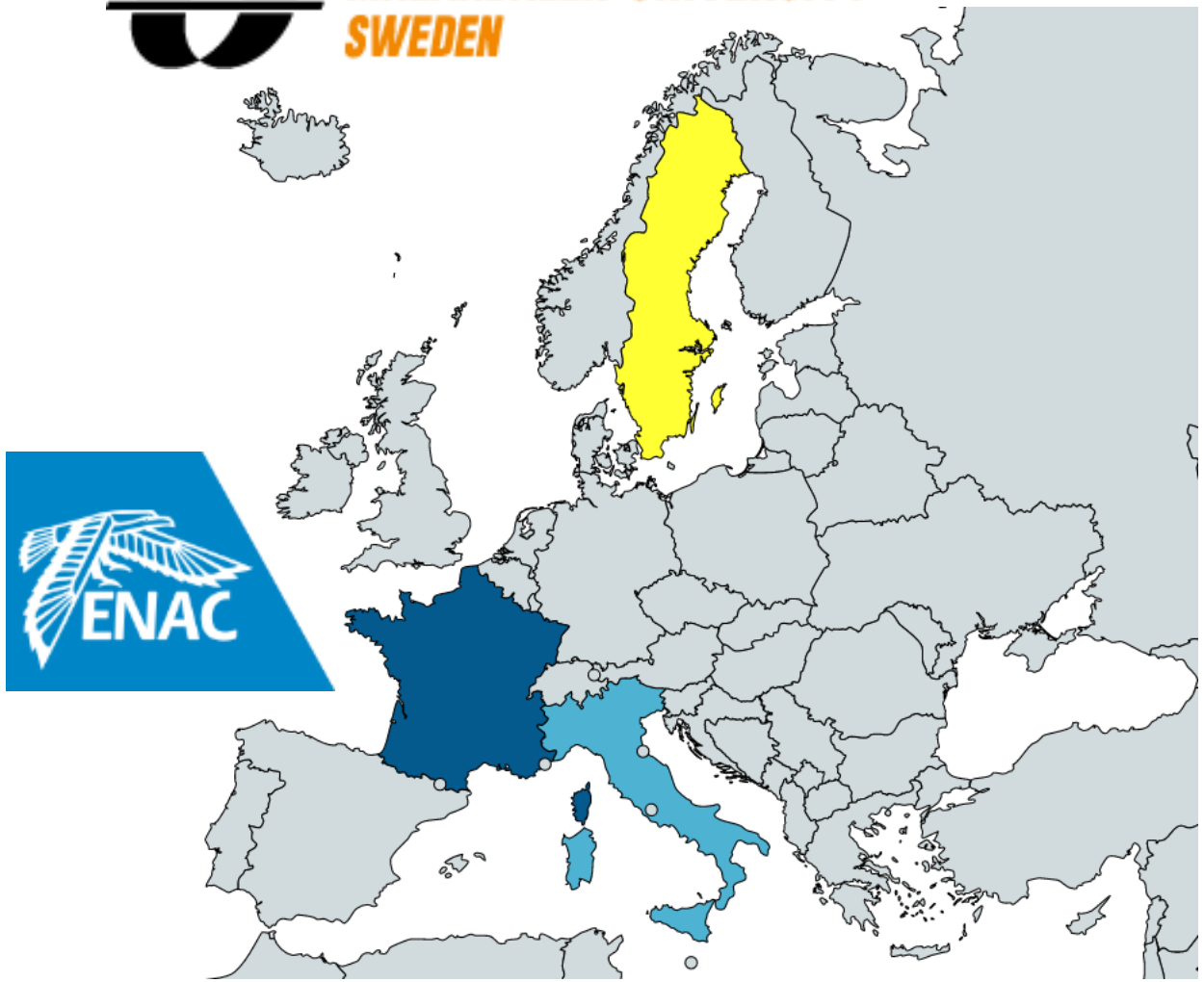
- Overview of Artimation
- Conflict Detection and Resolution Visualisation
- Delay Prediction results

TRANSPARENT ARTIFICIAL INTELLIGENCE AND AUTOMATION TO AIR TRAFFIC MANAGEMENT SYSTEMS

ARTIMATION

CONSORTIUM

MÄLARDALEN UNIVERSITY
SWEDEN



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Excellence

- Aims to improve the transparency and the explainability of AI application in ATM system.
- Investigate the applicability of AI methods from the domain of XAI, i.e., post hoc interpretability and understanding
- Design and develop a proof-of-concept of transparent AI models including
  - visualization, explanation, generalization with adaptability over longer time
  - and user acceptability in the domain of ATM systems to ensure safe and reliable decision support.

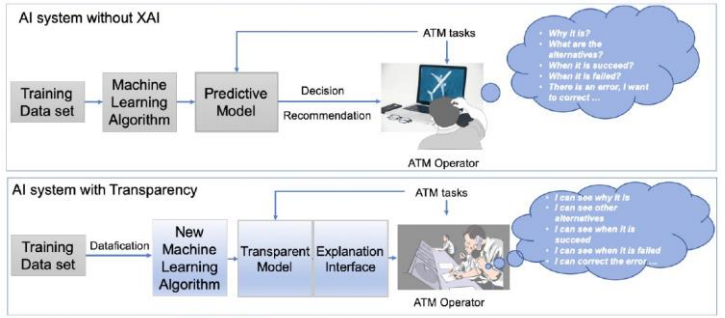


Figure 1 Overview of proposed ARTIMATION system with transparency and explainability

Project Goals and Objectives

Research Objective: Provide **transparency and explainability** to the AI, build a conceptual framework for building **human-centric XAI** and provide **user guidelines** for further AI algorithm development and application with AI transparency in ATM domain

Technical Objective: Design **human-AI-interaction (hAIi)** to provide a **data-driven storytelling**. And define a data exploration approach through visual analytics and evaluate the XAI by **novel immersive analytics** technologies with **virtual reality** and **Brain-Computer Interface (BCI) systems**

Social Objective: Develop **transparent AI models** for ATM operators with **better integrated approach** between them and AI, with guidelines for **shortening the training period**.

Methodology

An **iterative and cyclic** approach, with a close collaboration between work packages

Phase 1: Definition which consist in the definition of specifications (WP3)

- State-of-the-art
- use user-centric design principles,
- to define the possible decision support tasks in ATM e.g.
  - a tool supporting Conflict Detection and Resolution and
  - a tool supporting the take-off time delay prediction and propagation.

Methodology

Phase 2: Development Cycles (WP4, and WP5) that will include multivariate data analysis, data driven AI modelling, transparency, visualization, explanation and adaptation framework.

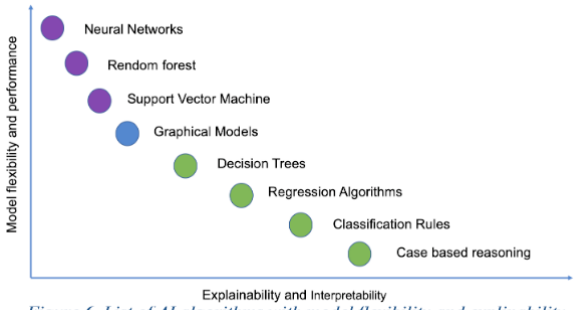


Figure 6. List of AI algorithms with model flexibility and explinability

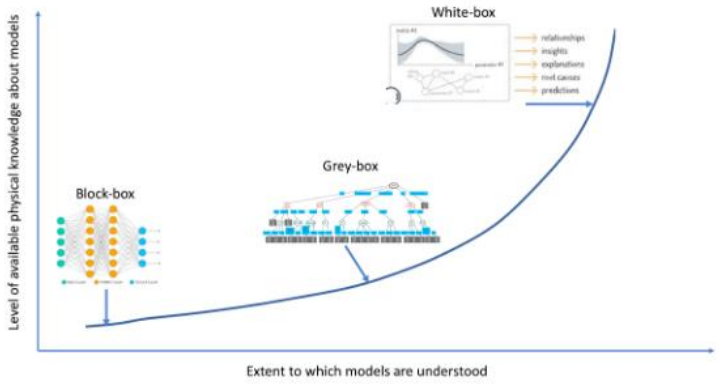


Figure 7. Black-box to White-box by providing explanation

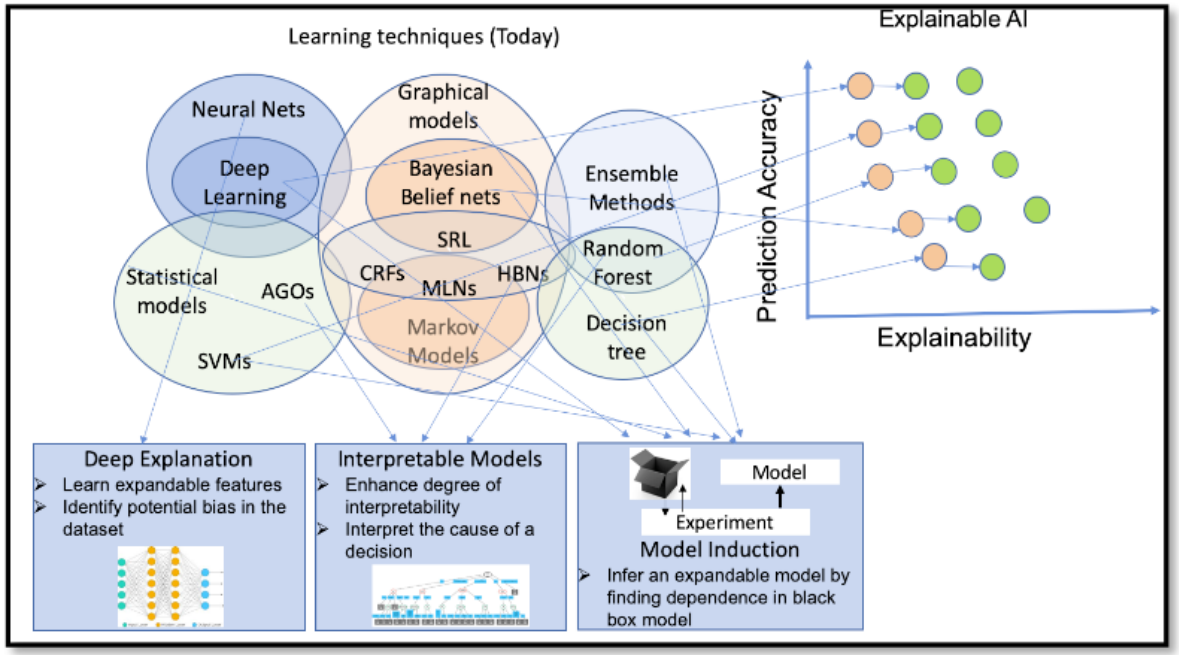


Figure 8. Development of transparent AI system in ATM domain

Methodology

Phase 3: Test and validation (WP6) where two different types of tests will take place, for the development of the models, and the user tests.

The user tests will be performed in simulated environment with realistic traffic scenarios (i.e. baseline and alternative scenarios) both considering existing and new data sets.

Professional ATCOs will be involved as experimental subjects by using ENAC facilities.

Phase 4:Guidelines and Training(WP7),in which a set of guidelines to optimize the training process of ATCOs in using new XAI-based solutions will be provided.

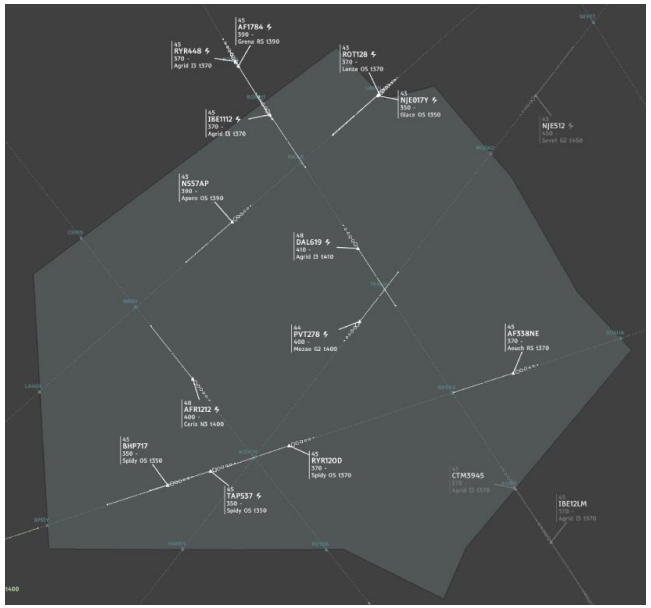
Content

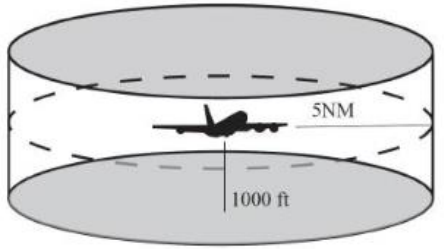
- Overview of Artimation
- Conflict Detection and Resolution Visualisation
- Delay Prediction results

Use Case 1 : Conflict Detection and Resolution

- Conflict Avoidance Scenario
  - Set of aircraft and their trajectory
- Avoid conflicts
- Minimize emissions/delays

