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Copyright Statement

AUTOPACE

FACILITATING THE AUTOMATION PACE

This document is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 699238 under European Union's Horizon 2020 research and innovation programme.

Abstract

AUTOPACE aims at supporting a better understanding on how human cognition and ATC system live together in high automation environments. Automation will unavoidably change the ATCo work environment and the role of the human will move towards tasks focused on monitoring and supervision of the system actions, keeping the tactical interventions to a minimum.

However, human-automation interaction in highly automated environments presents serious performance drawbacks due to the risk of the "out of the loop" effect (OOTL) especially in case of automation fail or "fears of automation" when the ATCo is afraid of a system failure. Unforeseen operational conditions and malfunction of automation could lead to disorientation and panic behaviour.

AUTOPACE proposes the research on future ATCo Competences and new Training Strategies to mitigate those performance drawbacks supported by (a) the research of an ATCo psychological model to characterise the automation effects on ATCo cognitive system and its functioning and (b) a preliminary safety assessment of potential hazards for training strategies refinement.

The current document presents an outline of the researched solutions in the most likely future operational scenarios in 2050 time frame at nominal and non-nominal situations. The solution feasibility is substantiated with a positive maturity assessment that demonstrates that AUTOPACE is ready to move from Basic Research to Applied Research.

A preliminary experimental plan for next R&D phase is also included.

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1 Executive Summary

AUTOPACE is a research project funded by the SESAR Joint Undertaking within the European Union's Horizon 2020 research and innovation programme under grant agreement No 699238. Particularly AUTOPACE addresses the Research Topic *ER-01-2015: Automation in ATM with the aim of increasing the awareness of the interaction between automation and human performance.* AUTOPACE is a fundamental research project aiming at achieving TRL 1[1]. AUTOPACE is focused in En-Route environment and 2050 timeframe.

AUTOPACE is led by CRIDA, the R&D+i Centre of the Spanish Air Navigation Service Provider (ENAIRE) and participated by the University of Granada – Faculty of Psychology, the Polytechnic University of Madrid – Aerospace Systems, Air Transport and Airports Department, the University of Bologna and the University of Belgrade – Faculty of Transport and Traffic Engineering.

The main achievements of AUTOPACE have been:

- The definition of AUTOPACE **Concept of Operation and future Automation Scenarios in nominal and non-nominal situations** [2]**.**
- The research of **an ATCo Psychological Model** based on established attentional theories to predict the effects of high automated environments on the ATCo performance [3], such as the drawbacks due to the risk of the "out of the loop (OOTL)" and "fear of automation" whose consequences are especially severe in case of automation failure.
- The identification of new **ATCo Competences and a Training Strategies catalogue** addressing not only the technical system interaction needs but also the psychological (cognitive and non-cognitive) aspects to mitigate the ATCo performance drawbacks due to automation. This research has also provided a **feasibility study on a validation platform** to emulate future ATCo and system responsibilities to be used for further validation [4].
- **Conclusions on selection criteria** along with prerequisites on Skills, Abilities and Personality Characteristics **for future ATCo** (information included in current document, Appendix C and Appendix D).
- A **Preliminary Safety Hazard Assessment (PHA) in future automation Scenarios for nominal and non-nominal situations** to provide a set of automation risks that could be mitigated by modifying ATCo training or refining the system and procedure design. Based on this analysis, training strategies have been refined to mitigate those related hazards [5].
- **Recommendations on system features and operational procedures** for high automation environments to address those risks not covered or mitigated with ATCo future competences and training (information included in current document, section 4.2.1).
- A **Qualitative Performance Assessment (CAP, CEFF, HP)** showing the benefits brought by AUTOPACE concept elements [5].

[1] Technology Readiness Levels (TRL) are a type of measurement system used to assess the maturity level of a particular technology. Each technology project is evaluated against the parameters for each technology level and is then assigned a TRL rating based on the projects progress. There are nine technology readiness levels. TRL 1 is the lowest and TRL 9 is the highest. When a technology is at TRL 1, scientific research is beginning and those results are being translated into future research and development.

- The identification of **commonalities and complementarities along with jointly further research with MINIMA and STRESS** (SESAR Exploratory Research projects addressing the same topic and call on Automation as AUTOPACE) (information included in current document, section 4.2.2).
- A preliminary exploration of the potential impacts of automation throughout the different sequences of actions and within overall ATC operations **through modelling with Functional Resonance Analysis Method (FRAM)** (information included in current document, Appendix E)**.**

With all previous achievements, AUTOPACE demonstrates that the research solutions have achieved the maturity for moving to the next R&I phase, namely Exploratory Science/Applied Oriented Research.

