# HALA!: TOWARDS HIGHER LEVELS OF AUTOMATION IN ATM. POSITION PAPER - STATE OF THE ART AND RESEARCH AGENDA

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## Abstract

*HALA! (Higher Automation Levels in Air Traffic Management) is a Research Network which was initiated in September 2010, inspired and underpinned by the highest principles of collaboration, transparency and innovation for the effective application of automation of Air Transport processes, that pretends to develop research in high-risk, novel or unconventional areas. This paper presents the mayor strategic research principles stated by the network in a "Position Paper" titled "Air Traffic Management Automation State of the Art and Research Agenda".*

## 1 Introduction: SESAR and the need for innovative and long term research.

SESAR (Single European Sky ATM Research) [1] is a global (end-to-end) project involving the whole air transport system including Navigation, Air Traffic Management and Airports as part of the same network. The challenging SESAR capacity and safety objectives are to be achieved by a significant enhancement of integrated automation support, with the human operators at the core of the system.

However, there are issues requiring research and innovation which are not currently covered by the programmed activities, including research into "Concepts" for implementation beyond the nominal SESAR timeframe of 2020. To achieve these goals four specialized networks have been organized [2]:

- Towards Higher Levels of Automation in ATM (HALA!). [3]
- Mastering Complex Systems Safely.
- Economics and Performance.
- Legal Aspects of Paradigm Shift.

## 2 HALA! Research Network.

HALA! is financed by SESAR with a total budget of 2.4 million Euros in 4 years. The network provides a Scientific Collaborative Platform through the participation of more than 60 of the most relevant world class universities, R&D centres and industry in ATM from to seventeen different countries. Fig. 1 shows the proportion by type of the participants. Nearly 50% of the partners are Universities giving the HALA! Research Network a high level of Research capability also holds by the R&D Centres (20%). Additionally a 31% of Companies gives the consortium a complete representation of the European ATM Industry.

HALA! is coordinated by the Air Navigation Research and Development Group (GINA) of the Universidad Politécnica of Madrid (UPM). GINA-UPM is backed by some of the best European Universities in ATM R&D: Imperial College London, KTH, TU Braunschweig and TU Dresden.

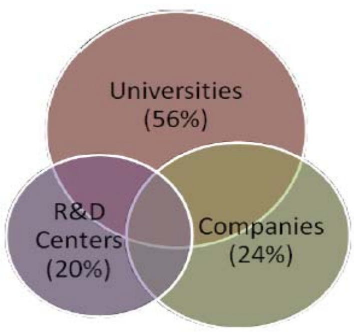


**Figure 1. Network participants**

## 2.1 HALA! objectives

The main objective pursued by the "research" into "Higher Automation Levels in ATM" is to explore unconventional and high risk areas, involving new technologies and concepts around the theme "Toward higher levels of automation" in future Air Traffic Management Systems.

The Research Network activities to support the achievement of these objectives are:

- Interaction with worldwide experts from multidisciplinary research environments.
- Coordination with worldwide ATM experts.
- Funding PhDs programmes at leading European Universities.
- Organization of meetings, workshops and conferences to raise the awareness on the research conducted .
- Development of a "Position Paper" reflecting strategic principles to foster the research on automation in ATM.
- Coordination with SESAR funded R&D projects on related topics.

## 2.2 Scientific collaborative platform for knowledge management.

The project is back it up by a scientific collaborative platform for knowledge management, called Pollenizer, that provides an optimal flow and use of the information. Its main goal is supporting the Research Network with communication and collaborative as well as Data storage tools in an orderly and accessible way. It enables members interact in a cyclic, collaborative process for the elaboration of knowledge for and from workshops, white papers and other activities performed within the Research Network. The outputs may become into inputs feeding again the platform by fostering new collaborative activities or creating new dissemination materials.