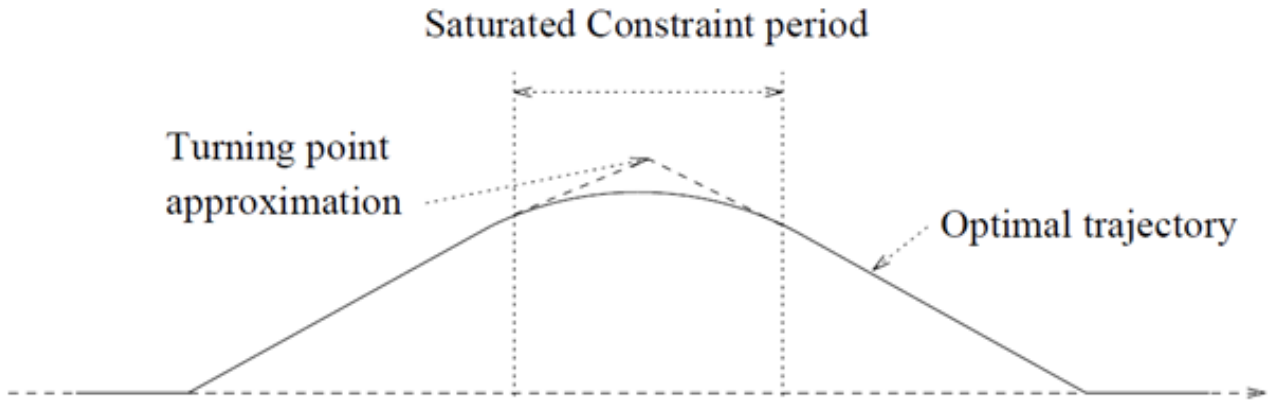
- Decision support tool for ATCOs

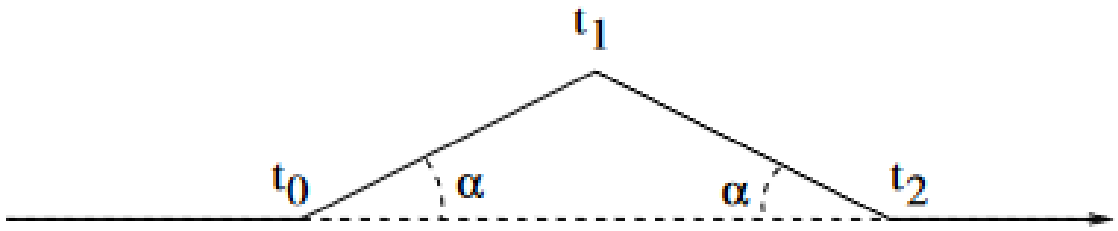


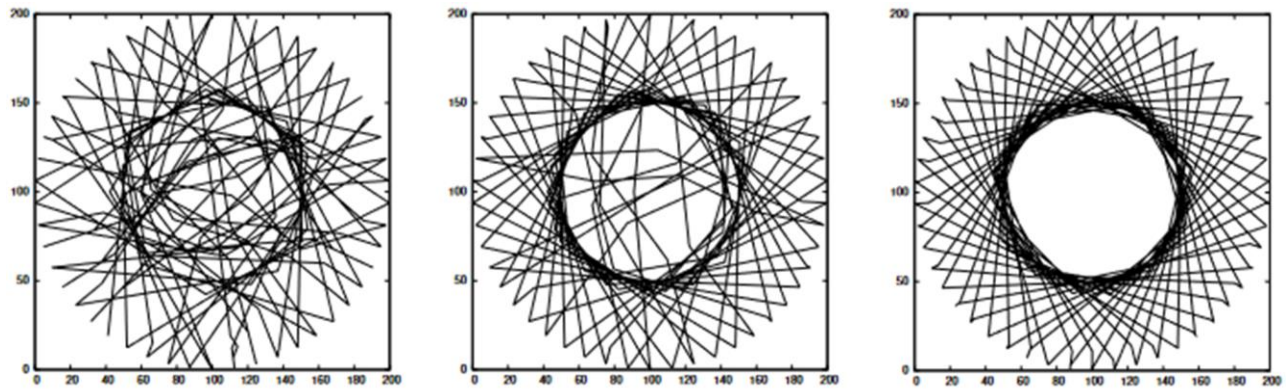


Genetic Algorithm

- Used in other projects (e.g., **STRESS**)
- **Population** and **Evolutionary** based Meta-Heuristic
- Modifies trajectories with **turning point** maneuver
- Criteria:
  - Avoid conflicts (for a bit of safety, 7NM)
  - Reduce the length of the modified trajectories
  - Reduce the number of trajectory modifications

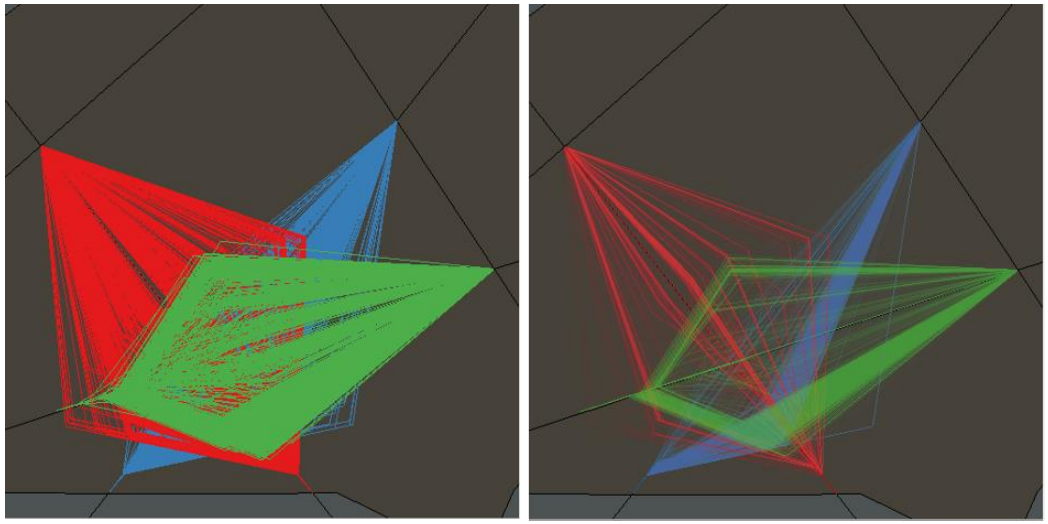






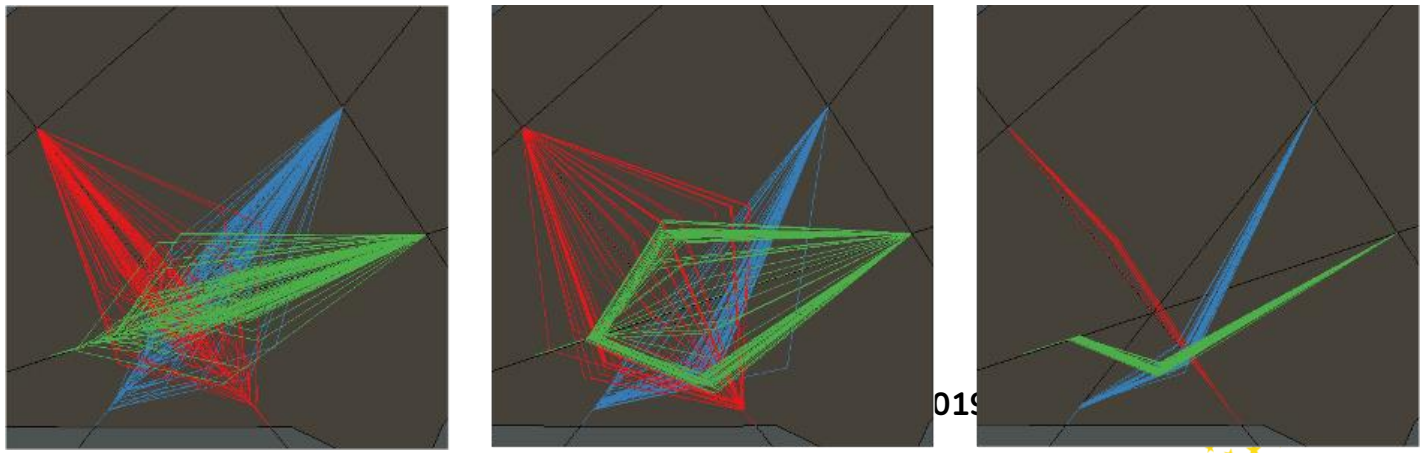
ARTIMATION

Genetic Algorithm: Iterative exploration



Explored trajectories

Evolution of the candidate solutions in function of the iterations



ARTIMATION

Objectives

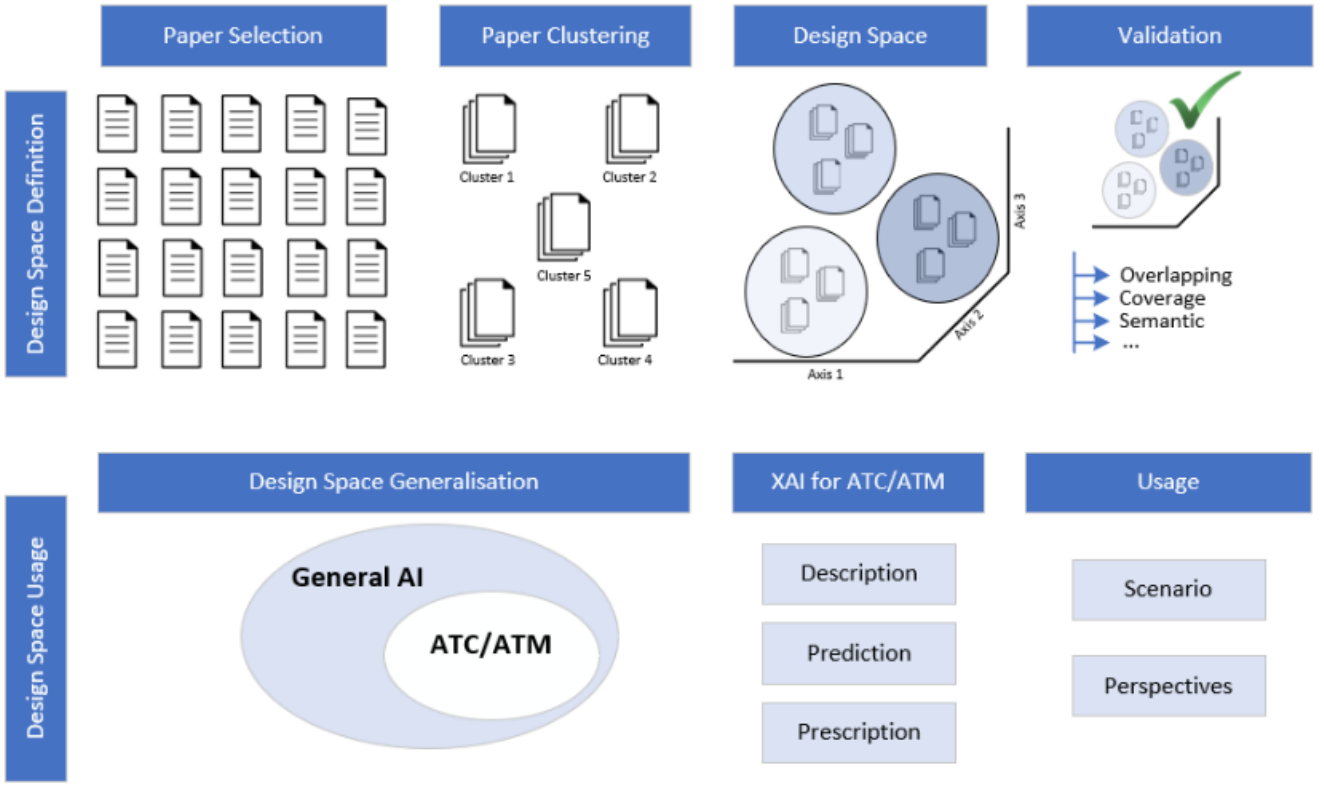
Provide explainability to the Genetic Algorithm and assess the impact on:

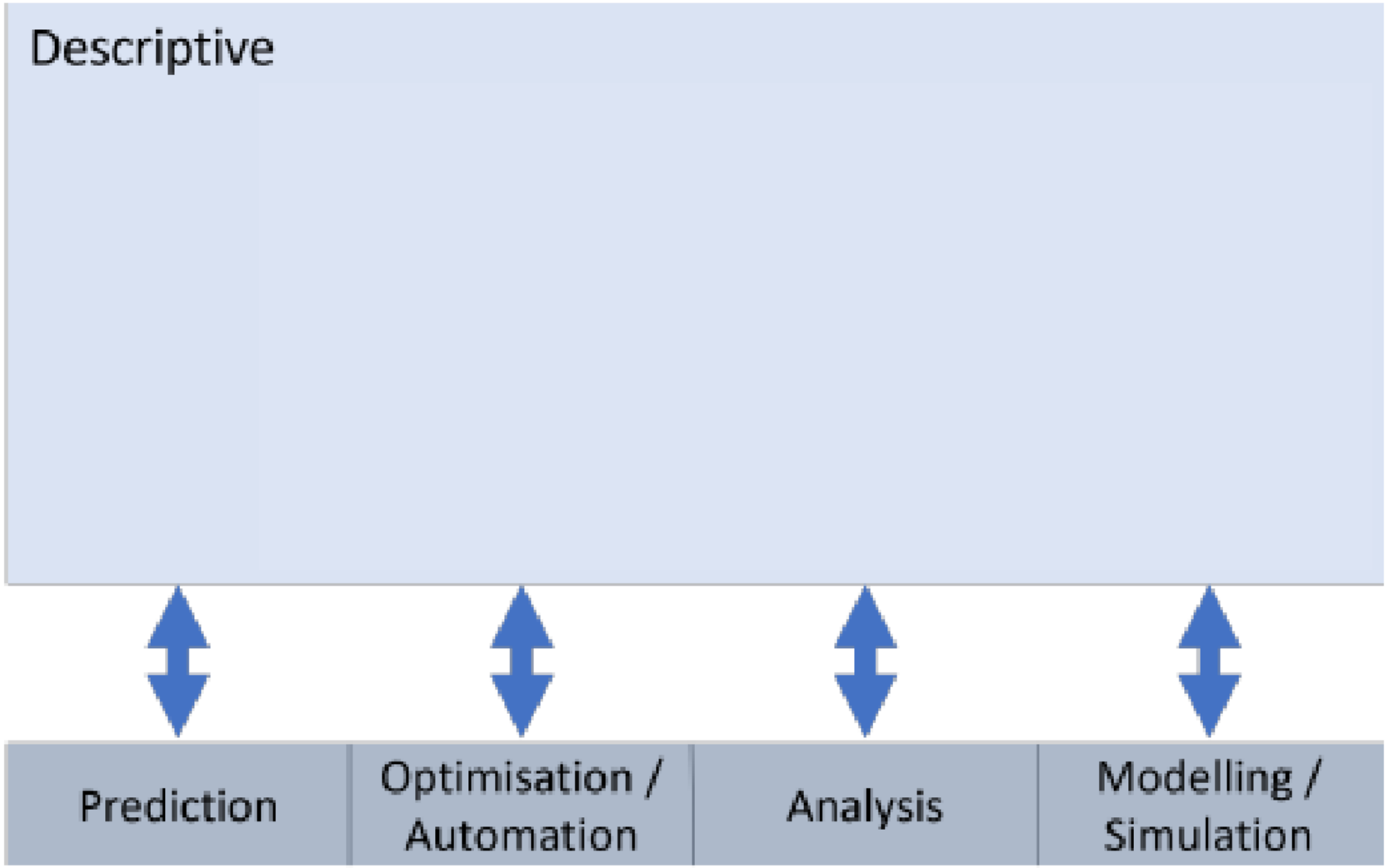
- **Acceptance**
- **Human performance**
- **System performance**

Systematic Review

A Survey on Artificial Intelligence (AI) and eXplainable AI in Air Traffic Management: Current Trends and Development with Future Research Trajectory

Augustin Degas [1,*], Mir Riyanul Islam [2,*], Christophe Hurter [1], Shaibal Barua [2], Hamidur Rahman [2], Minesh Poudel [1], Daniele Ruscio [3], Mobyen Uddin Ahmed [2], Shahina Begum [2], Md Aquif Rahman [2], Stefano Bonelli [3], Giulia Cartocci [4], Gianluca Di Flumeri [4], Gianluca Borghini [4], Fabio Babiloni [4] and Pietro Aricó [4]