2 Project Overview

2.1 Operational/Technical Context

AUTOPACE is a project funded by the SESAR Joint Undertaking within the European Union's Horizon 2020 research and innovation programme under grant agreement No 699238. AUTOPACE responds to the **first Call for Proposals of SESAR Exploratory Research** projects launched under Part III "Societal Challenges" of the Horizon 2020 Research Framework Programme, and related to the Smart, Green and Integrated Transport activities. Particularly AUTOPACE addresses the Research **Topic ER-01-2015: Automation in ATM**. It performs fundamental research on psychological modelling to predict how future automation would affect ATCo performance and to identify competences and training to safely cope with the effects of automation.

The Air Traffic Management (ATM) system moves towards an increasingly high level of automation [26] which will provide higher capacity at high standards of efficiency and predictability. Automation will unavoidably change the ATCo work environment and the role of the human will move towards tasks focused on monitoring and supervision of the system actions keeping the tactical interventions to a minimum. However, human-automation interaction in highly automated environments presents serious performance drawbacks due to the risk of the **"out of the loop" effect (OOTL)** especially in case of automation fail or **fears of automation** when a fail might occur. Future ATCos should be trained not only to acquire new technical competences but also to acquire psychological cognitive and non-cognitive competences for keeping attention to avoid the OOTL effect and for coping with stress or fear of system failure.

AUTOPACE aims at supporting a better understanding on how cognition and automation live together to support **new training strategies and automation suitability assessment**. To do so, AUTOPACE research path has been oriented to develop an **ATCo psychological model** to quantitatively predict how automation impact on performance based on a representation of human cognitive system and established psychological attentional theories. This model would allow prediction of optimal states of human-automation interaction to ensure a safe operation.

AUTOPACE is focused in En-Route environment and a 2050 timeframe. AUTOPACE Project **starts in TRL 0** (Technology Readiness Level) **and aims at finalising in TRL 1.** Existing psychological theories identify the principles that underlie the ATCo Psychological Model, however the applicability of these theories to analyse automation features to human-automation interactions based on Mental Workload need to be researched (TRL0). Also new training strategies applied in other fields to cope with stress or to ensure attention on the main task at high automation levels need exploration.

2.2 Project Scope and Objectives

AUTOPACE Grant Agreement [1] establishes AUTOPACE's main objective:

The research on a Psychological Model to predict human-automation interaction effects on ATCo performance for

- the research of required Competences and Training Strategies to operate at highly automated environments

- the exploration of automation features suitability to manage future traffic safely maximising performance benefits.

To achieve these objectives, AUTOPACE has proposed three complementary Research Areas (Figure 1) to face up with high levels of automation, maximising the automation effectiveness and traffic management safety:

- **A Psychological Model to predict the effect of Automation on ATCo Human Performance.** The ATCo Psychological Model is based on the functional structure of the cognitive system and the cognitive functioning of a human, explained through the "mental resources" concept. For that, two types of resources are considered: demanded resources and available resources. While demanded resources are those required by the task and essentially depend on the task complexity, available resources are the resources that the ATCo has to perform the task. The relationship between demanded and available resources is called the Mental Work Load (MWL). AUTOPACE has applied new attentional theories proposing that automation affects not only demanded resources but also the available resources. From this point of view, the level of activation and the engagement with the task will modify the pool of available resources and the amount of resources allocated to the task. When the ATCo feels overconfidence on automation, he/she will divert available resources to secondary tasks with the consequence of the famous Out of the Loop effect (OOTL). On the contrary if the ATCo fears of a potential system failure, the ATCo will experience stress, increasing the available resources that might provoke panic and/or erratic behaviour.
- **New Training and Competences for future ATCos to cope with the expected highly automated systems.** ATCo are imagined to provide the control service by supervising and monitoring an automated system being trained to be kept "into the loop" and to cope with stress in order to be resilient to failures of automation. ATCo are expected to be prepared to quickly and effectively react in non-nominal situations. Therefore, ATCO should be trained to master the concentration and alertness in case the ATCo has overconfidence on automation, or to keep the stress levels acceptable in case the ATCo has fears of automation failing. New tasks and responsibilities coupled with new competences have imposed the research of new ATCo curricula that will detail the course of study required to learn and develop the required competences. In coordination with the new ATCo curricula, the personnel selection processes have been re-evaluated to ensure that the potential ATCo have the ability to acquire the required new competences through training addressing not only technical aspects but also psychological ones.
- **Automation Suitability Assessment to safely manage future traffic maximising performance benefits.** The expected high levels of automation have been analysed to check if traffic is safely managed with training strategies support. A preliminary hazard assessment has served to support the refinement of the competences as well as the training program definition. For those hazards not addressed with technical and psychological training techniques, recommendations are provided in this document related to operational procedures, ATCo supporting tools and overall system design. In turn, the automation suitability analysis has been complemented with the performance benefits brought by automation. These benefits have been also assessed to support the automation features analysis as well as establishing guidelines about how psychological modelling may support automation design.