Scientific Collaborative Platform Process is shown in Fig. 2. The figure presents the main actors involved in the process (Members, Participants, EUROCONTROL and SESAR JU); inputs and outputs; and three blocks representing the services provided by the platform: Dissemination tools, Pollenizer Data and Collaborative tools. Different inputs are represented by yellow arrows and outputs are represented by orange arrows

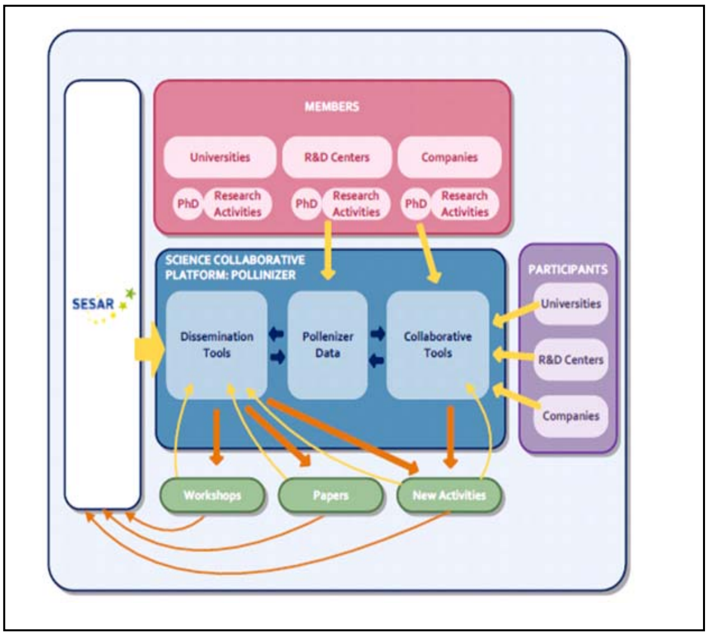


**Figure 2. Scientific Collaborative Platform**

## 2.3 Dissemination events.

Main HALA! dissemination events are:

- Yearly conferences complementing the Pollenizer internet-based interaction. First HALA's conference was hold at Barcelona in May 2011 and the second one at London in June 2012.
- Yearly joint conference with all the networks of WP E towards to cross-fertilise the research by feedback from respective disciplines and explore overlapping areas. In 2010 and 2012 these events took place at the Innovative Research Workshop and Exhibition (INO) at the EUROCONTROL Experimental Centre.
- Yearly Summer school, at least of one week duration, orientated towards PhD candidates and researchers. The two last years these courses were organized by UPM as part of their summer courses, held every July at La Granja de San Ildefonso (Segovia).

## 2.4 PhD programme

The network places PhD research at the core of its activities. Every two years the network asks participants to propose PhD projects on any topic in the area of 'Automation in Air Traffic Management' that will be funded by the Network with 35.000€ per year.

Proposals are selected based on: overall scientific merit of the proposal, including level of risk and potential impact; availability of the relevant facilities at the University; profile and track record of the Supervisor(s), including any co-supervisors from non-University members; exploitation of the relevant varied expertise within the network; both in academia and industry; requirements for mobility; co-funding; and co-supervision arrangements, including with non-University members and participants.

In addition to the traditional university supervision, PhD researchers will be guided by Members representing ATM industry in order that the knowledge that is developed can be most efficiently translated into effective tools.

# 3 HALA Position paper

The network has stated their mayor strategic research principles in a "Position Paper" titled "Air Traffic Management Automation State of the Art and Research Agenda". It reflects the main ideas and contributions of the network to foster research in ATM automation, offering a framework conditions for research, go beyond traditional approaches on automation in ATM and cover ATM automation activities not currently addressed by the other research programmes.

This document is written as a rolling and life "White Paper", updated every 6 months through and open and collaborative process in which all the Air Traffic Managements (ATM) community is invited to participate. The intended audience of this Position Paper are researchers, engineers and mathematicians in all relevant fields of research that are eager to contribute to the objectives of HALA!. The document revise heritage in ATM and Automation and proposes a new research approach summarised hereafter.