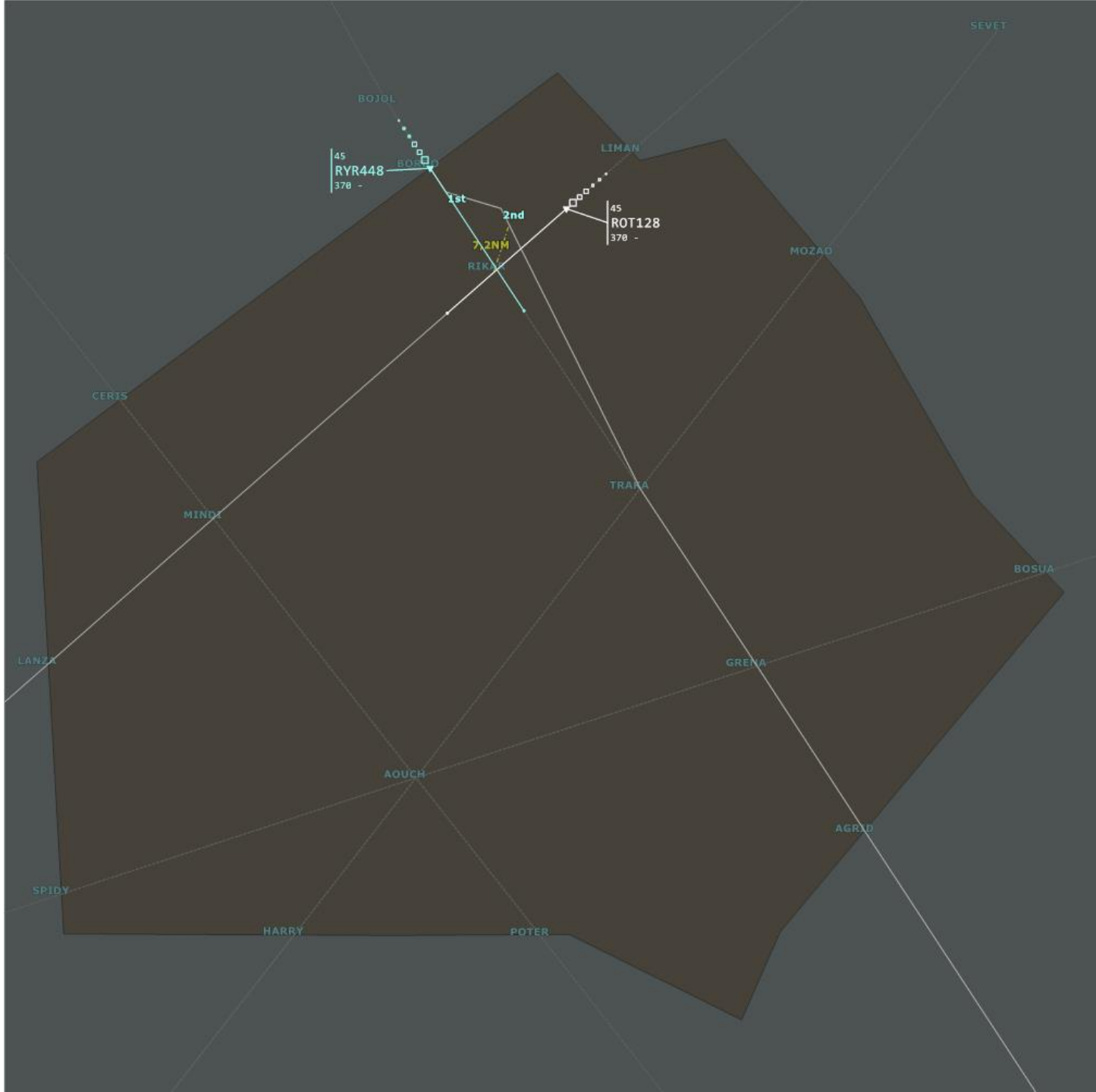
Degas, A.; Islam, M.R.; Hurter, C.; Barua, S.; Rahman, H.; Poudel, M.; Ruscio, D.; Ahmed, M.U.; Begum, S.; Rahman, M.A.; Bonelli, S.; Cartocci, G.; Di Flumeri, G.; Borghini, G.; Babiloni, F.; Aricó, P. **A Survey on Artificial Intelligence (AI) and eXplainable AI in Air Traffic Management: Current Trends and Development with Future Research Trajectory**. *Appl. Sci.* **2022**, *12*, 1295. https://doi.org/10.3390/app12031295

XAI presented

- Different screen-based visualization techniques (with different levels of Explainability of AI)
  - Condition 1: Black Box
  - Condition 2: Heat Map
  - Condition 3: Storytelling

Blackbox

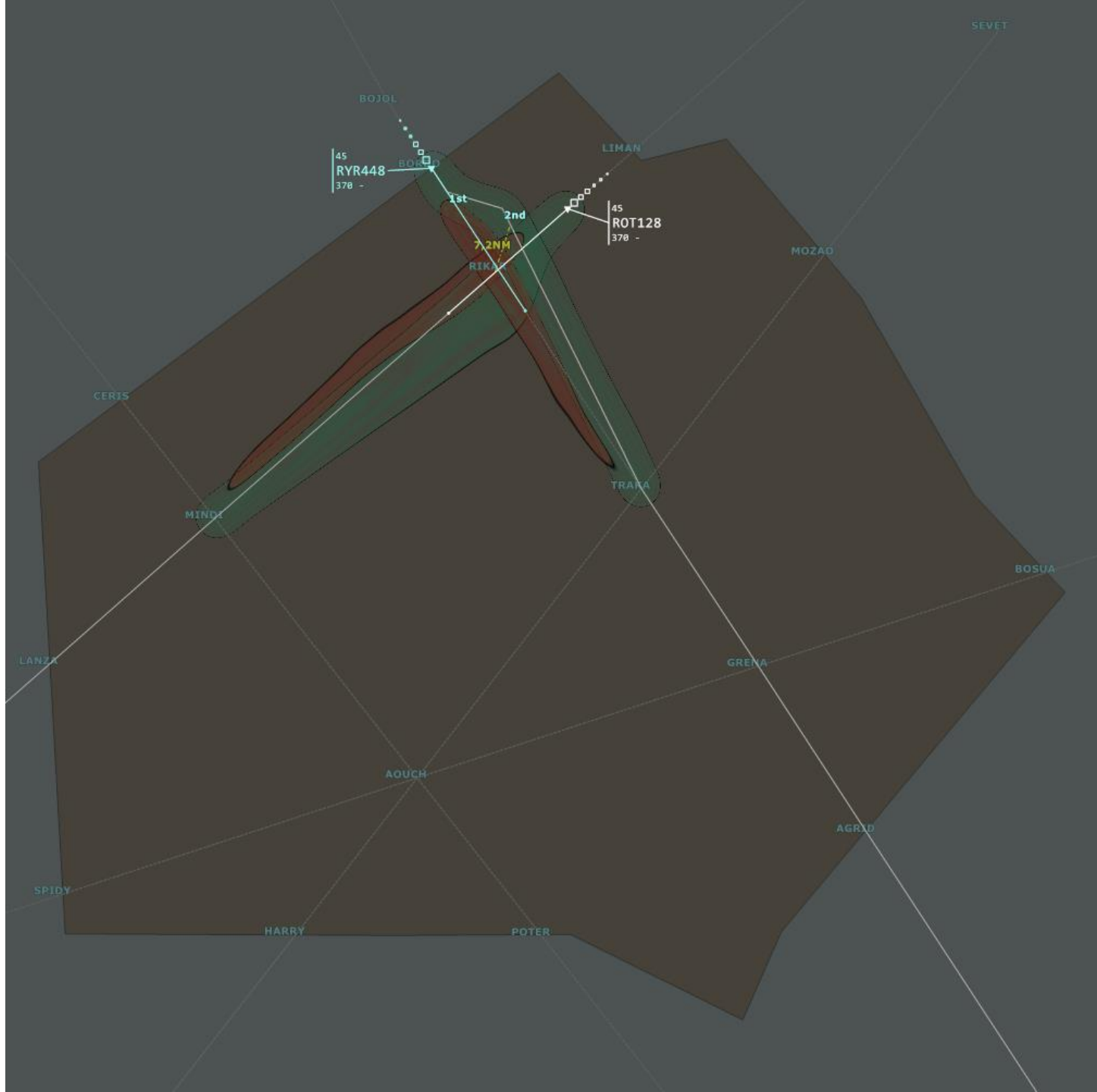
- Displaying only the solution from the GA
  - Line to describe the trajectory of each aircraft involved
  - Coloured if trajectory modified
  - Minimum of distance
- Baseline of the experiment



ARTIMATION

Heatmap

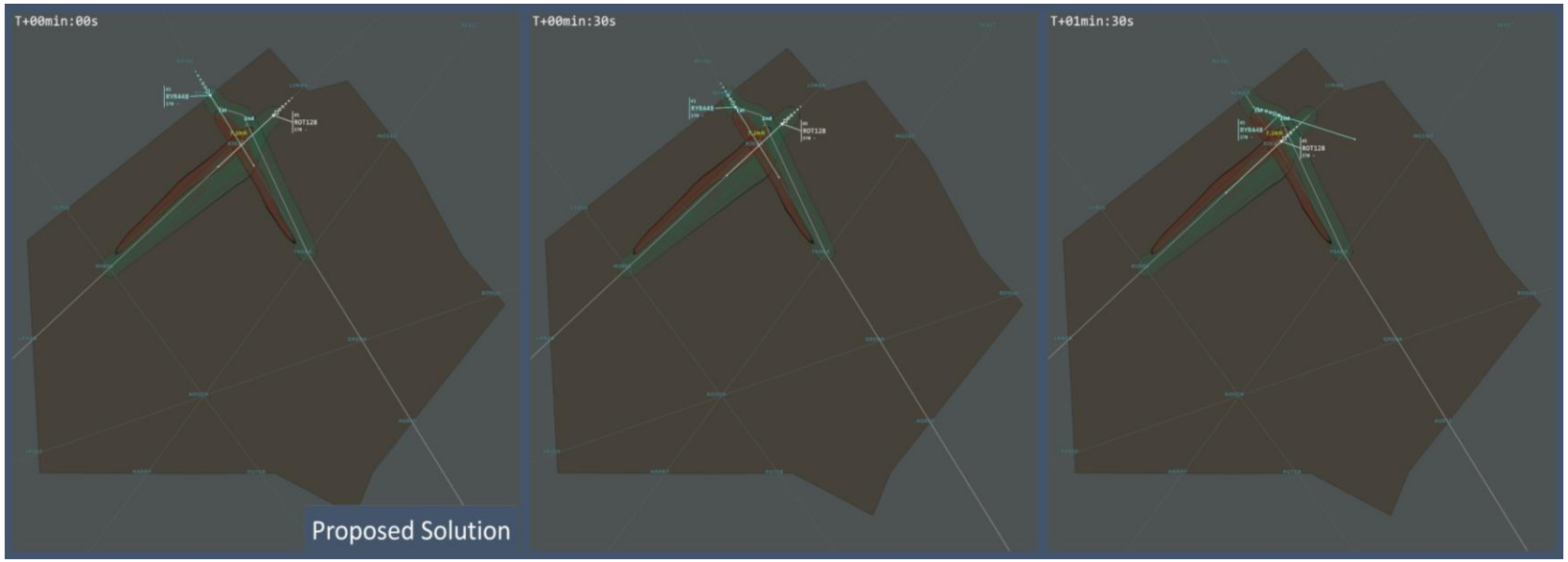
- Aggregation of the candidate solutions:
  - an envelope of "good modifications" of trajectory in green (> 7NM),
  - an envelope of "bad modifications" of trajectory in red (< 7NM)
- Provide a view of explored space
  - Uncluttered
  - Cleared of the least interesting candidate solutions
  - Support some “why/why not” questions



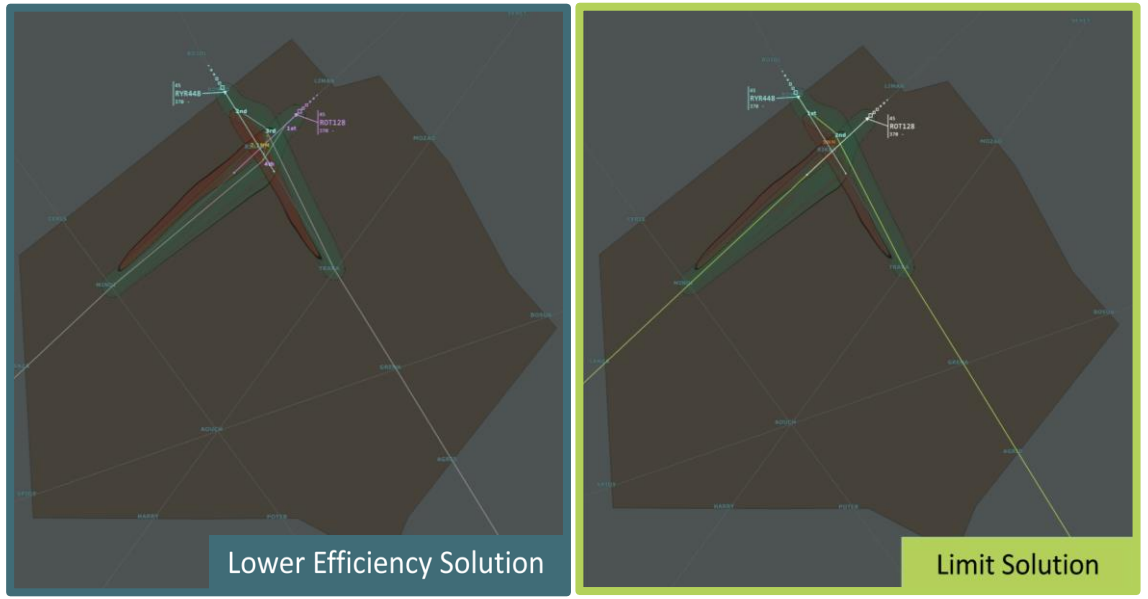
ARTIMATION

Storyboard

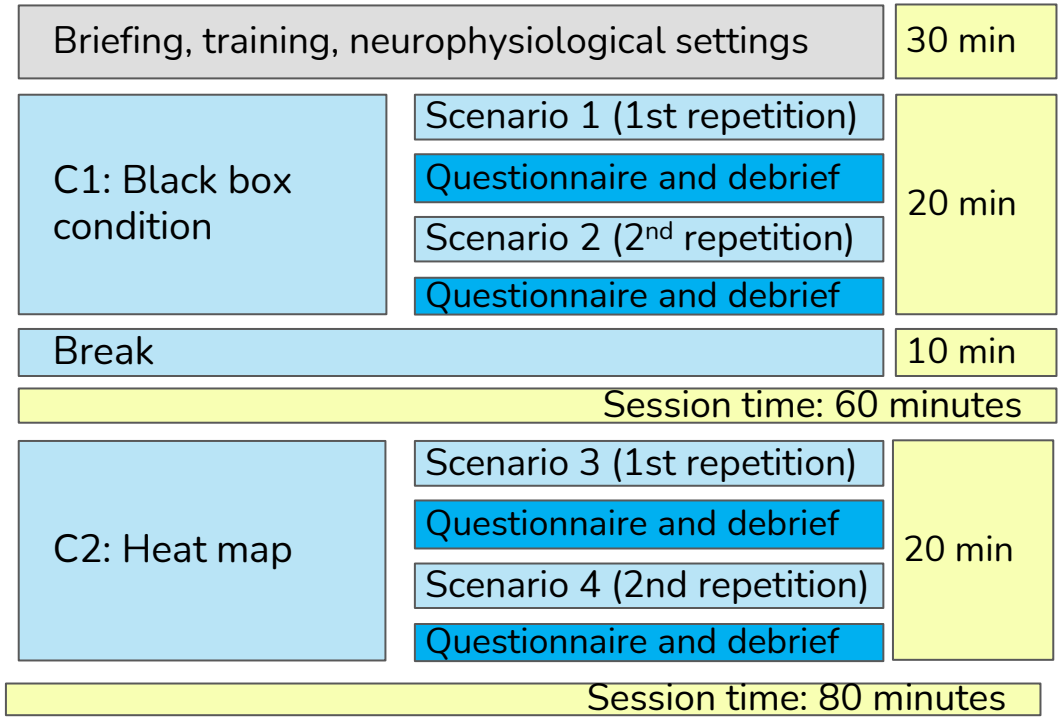
- Timeline of the proposed solution
  - Allows to better understand the proposed solution

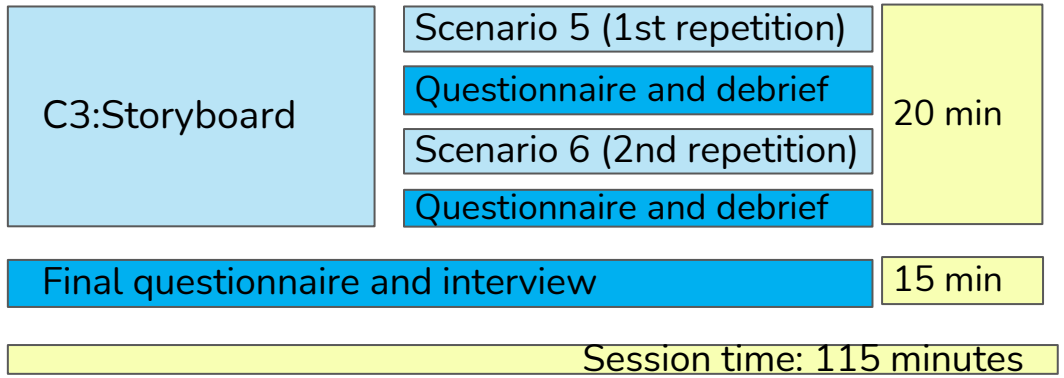


- Lower efficiency solution
- Limit solution
  - Alternative solution and limit solution aims at answering contrastive questions, and reinforce proposed solution



Validation procedure





Video showing the conflict to resolve → Explanation of the AI solution → Drawing of your own solution → Few questions

Objective measurements

Objectives	Sub-objective	Methods
1. Assess the impact on **Acceptance**	Level of Understanding	Questionnaire
	Level of Agreement	Questionnaire
	Level of Acceptability	Questionnaire
		Neuormetrics
2. Assess the impact on **Human performance**	Usability	Questionnaire
	Situation Awareness	Questionnaire
	Trust	Questionnaire
	Mental Workload	Neuormetrics (EEG)
	Stress	Neurometrics (GSR)
	Task Performance	Questionnaire
3. Asssess the impact on **System performance**	Safety and impact on ATM	Debriefing

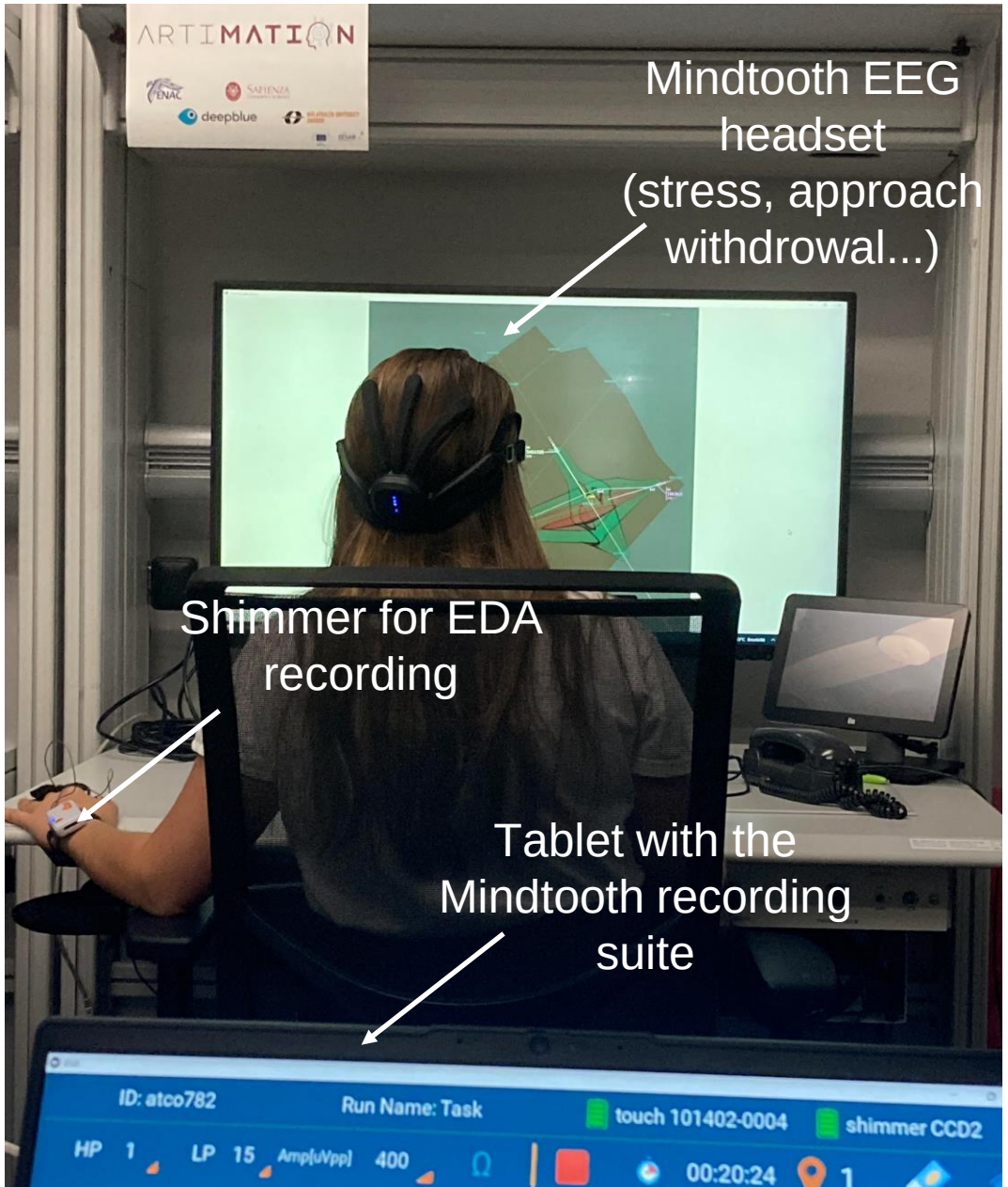
Post-Scenario Questionnaire

- **Agreement with the solution**
  - “Do you agree with the solution?”
- **Understanding of the solution**
  - “The solution was easy to understand”
  - “I understand why the solution has been generated”

Post-Condition Questionnaire

- **Usability**
  - “Learn to operate the tool would be easy for me”
  - “I find the tool clear and understandable”
  - “I find the tool easy to use”
- **Trust**
  - “I felt confident when using the too”
- **Situational Awareness**
  - “The tool improved my Situation Awareness of the conflict presented”
- **Acceptability**
  - “I would like to use this tool in the future”
  - “I like the new decision support interface”
- **Work Performance**
  - “Using this tool in my job would allow me to solve conflicts faster”
  - “Using this tool in my job would increase my accuracy in solving conflicts”
  - “Using this tool would improve my work performance”
  - “Using this tool would make my work easier”

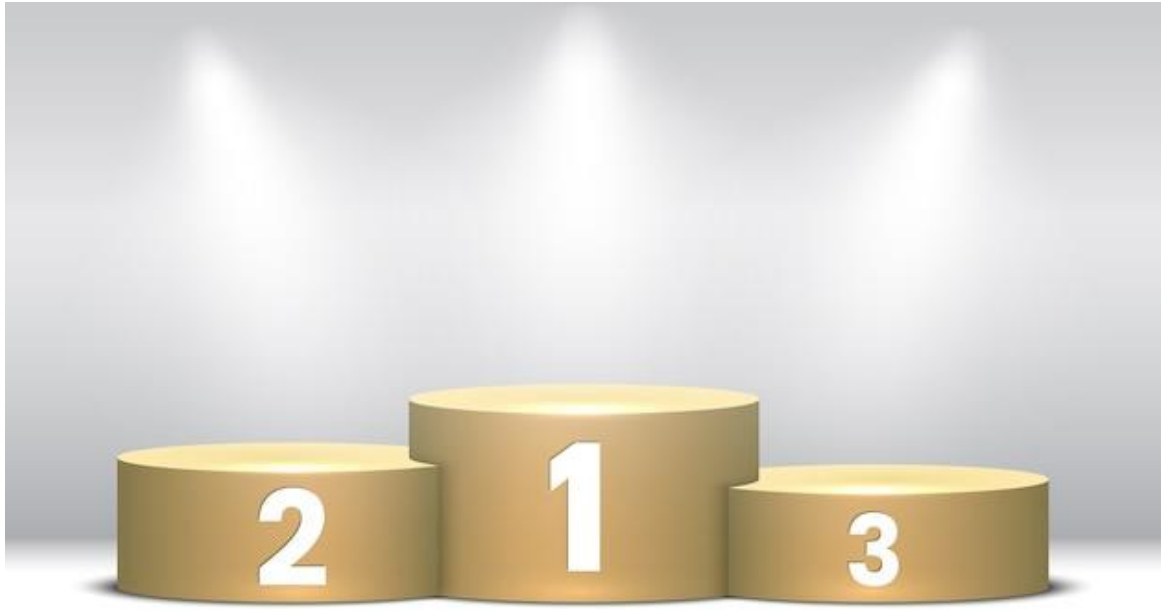
Participants



Participants	
Experts	◦ 11 professional ATCOs ◦ Ages: 34-51 years old ◦ 3 female and 7 male ◦ Mean 15 years of working experience
Students	◦ 10 student ATCOs ◦ Ages: 20-26 years olde ◦ 4 female and 6 male

Total: 21 participants

Results?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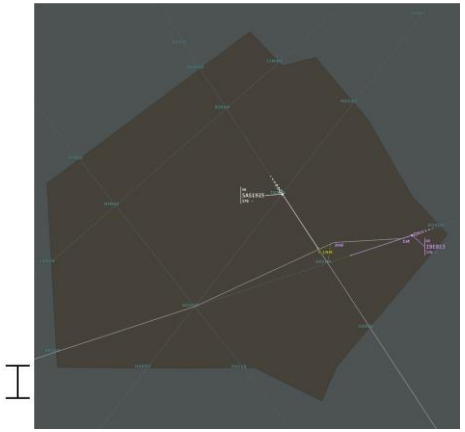
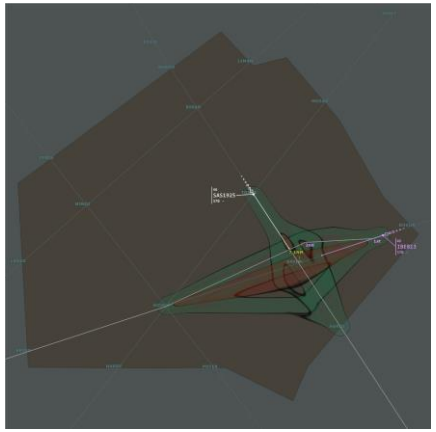
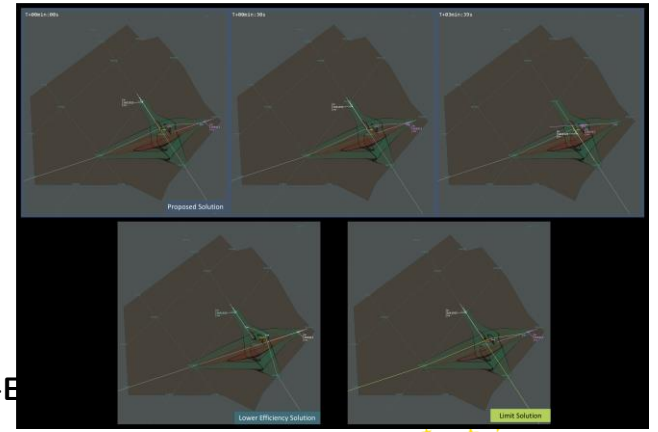