## 3.1 Heritage in ATM.

Air Traffic Management encompasses all airborne and ground-based functions and services required to ensure the safe and efficient movement of aircraft during all of the planning and execution phases of the flight. Within current approach ATM is based on 3 major functions:

- Air Traffic Services (ATS): to provide and ensure safety and efficiency of air traffic during all phases of flight, including Air Traffic Control (ATC) service, flight information service, and alerting service.
- Air Traffic Flow Management (ATFM): to ensure an optimum flow of air traffic through airspace, respecting all Air Traffic Flow constraints such as airspace sector and airport capacity, ATC, etc…
- Airspace Management (ASM): to maximise the utilisation of available airspace.

Europe ATM does not have a single sky managed at a European level; it airspace is still largely organized and managed along national borders. Current status leads to around up to 600 ATC sectors [4] over Europe, with relevant capacity limits and bottlenecks. European airspace is amongst the busiest in the world with over 33,000 flights on busy days, and the number of flights per day is expected to double by 2030 [5].

The airport is considered the largest capacity bottleneck in the European ATM system. ICAO records 2,234 airports in the 36 EUROCONTROL member states, of which 766 are recognised by IATA as commercial airports. The possibilities of these airports to expand to increase capacity are typically limited due environmental/noise, physical constraints and high costs.

Although in the past decade ATM System has managed to cope with a significant traffic growth in an acceptably safe and expeditious manner (with delays being historically low at 1.9 mins./flight); the current ATM system shows clear signs of saturation. An increased environmental awareness calls for more efficient operations and better technology; and the economic crisis imposes extra requirements are placed on the European ATM system to reduce cost (e.g., ATM costs are estimated to be at 800 EUR/flight), and increase safety.

## 3.2 Heritage in Automation

Advances in information and communication technology, along the last 30 years, have led to a constant increase in the level of automation of control systems in aviation and Air Traffic Management (ATM). However more advanced level of automation for different ATM functions is required for a more efficient system to cope with a growing traffic demand. In automated systems, "function allocation" means that the actor, either human or machine, that is best suited based on some continuum of parameters should perform the function. One early static model of function allocation is the MABA-MABA list (Men Are Better At – Machines Are Better At) [6], notably based on material from Air Traffic Control.

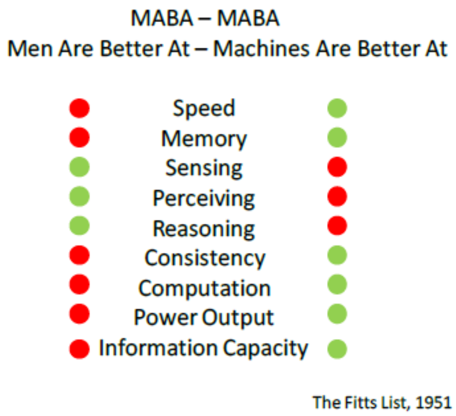


**Figure 3. MABA-MABA list**

Evolving the static approach, Sheridan, Parasuraman and others have constructed stepwise function allocation models of automation using two main dimensions: proper task and proper level. Several levels have been specified (usually between eight and ten) where the extremes denote full action performance by either human or computer, and the intermediate levels state to which degree the computer performs tasks and what is left for the human. The application of automation is also divided into specific tasks in the sequence: information acquisition, information analysis, decision making, and implementation. This approach is the one considered in the SESAR WP E Thematic programme [7-10]. The application of Parasuraman"s model has suggested recommendations for future ATC system automation, as indicated in Fig. 4.

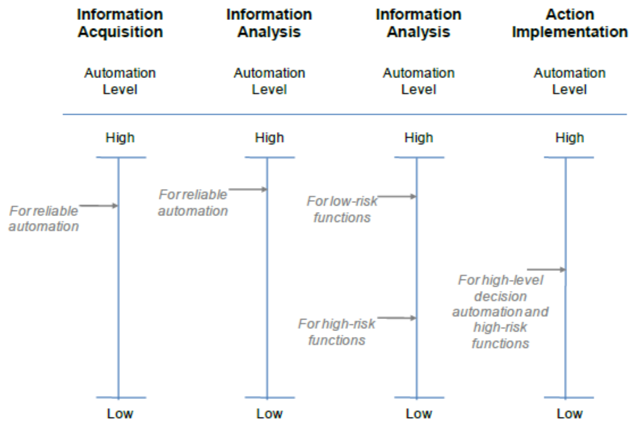


**Figure 4. Levels of automation for independent functions of information acquisition, information analysis, decision selection, and action implementation. Recommended types and levels for future ATC systems.**