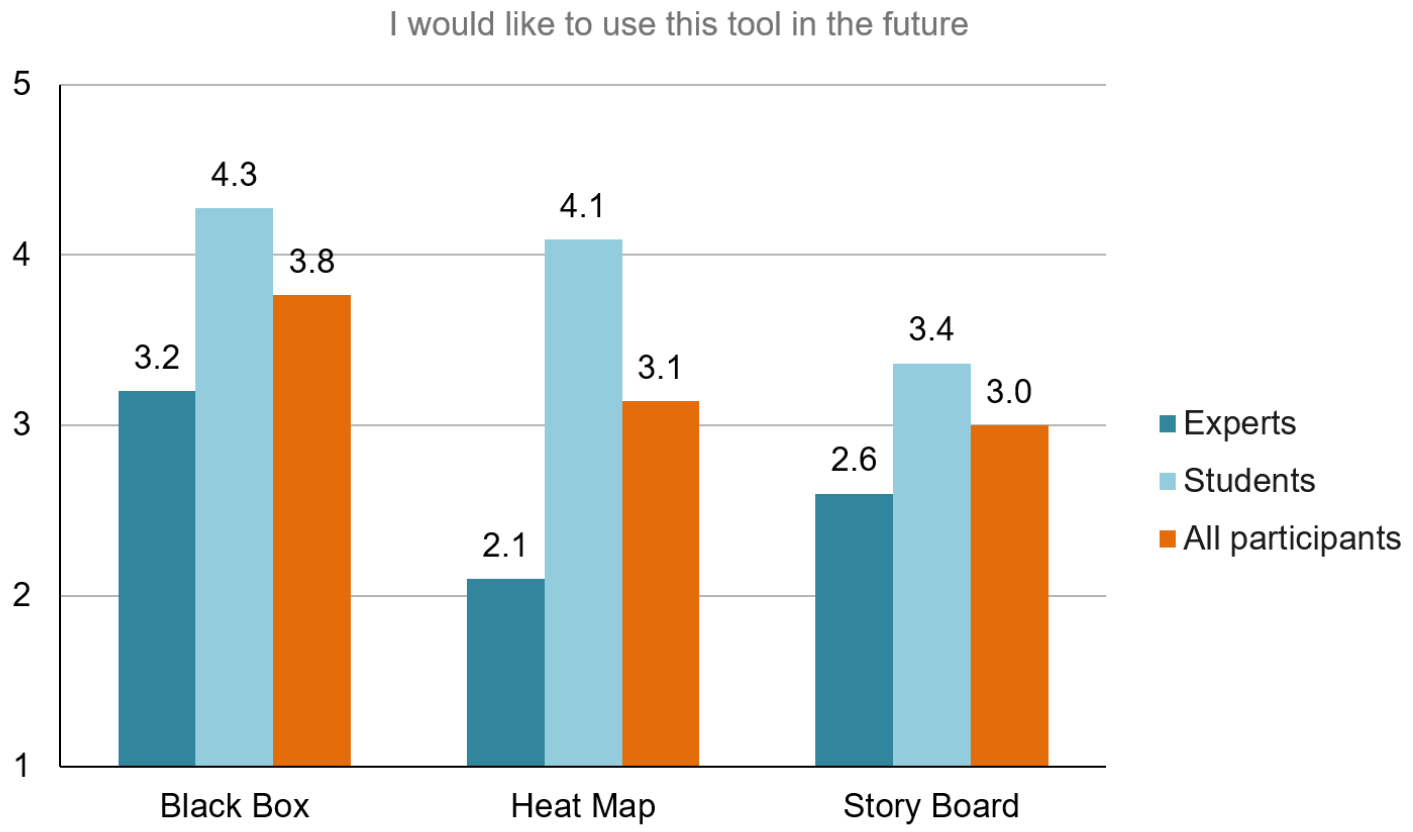



Proposed Solution
Lower Efficiency Solution
Limit Solution

ACCEPTANCE

1.3 ACCEPTABILITY

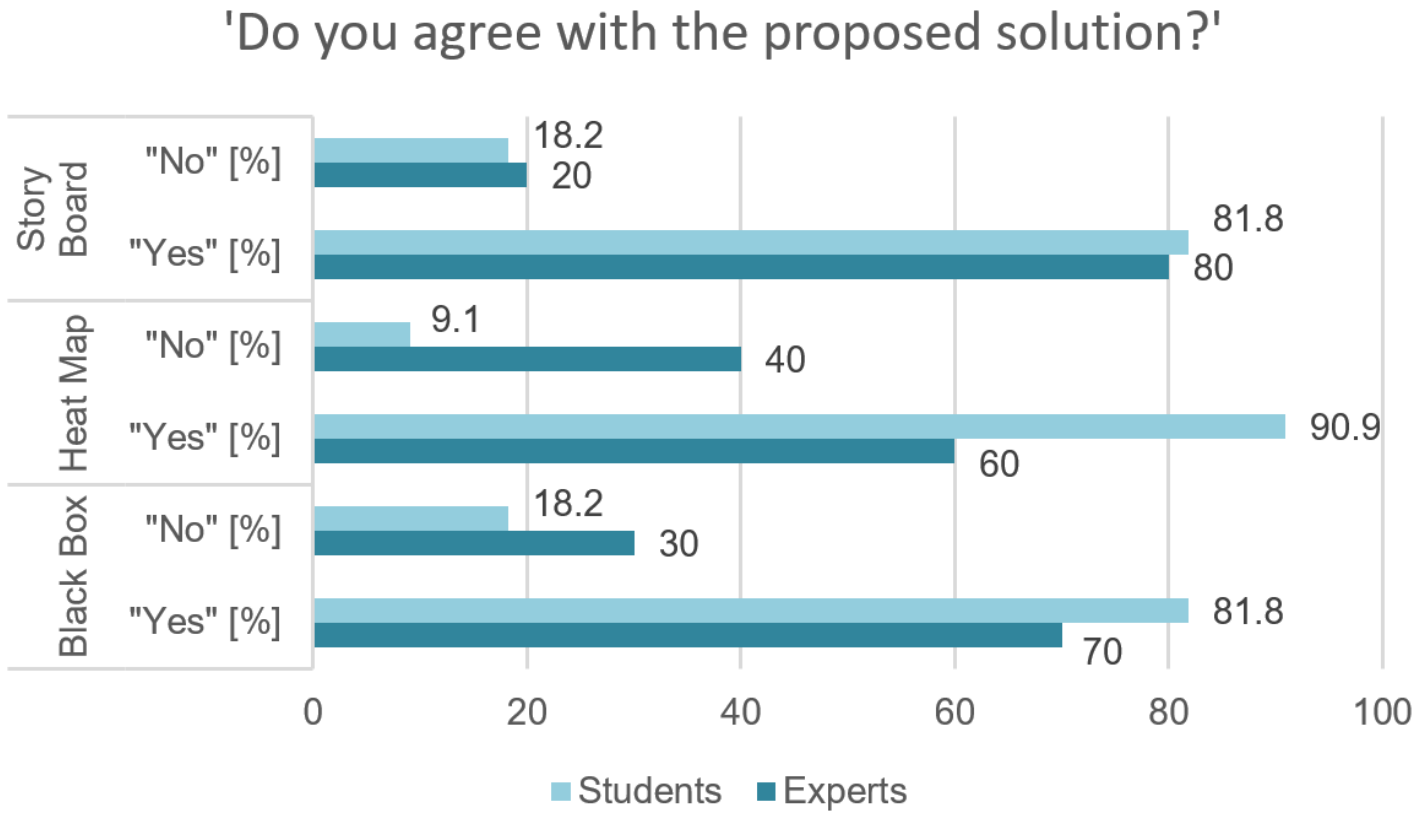
- 11/11 ATCOs reported that they preferred the Black box (BB) solution, even if one of them also liked the concept of the heatmap (HM).
- From the 10 students, 6 preferred the BB, 3 the HM and 1 the SB.



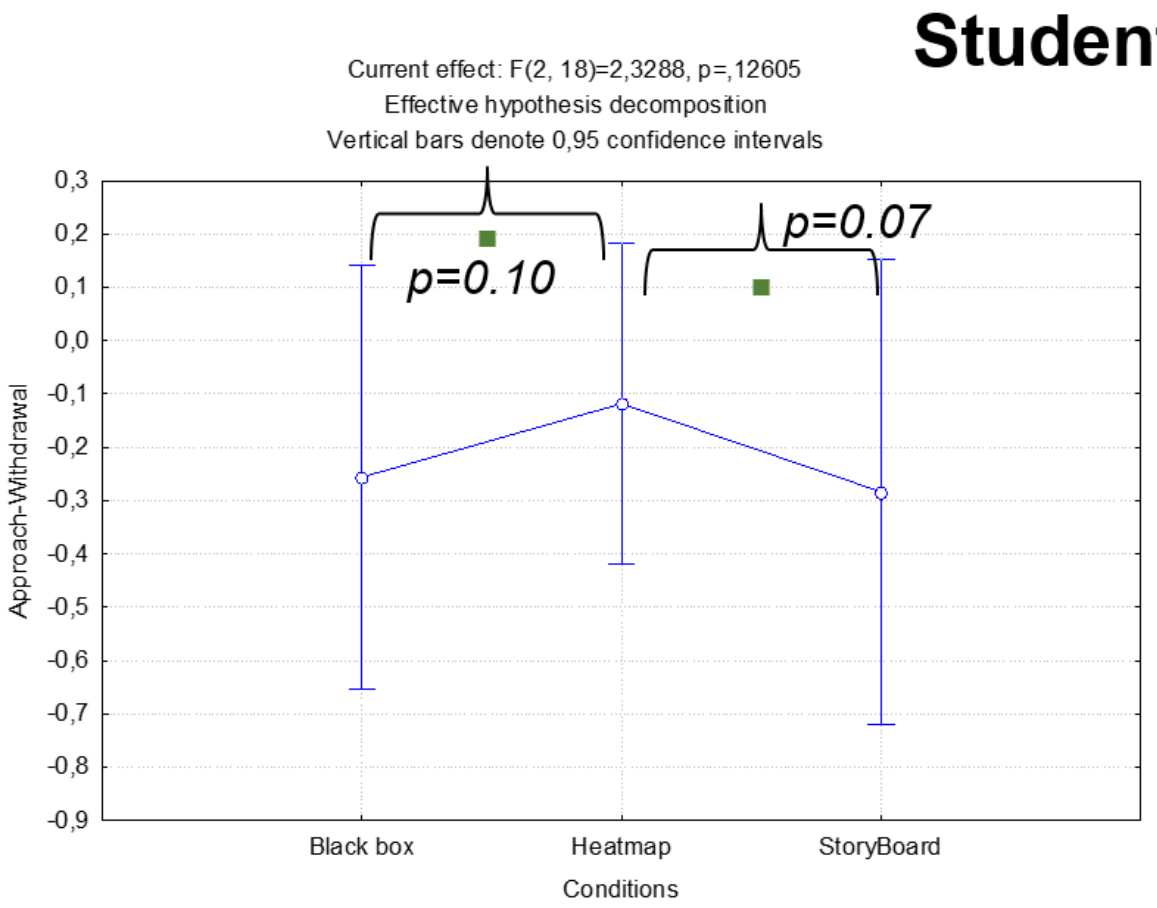
ACCEPTANCE

1.2 AGREEMENT

- In general, experts were accepting/ agreeing with the proposed AI resolution less frequently.
- In some situations ATCOs were **reluctant to accept a solution that is not their own** simply because they might find themselves **'out of the loop'.**



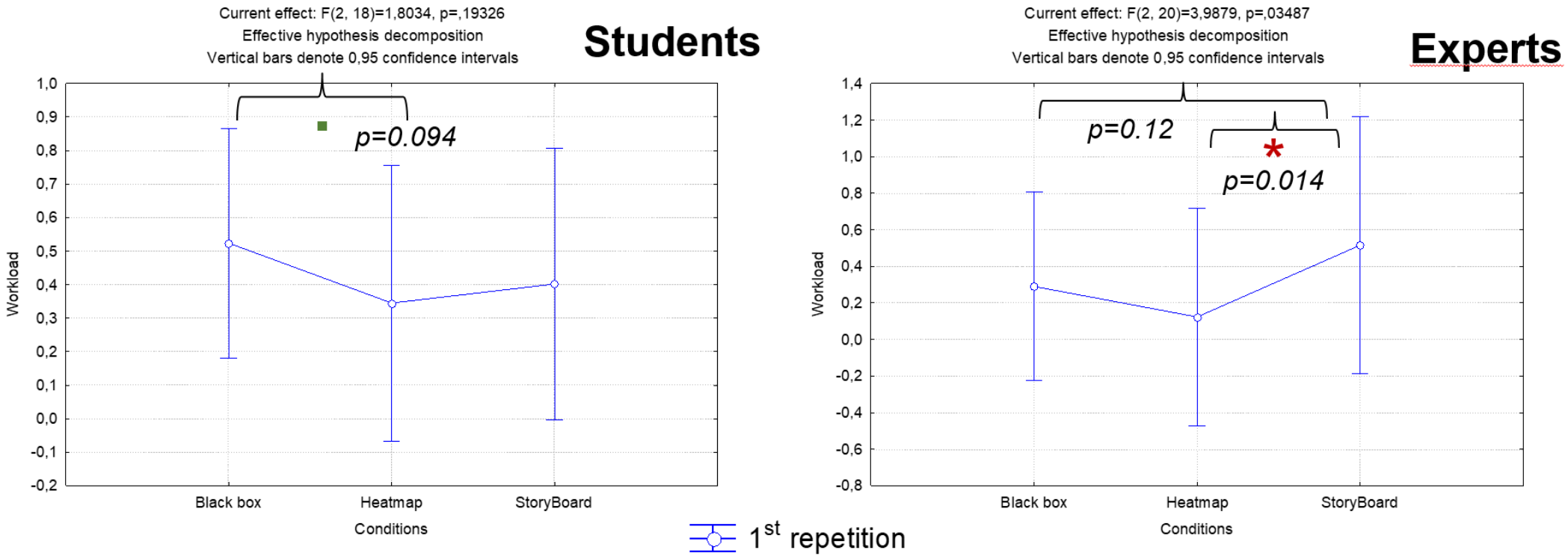
Acceptability (approach-withdrawal index)



Students and experts exhibited a different behaviour.

In particular, students exhibited the highest approach-withdrawal on the heatmap solution.

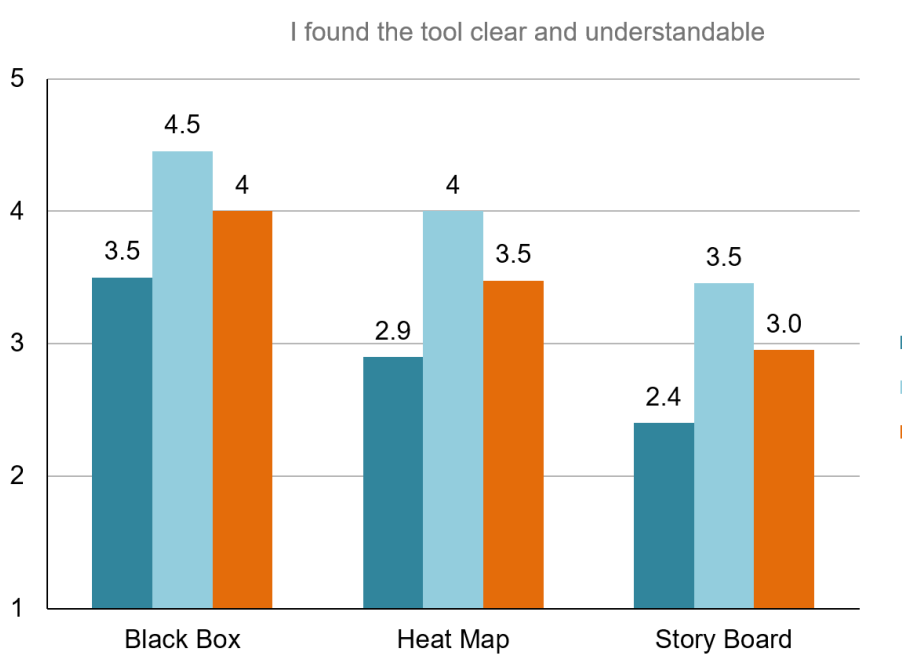
HP- WORKLOAD (EEG)



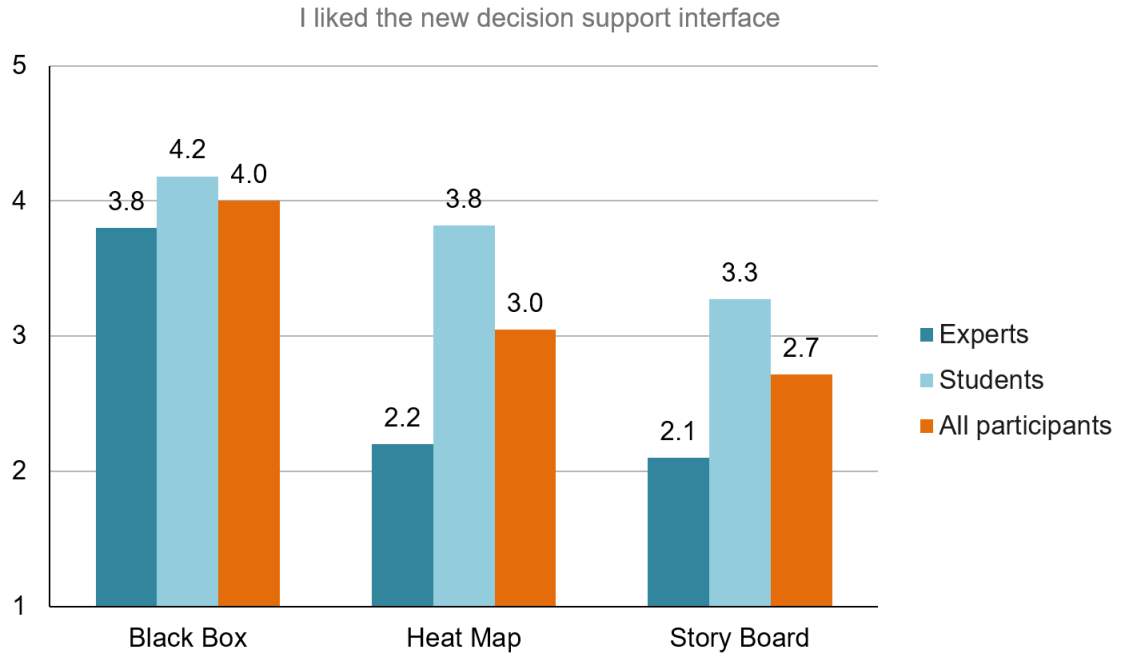
- For both the students and the experts groups, the heatmap exhibited the lowest value of workload on average.
- Students experienced the highest level of workload during the black box condition.

HP - USABILITY

CLEAR AND UNDERSTANDABLE

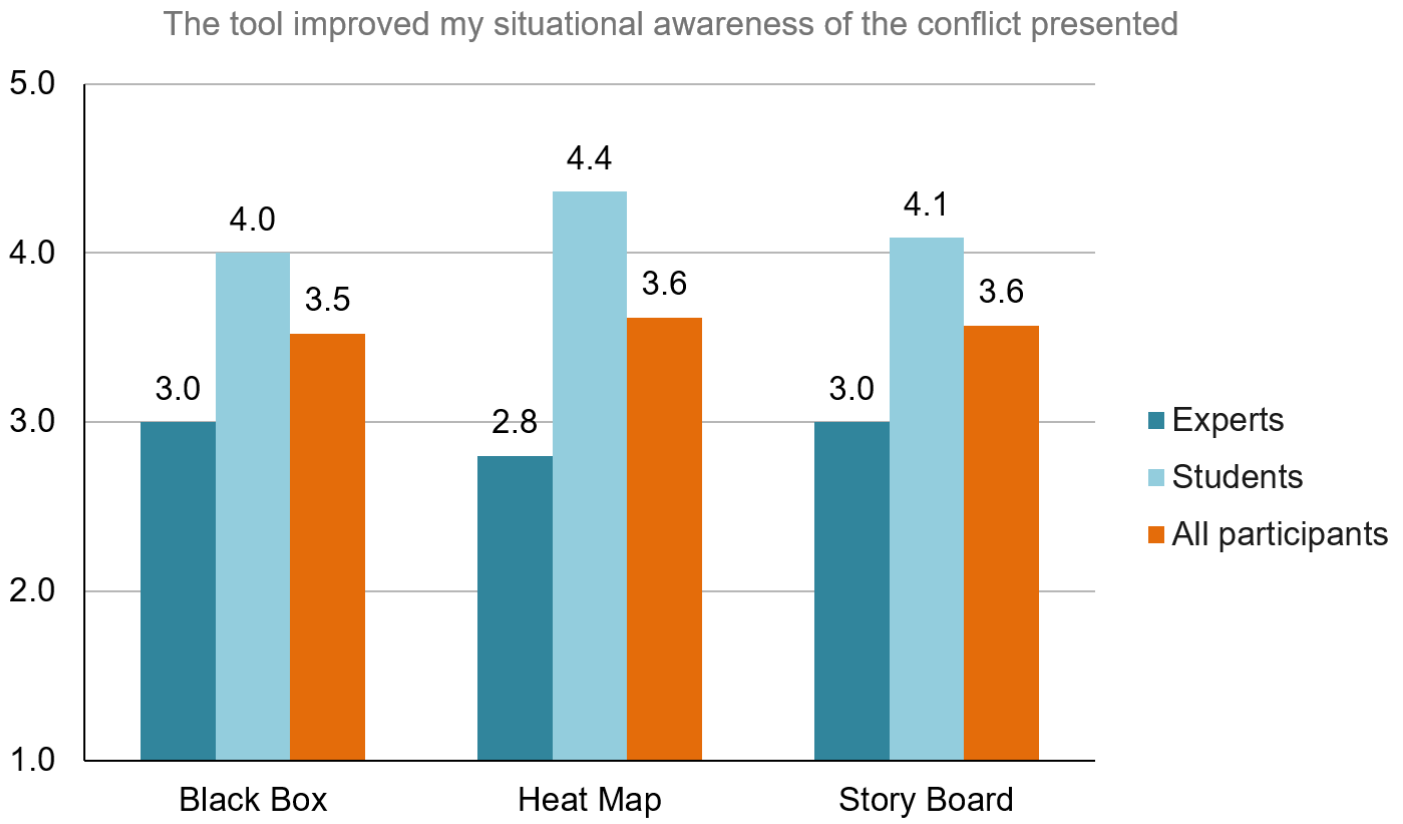


TOOL INTERFACE



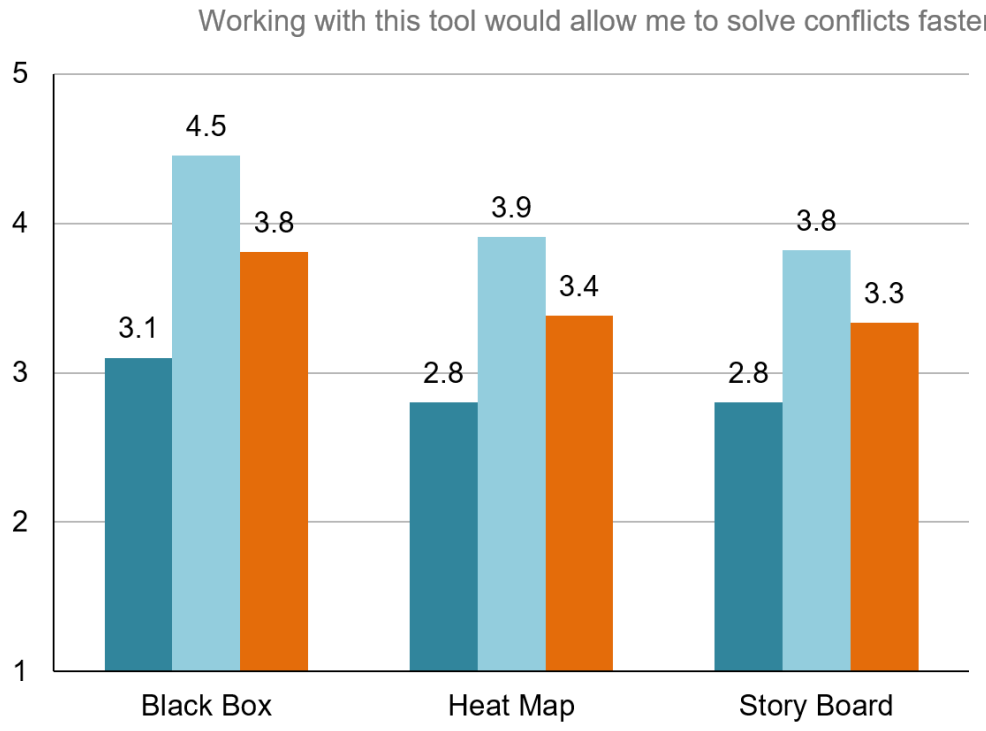
RESULTS – HP – SITUATION AWARENESS

- No improvements in terms of SA from the experts point of view.
- These results might have been impacted by the experimental limitations and lack of realism in the task.

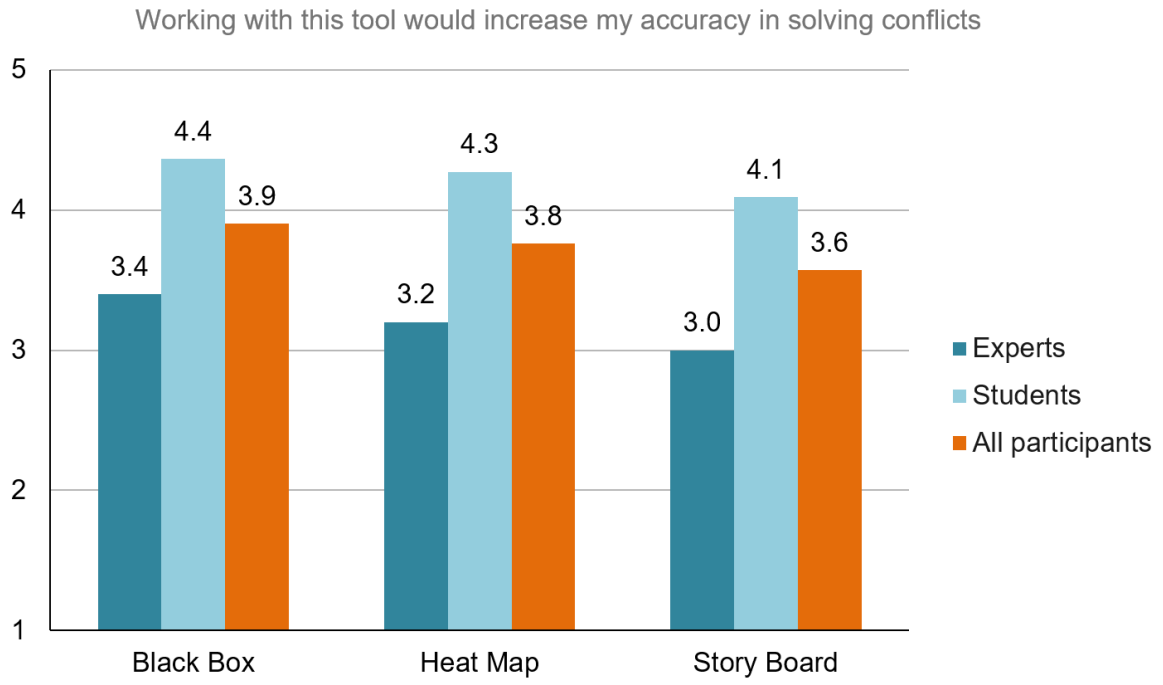


RESULTS – HP – TASK PERFORMANCE

1.2 CS SPEED

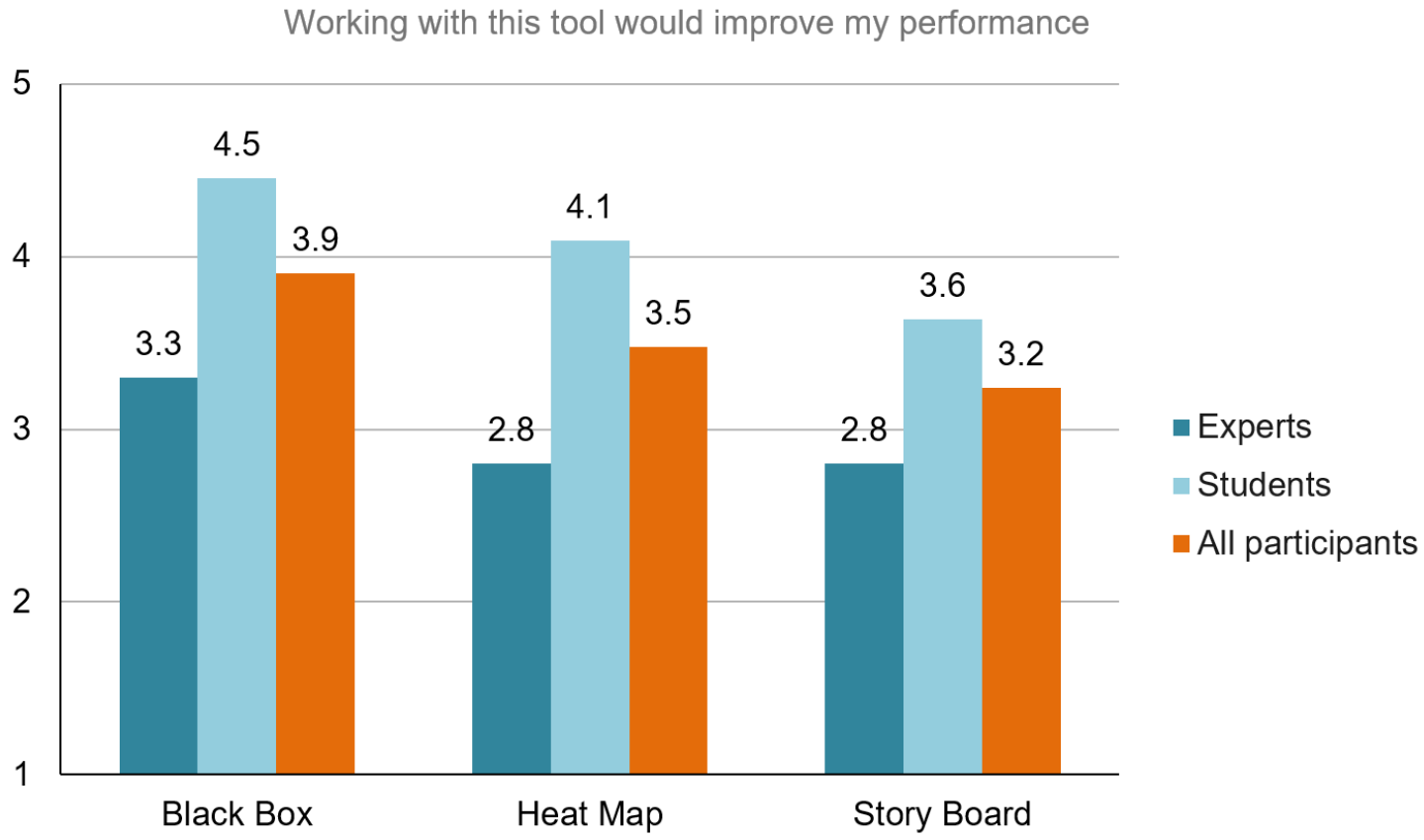


1.2 CS ACCURACY



RESULTS – HP – TASK PERFORMANCE

1.2 PERFORMANCE IMPROVEMENT



Conclusions

- Work experienced played an important role in terms of visualization tools acceptance
- All participants with ATC work experience reported a preference towards the Blackbox (BB) . The motivation was that it was more straight forward, easy to understand and mainly allowed them to make their decision in less time compared to the heat map (HM) or the storyboard (SB) solution.
- From the 10 students that participated in the simulation, 6 preferred the BB, 3 really the HM and 1 liked the SB. These outcomes are supported by the neurophysiological results (approach-withdrawal index).
- There was a trend in the questionnaires that showed that students had a tendency agreement with the AI tool proposals than compared with experts.