Some authors such as Hollnagel [11] suggest that some functions could benefit from a more fluid allocation, with continuous task transfer based on continuous mutual coordination between human and machine; much like optimal human team work is conducted.

Current SESAR Concept of Operations has been developed under the understanding that "humans will constitute the core of the future ATM Systems operations". This human-centred philosophy places significant constraints on the system design. The limits of automation are based on Human performance consequences rather than on System performance consequences.

Unfortunately the ATM automation has evolved at a remarkably slow pace and today is still based on paradigms and conceptions that have not fundamentally changed for decades. Nevertheless, the technical developments in computer hardware and software now make it possible to introduce automation into virtually all aspects of human-machine systems. The analysis of the state of the art in automation and its application in other safety critical industries could bring new ideas on how higher and efficient levels of automation can be implemented in ATM.

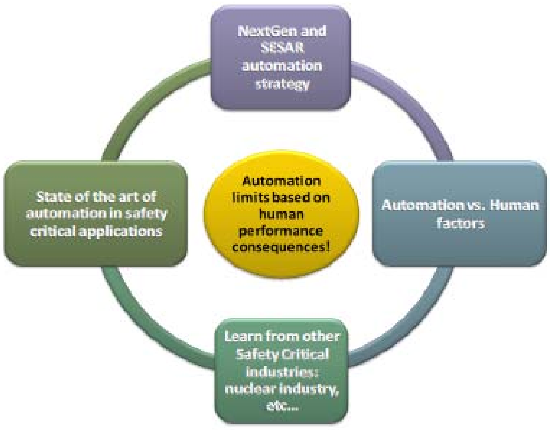


**Figure 5. Key issue in current ATM automation approaches.**

## 3.3 The three interdependent dimension for a paradigm change in ATM Automation

Given current technical capabilities the question to be answered with the next level ATM system is: which functions of the system should be automated, to what level and where should these functions logically be implemented? Appropriate selection is important because automation does not merely supplant but changes human activity and can impose new demands on the human operator.

In order to go further than SESAR and NextGen a paradigm shift is required in ATM Automation as indicated on Fig. 6. This shift will be focused on ATM invariant processes and will allow for new role assignments based on three interdependent criteria, having overall system performance as main driver for ATM automation.

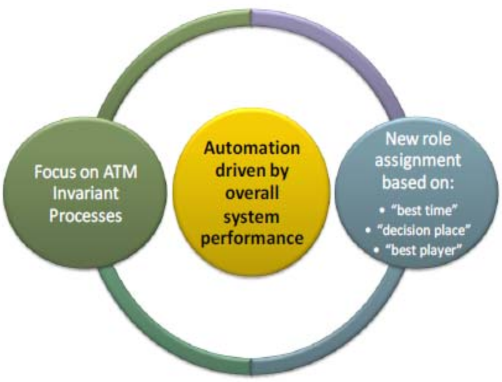


**Figure 6. New paradigm Shift in ATM Automation**

ATM automation should be based on overall system performance rather than in heritage inertia or competitiveness human vs. machine. The only principle about the assignments of new roles should be that the "decision about aircraft trajectories could be taken by the actor that is ideally placed at each moment and for the given scenario to take such a decision" and the impact on overall system performances should be its main driver.