Conclusions (2)

- In general, experts were less optimitic about the conflict resolution visualisation in terms of performance improvement.

- Most ATCOs mentioned that if they would need more time to analyze and double check the proposals from the solution with explainable AI, that could ultimately translate in an increase of workload during operations and/or loss of situational awareness of other events in the sector.

- At the same time debriefings most participants admitted that some of the solutions (HM and SB) that were more complex could be an added value for training.

Content

- Overview of Artimation
- Conflict Detection and Resolution Visualisation
- **Delay Prediction results**

Delay Prediction

- On average, Air Traffic Flow Management (ATFM) costs approximately **100 Euros per minute** for airlines[1].
- The high cost creates the interest of **predicting delays**.
- Research studies identify that the **take-off delay** is one of the **root indicator** of flight delays.

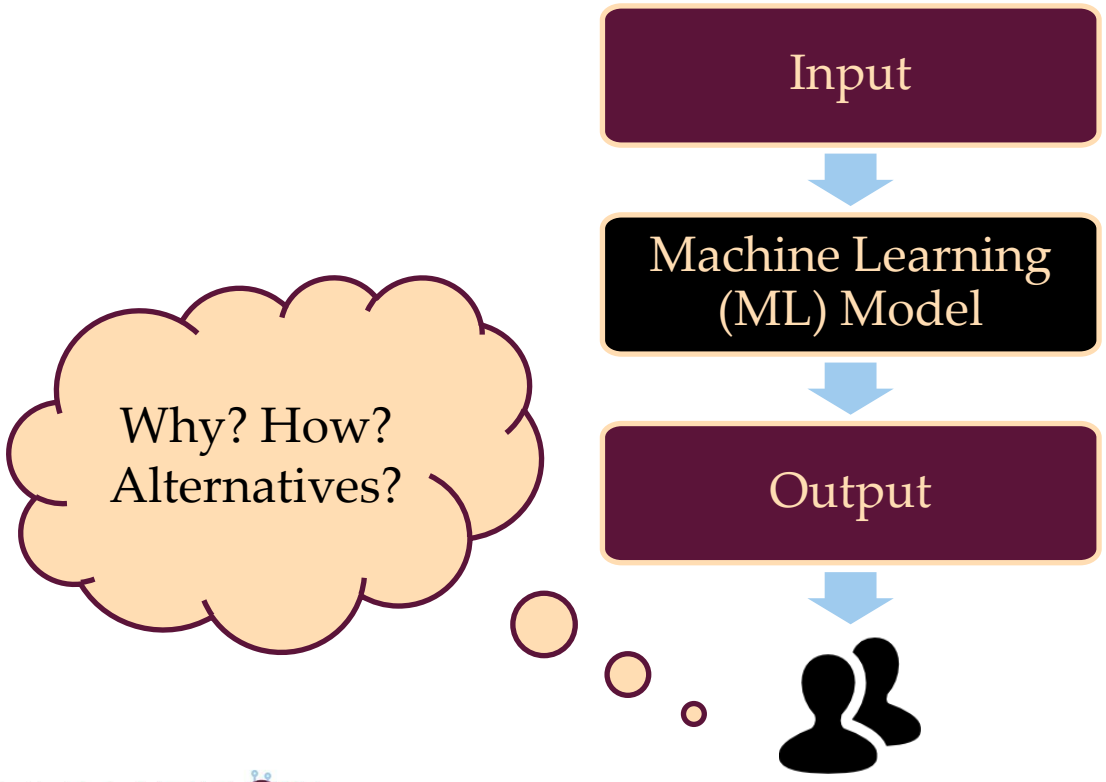
[1] A. J. Cook, G. Tanner, European airline delay cost reference values (2011).

Data and Predictive Model

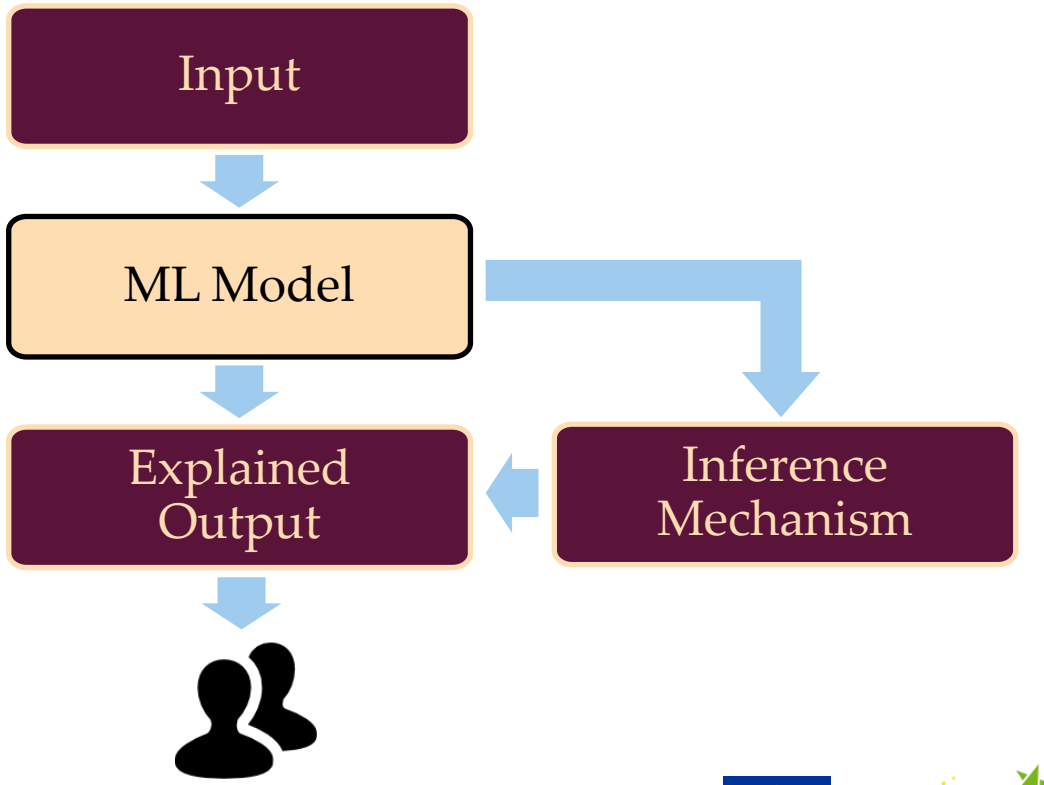
- The dataset was collected from the EUROCONTROL
- It contains Enhanced Tactical Flow Management System (ETFMS) flight data with (EFD) messages for all flights during the year 2019 (i.e., May to October)
- The dataset consisted of 9,509,954 instances
- Data pre-processing e.g., encode categorical values, adding of aircraft registration numbers, removal of instances without registration numbers, etc.
- Predictive models
  - Gradient boosted decision tree (GBDT),
  - Random Forest and
  - XGBoost

Intuition of XAI

Current Automated Systems with AI



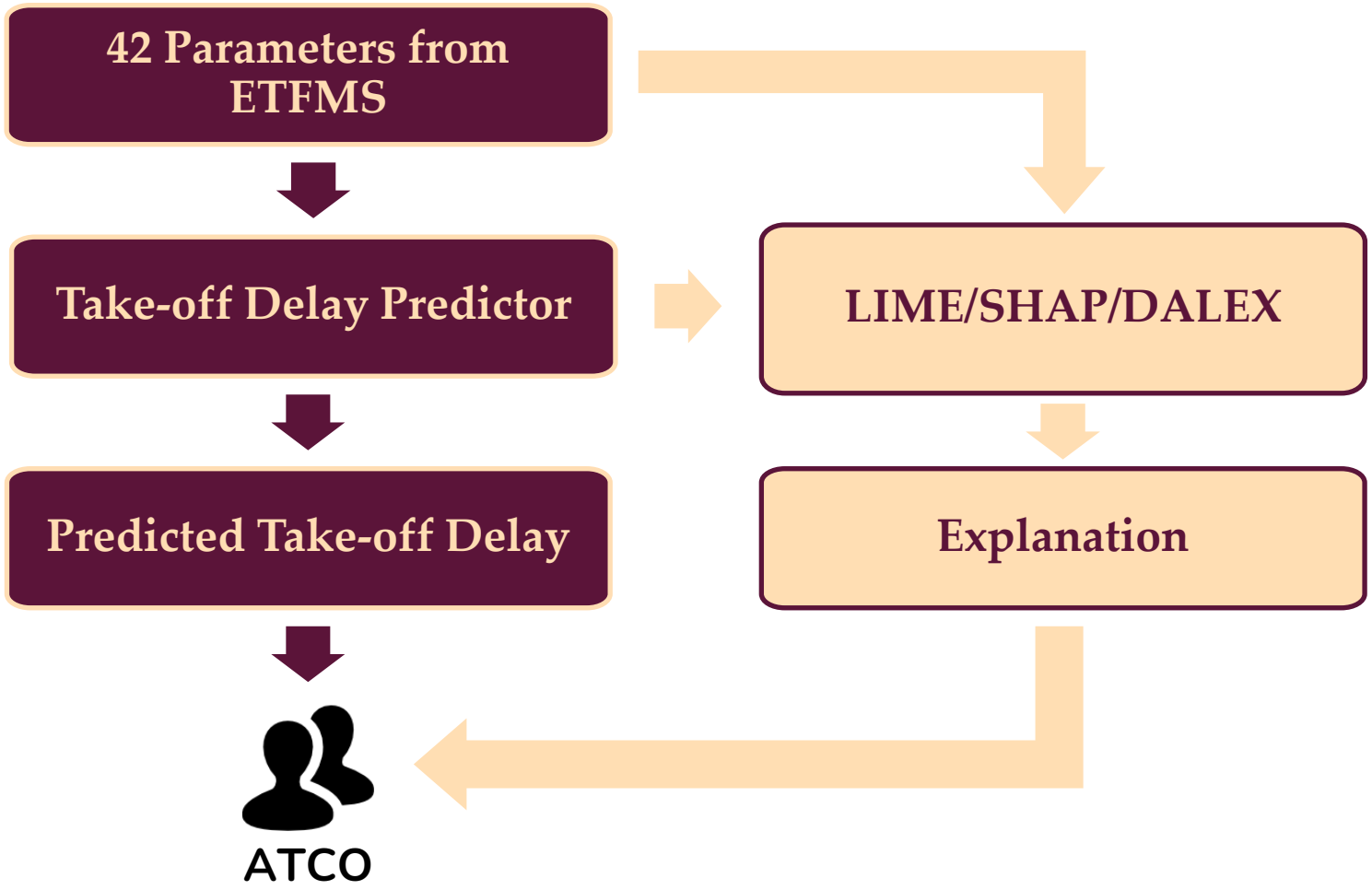
Transparent Automated Systems with XAI



Black-box Prediction

As a black-box prediction, the **delay** in **minutes** will only be presented alongside the existing interface for the given scenario.

Take-off Delay Prediction



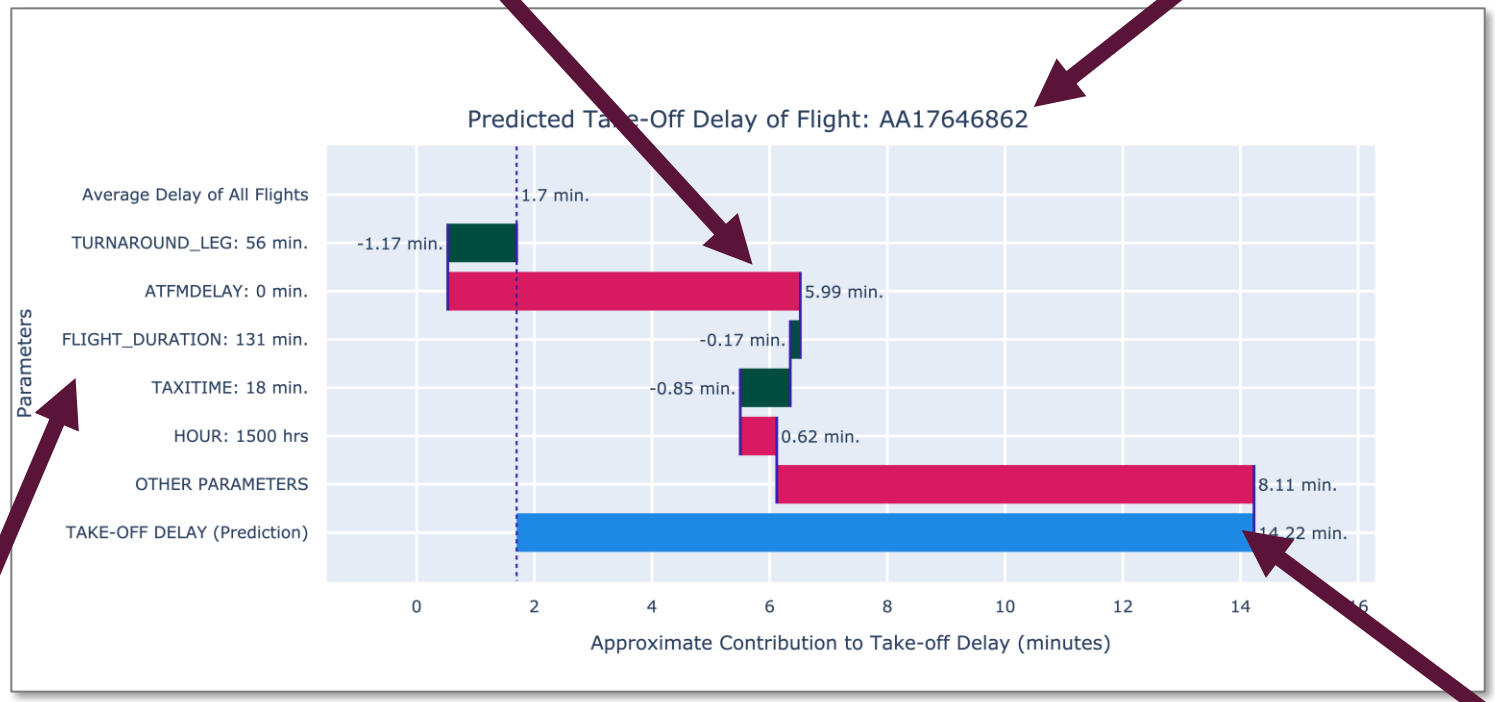
Prediction with Explanation (Breakdown Plot)

Individual contribution from Parameters

Increases DELAY: RED

Decreases DELAY: GREEN

Flight ID



(Top 5) PARAMETER: VALUE

Existing Interface | 14.22

Predicted Take-off Delay (minutes)

LIME: Local Interpretable Model-agnostic Explanations[1]

- LIME provides **explanation** by training a separate **interpretable model** to **approximate** the **predictions** of a **machine learning model**.
- LIME **tests** what happens to the predictions when **variations of data** is given into the machine learning model.
- LIME **accumulates new data** through permutation of the given samples and the **corresponding predictions** of the black box model.
- Analysing the similar data, LIME tries to **weight** the effect of different **parameters** and determine their **contribution** to final **prediction**.