Evolution from a purely tactical intervention model towards a more strategic trajectory management concept and progressive introduction of more autonomous and decentralized operation are key concepts in the paradigm shift. Implementation of these future ATM concepts will change the human role in the ATM system, and his relationship with the automated processes. Who is the best player against overall system performance should be the choice criterion. The choice of this best player will be derived from the consideration of the three decision criteria identified on Fig. 7:

- Optimal decision time for all and any relevant event in ATM, which involves strategic vs. tactical planning layer;
- Optimal decision place, which involves centric vs. autonomous consideration to decide, which place is suited best to take the required decision;
- Optimal decision player, which involves human vs. automated player considerations.

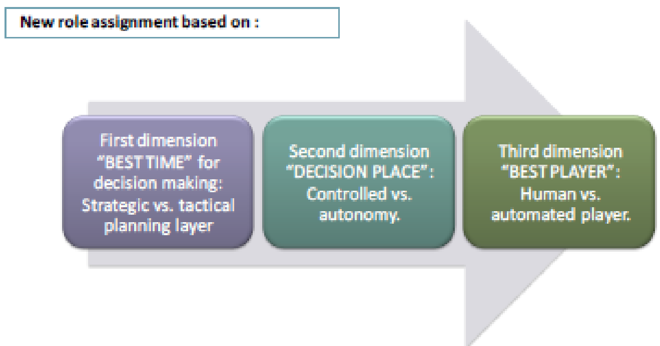


**Figure 7. The three dimensions involved in the identification of new roles assignments.**

Time scale needs to be found along the various required functions that are carried out by pilots, controllers and other operators (on ground) on the pre-operational level The general principle will be to move decision time towards a more strategic handling of ATM events while improving the efficiency of these actions, despite a raising data uncertainty.

In general terms, to expand the planning timeframe is positive to facilitate the management of the involved resources, but it brings us, as a consequence, a loss of accuracy in the required data, particularly in the estimation of atmospheric behaviour. Thus, the largest "best time" for trajectory planning should be established making some kind of trade-off between both, better use of resources on one side, and accuracy of the data required for trajectory prediction on the other side.

Autonomy of decision supported by higher level of automation arises as the best option when unpredictable events occur with low available reaction time, low number of aircraft and/or small spatial affected area. There are two main reasons for that: corrective autonomous decision usually needs smaller reaction time and, at the same time, uses fewer amounts of resources (only those available in the affected aircraft), thereby reducing the costs. Furthermore, the limited number of affected aircraft and the small dimensions of the area, reduce the probability of secondary effects.

In the other extreme, when the event involves a significant number the aircraft as well as an extensive area, if reaction time permits, the use of centric systems, where humans using DST play an important role, arises as the best option. The main reason for that is that autonomous and automated reaction could produce secondary effects, introducing instability in the global air traffic system. Furthermore, these situations usually involve economic and human factors that complicate the management in a fully autonomous/automated ATM scenario.

Although the starting point for the new human role assignment will localize inside the current SESAR concept of operations, future functions and procedures being allocated to the human may be quite different from those performed in ATM today.

Additionally, trajectory management in scenarios where no capacity restrictions or constraints are derived from human intervention, best actor (human vs. machine) is then envisaged as a permanent trade off between safety and aircraft performance. Even in this trade off it will require an intense enhancement of integrated automation and complexity management support.

New roles for different actors in the long term future ATM are, even today, a matter of conceptual proposals; the overall system performance as central metric should be the main driver. The roles assignment will conceptually follow the presented three dimensional model comprising:

- Dimension one: searching for the "best time" to take a decision. This deals with finding the right time to act along the strategic to the pre-tactical and tactical planning layer;
- Dimension two: searching for the "best place" to take a decision. This deals with deciding on whether giving pace to a centralized function versus place the function to a (set of) actors and let them decide autonomously;
- Dimension three: searching for the "best player" to take a decision: This deals with deciding to what extent human or an automated function should participate in the decision while taking into consideration that this decision may invoke different logical strategies as the human rather acts on an aggregated system monitoring level whereas the automated function will run at dedicated function control levels.

The following section elaborates potential dependencies between these dimensions.

### 3.3.1 Dimension One: "Best decision time"

The "best time" approach consists in determining the optimal moment to initiate an event that generates or modifies any flight trajectory. This should be applied to all flights, on an "ad hoc" and context basis.

Increasing look-ahead time applied to planning and support functions regardless whether automated of manual, will decrease reliability and validity of the function outcome, e.g. resolution advisories for aircraft or (work) load conflicts. The nature of this accuracy degradation relies on the quality of the expected system behaviour, so the data intent quality. As more and more information become available, these have to be integrated and used to minimize uncertainties. As stated, it is assumed that this dimension is hardly coupled with the other dimensions “best decision place” and “best player”. The proof-of-concept will have to confirm that thesis.

### 3.3.2 Dimension Two “Best decision place”

The main questions regarding the second dimension “Decision Place” relates to whether a centric or an autonomous decision approach shall be used in a future ATM system and what correlation shall exists between them. A key aspect to be considered about where to locate the required ATM function will be the impact on the resulting level of complexity.

The implementation will also consider the question on when and where autonomy is a useful extension to the current ATM network and how it can be integrated into the ATM network. The integration of all ATM components, split into the airborne and ground component on an highly aggregated level, is a key task for a successful automation in the overall ATM system and consequently calibrating the “best place” strategy.It will further be investigated, in which scenario (centric or autonomous) automation will provide a higher overall system performance and if the automation may be limited by complexity, due to high traffic density, solving time restriction or deficit information condition. Furthermore an analysis must be performed regarding whether tactical decisions imply autonomous and fully automated processes or, if a strategic decision making process implies centric controlled scenarios.

### 3.3.3 Dimension Two “Best decision player”

This third dimension reveals the question on what should be the role of automation and whether and to what extent humans will remain within the trajectory management processes. It is the nature of strategic systems to provide increasingly complex solution outcomes (such as e. g. multi-dimensional re-routing advisories for conflicting aircraft several minutes ahead of reaching their closest approach point); the decision obviously requires “management qualities” to handle the situation. These management capabilities are typically not fully addressed by automated functions. As such, a dilemma between two of the main ATM concept targets may occur and priority must be granted to either: Act for more strategic functions where human skills still plays a relevant role although supported by automation, or increase the level of automation where only humans monitoring skills are required.

The current trend of larger and more automated systems moves the impact of human actions from the sharp end of the operator to the developer side. In other words, the area of Human Factors in automation related to system performance will in the future have to focus less on preventing active failures and more on preventing the inclusion of latent conditions.

With increased size and integration of automated systems follows the issue of system complexity, defined as the possibility to understand and predict system state.

The dimension “best player” is interrelated to the other dimensions “best time” and “decision place”, where “best time” has been mentioned in previous paragraphs. The dimension “decision place” (central or distributed) is related to “best player” in that the ATM system will inhabit not only the two categories humans and automation, but each category may be divided into sub-categories with their own function allocation, the most apparent ongoing effort being the current re-definition of tasks for air traffic controllers and pilots.

## 4 Hala main research areas

Considering that the overall system performance is taken as the main driver to decide when, where and by whom the decision or event should be initiated, the next table identifies questions still need to be answered, and that are the bases for Hala! main research areas.

| When, where and by whom the decision or event should be initiated. Potential research areas | | |
|---|---|---|
| Best Time | Best Place | Best Player |
| - Will the overall system maintain the required stability under the decided “best time”?<br>- What is the impact of uncertainties in a system when most decisions are taken a long time in advance? E.g. how can this system react on a late passenger? Would it become mandatory to act like those airlines which “won’t wait, if you’re late”?<br>- How can an adaptive system be designed where the degree of strategic decisions can be chosen, e.g. depending on uncertainty and/or others factors?<br>- Do the greater number of functions allocated at strategic planning layers imply more complex and rigid operational scenarios?<br>- Can ATM system deliver required safety and efficient when most of decisions are allocated at tactical level? | - What is the level of correlation between complexity and centric processes?<br>- What is the level of correlation between autonomy and centric process?<br>- Up to what extend are segregated airspaces structures the solution to the questions of where and when implementing autonomy?<br>- Do tactical decisions imply autonomous and fully automated processes?<br>Is high traffic density/complexity a key factor limiting autonomy?<br>- In which scenario (centric or autonomous) will automation provide higher overall system performance?<br>- Does strategic decision making imply centric scenarios? | - Should trajectory management (e.g. Trajectory deconfliction, even tactical decisions) be fully automated?<br>- To what extent do strategic decisions require human intervention?<br>- How can uncertainty be managed in automated systems?<br>- Are the current frameworks for automation, cognition and human factors enough to capture ATM singularities?<br>- Is a fully automated air transport system socially/psychologically acceptable?<br>- Can the ATM system be decomplexified through automation?<br>- How to deal with transition issues when implementing higher levels of automation?<br>- How can resilience be taken into account in automated systems design?<br>- Does uncertainty require human centred decision making? |