[1] Ribeiro, M. T., Singh, S., & Guestrin, C. (2016, August). " Why should i trust you?" Explaining the predictions of any classifier. In Proceedings of the 22nd ACM SIGKDD international conference on knowledge discovery and data mining (pp. 1135-1144)

LIME in Explaining Delay Prediction

Departure Airport

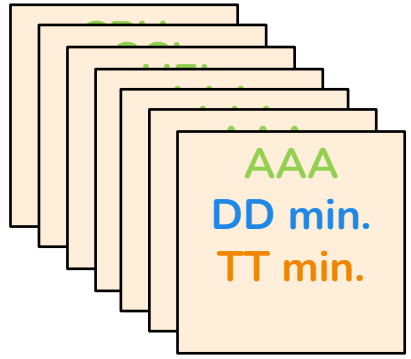
ATFM Delay

Taxi Time

Predicted Delay

ARN
21 min.
13 min.
29 min.

LIME picks similar dummy data

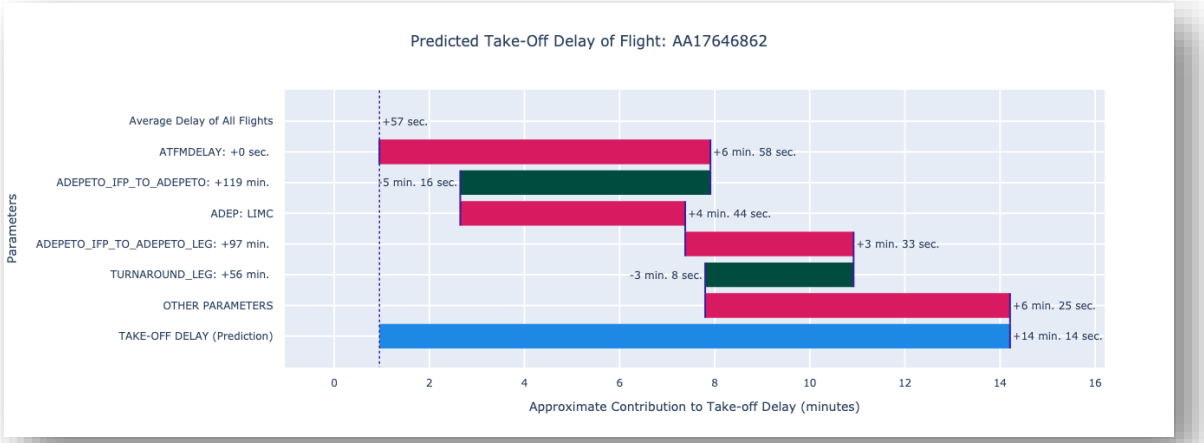


Importance of the Parameters

Departure Airport

ATFM Delay

Taxi Time



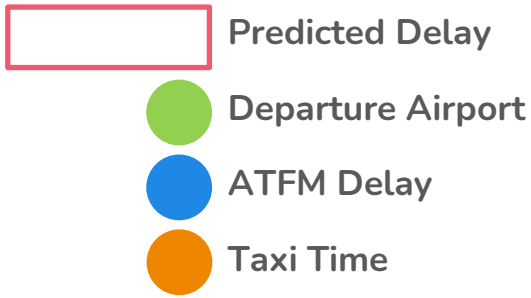
SHAP: Shapley Additive exPlanations[1]

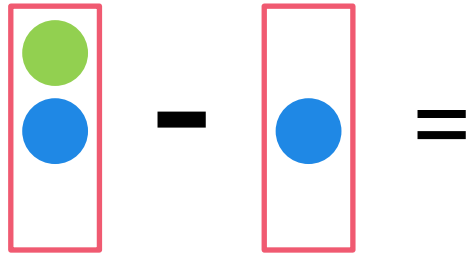
- The solution comes from **cooperative game theory -**
  - The **Shapley value**, coined by Shapley[1].
  - Assigns **pay-outs** to players depending on their **contribution** to the **total pay-out**.
  - Players cooperate in a **coalition** and receive a certain **profit** from this cooperation.

- The Shapley value is the **average marginal contribution** of a player across **all possible coalitions** among them.

[1] Lundberg, S. M., & Lee, S. I. (2017). A unified approach to interpreting model predictions. Advances in neural information processing systems, 30.
[2] Shapley, Lloyd S. "A value for n-person games." Contributions to the Theory of Games 2.28 (1953): 307-317.

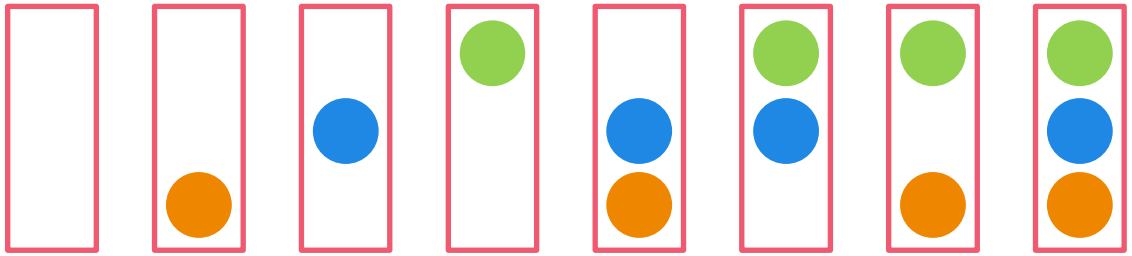
SHAP in Explaining Delay Prediction

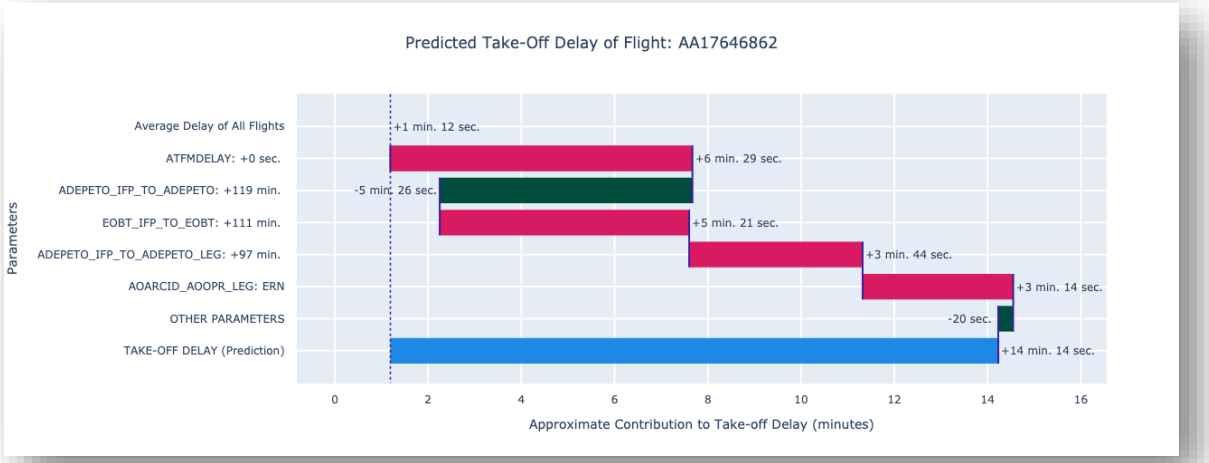




Marginal Contribution of 'Departure Airport' in the predicted delay for the coalition with 'ATFM Delay'.

All Possible Coalitions





DALEX: moDel-Agnostic Language for Exploration and eXplanations [1]

- Generally, **predictor** models are **not additive**, i.e., they do not provide individual contribution of the parameters to the final prediction.

- LIME and SHAP provides **additive explanation** but with the list of **parameters** according to their **computational relevance**.

- **DALEX** generates similar **additive explanation**, but it involves user to **select the parameters** of their preference.

[1] Baniecki, H., Kretowicz, W., Piatyszek, P., Wisniewski, J., & Biecek, P. (2021). dalex: Responsible machine learning with interactive explainability and fairness in python. The Journal of Machine Learning Research, 22(1), 9759-9765.

DALEX in Explaining Delay Prediction

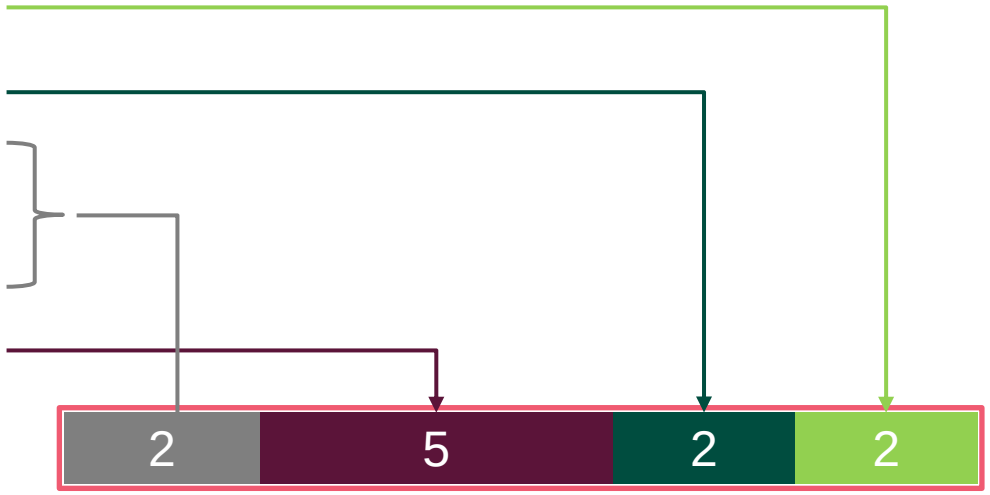
- DALEX **prompts** the user to provide their **preferences** from the **parameters** used for the prediction of delay.

- It captures the **contribution of a parameter** to the prediction by computing the shift in the expected value of the **prediction**, while fixing the values of other parameters.

- To discuss the working procedure of **DALEX**, let us consider **five** parameters from ETFMS to explain the predicted delay -
  - **Departure Airport**
  - **Destination Airport**
  - **ATFM Delay**
  - **Taxi time**
  - **Hour of the Day**

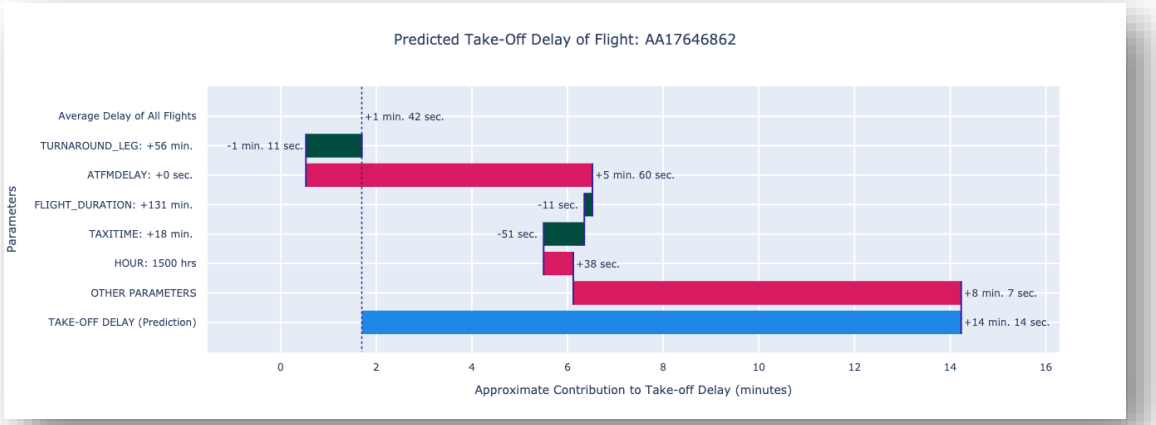
DALEX in Explaining Delay Prediction

- ✓ Departure Airport
- ✓ Destination Airport
- ATFM Delay
- Taxi Time
- ✓ Hour of the Day



Predicted Delay

11 min.



Evaluation

- Computing MAE for Predictive Models
  - Among several tree based ensemble models XGBoost has shown best MAE
- Comparing Local Accuracy of Explanation Models using MAE
  - Average MAE and standard deviation σ for local accuracy
  - SHAP has shown better results on three sets of instances
- Comparing Feature Attribution for Explanation Models
  - Normalized discounted cumulative gain (nDCG)
  - Explanation in terms of feature attribution from SHAP produce better nDCG across different subset of data

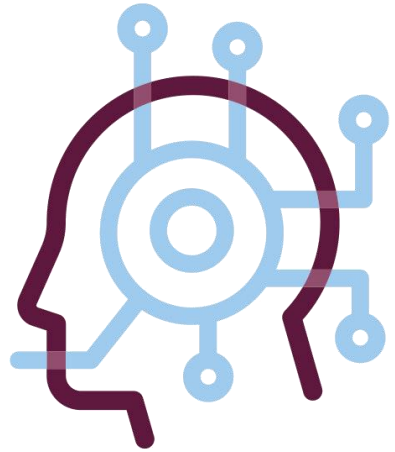
[1] Ahmed, M. U., Barua, S., Begum, S., Islam, Mir R. and O Weber, R. (2022). When a CBR in Hand is Better than Twins in the Bush. Fourth Workshop on XCBR: Case-Based Reasoning for the Explanation of Intelligent Systems, ICCBR22.

Demo

- **Demo**
  - ARTIMATION DEMO#2 Delay prediction

- **Validation Tool**
  - Go to: https://artimation-validation.herokuapp.com/
  - Or scan the QR code on the right

Thank you for your attention!



Project Coordinator: Mobyen Uddin Ahmed
mobyen.uddin.ahmed@mdu.se