**Table 1 HALA! main research areas**

## 5 Coordination with projects financed by SESAR.

In application of the principles stated at the Position Paper the network is currently coordinating its activities with 9 research projects and 13 Phds. The research projects and consortiums are summarised hereafter.

- **ZeFMaP**: “Zero Failure Management at Maximum Productivity in Safety Critical Control Rooms” run by SINTEF ICT and FREQUENTIS AG.
- **UTOPIA**: “Universal Trajectory Synchronization for Highly Predictable Arrivals Enabled by Full Automation” run by Technische Universität Dresden, Boeing Research & Technology Europe and Barco-Orthogon GmbH (Barco).
- **TESA: “**Trajectory prediction and conflict resolution for Enroute-to-enroute Seamless Air Traffic management” run by Imperial College.
- **SUPEROPT:** “Supervision of Route Optimizers” run by the University of Bristol.
- **STREAM**: “Strategic Trajectory de-confliction to Enable seamless Aircraft conflict Management” run by Advanced Logistics Group (ALG), Boeing Research & Technology Europe (BR&TE), and

Universidad Autónoma de Barcelona (UAB).

- **SPAD**: **"System Performances under Automation Degradation"** run by Deep Blue (IT), Association pour la Recherche et le Developpement des Methodes et Processus Industriels (FR), and Université Paul Sabatier (FR).
- **MUFASA:** "Multidimensional Framework for Advanced SESAR Automation" run by Lochkeed Martin UK.
- **C-SHARE:** "Joint ATM Cognition through Shared Representations" run by Delft University of Technology (TUD) ,National Aerospace Laboratory (NLR) and Thales Nederland (TNL)
- **ADAHR**: "Assessment of Degree of Automation on Human Roles" run by ISDEFE CRIDA: Centro de Referencia I+D de ATM. DLR and NLR.

## Conclusions

This paper presents the mayor strategic research principles stated by the HALA network in its Position Paper "ATM Automation State of the Art and Research Agenda".

The paper, after revising heritage in ATM and in Automation, discussed and propose a paradigm shift in ATM Automation, that is focused on ATM invariant processes and will allow for new role assignments based on three interdependent criteria or dimensions, having overall system performance as main driver for ATM automation.

Facing these ATM invariants, automation role should be based on overall system performance rather than in heritage inertia or competitiveness human vs. machine.

The new roles for the different actors in the long term future air traffic management and the future degree of automation is today a matter of conceptual proposals, based on conceptual or theoretical considerations and the general assumption that establishes: "humans will still be central corner stones as managers and decision-makers".

Nevertheless, the only principle about the assignments of new roles should be that the "decision about aircraft trajectories could be taken by the actor that is ideally placed at each moment and for the given scenario to take such a decision" and the impact on overall system performances should be its main driver.

The Position Paper proposes that the choice of this best player should be derived from the consideration of the three decision criteria:

- Optimal decision time for all and any relevant event in ATM, which involves strategic vs. tactical planning layer;
- Optimal decision place, which involves centric vs. autonomous consideration to decide, which place is suited best to take the required decision;
- Optimal decision player, which involves human vs. automated player considerations.

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