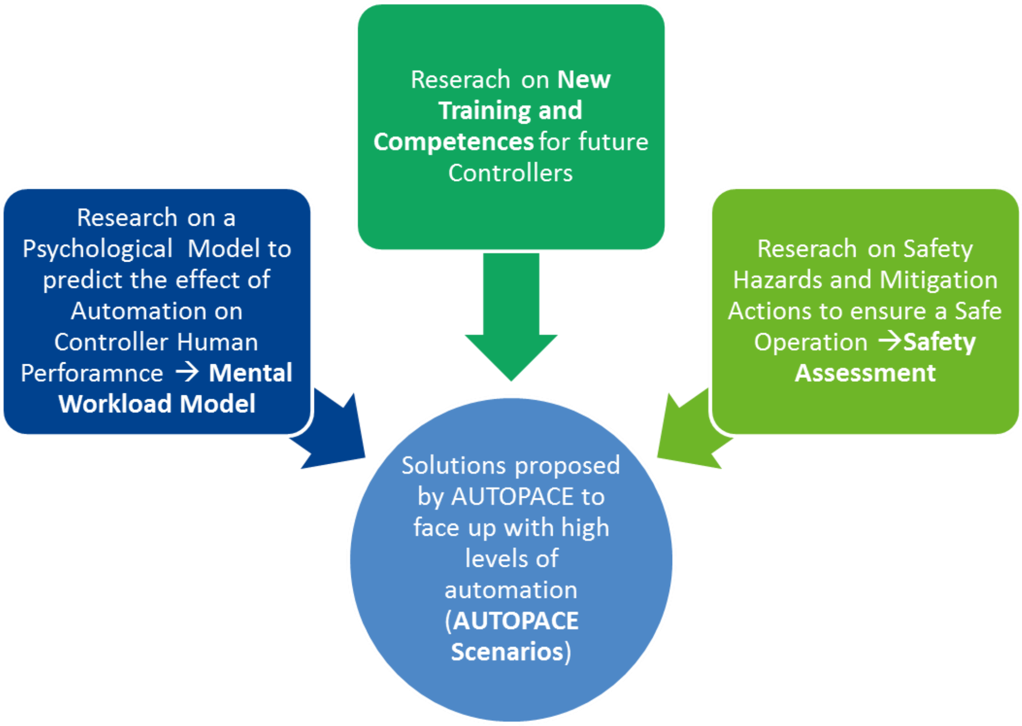

Figure 1: AUTOPACE Research Areas

The three complementary Research Areas underpin on the definition of a 2050 Concept of Operation where the ATCo roles and responsibilities are described. Nominal and Non-nominal scenarios have been considered.

According to the SESAR Performance Framework [40], AUTOPACE Concept impacts on the following KPAs and Focus Areas (Figure 2):

- **Safety:** In current ATM system, safety has two different dimensions: the safety outcome of the ATM system (occurrence of accidents and incidents) on the one hand; and the safety management practices and culture on the other hand. AUTOPACE addresses future ATC environment (system definition phase), so due to that Preliminary Hazard Assessment (PHA) is performed.

- **Cost-Efficiency:** This KPA has two focus areas: Direct gate-to-gate ANS cost and the Airspace User costs. AUTOPACE addresses the first cost impact.

- **Capacity:** The overall capacity framework splits into subsidiary Focus Areas related to Airspace Capacity, Airport Capacity, ARES airspace and Resilience. AUTOPACE addresses Airspace Capacity for nominal situations and Resilience for non-nominal situations.

- **Human Performance (HP) - Focus Area[2]:** HP is used to denote the human capability to successfully accomplish tasks and meet job requirements. The capability of a human to successfully accomplish tasks depends on a number of variables that are usually investigated within the discipline of "Human Factors (HF)". AUTOPACE addresses procedure and task design, partially addresses design of technical systems and tools and abundantly addresses individual competences and training background as well as recruitment and staffing.

The identification of the required **new competences and training** to operate in a future highly automated environment would allow the European Community to effectively implement advanced automation features, ensuring adequate safety level **(Safety)** and optimized implementation costs in terms of training and technology adaptation **(Cost-Efficiency and Human Performance)**. Moreover, the delivery of an effective ATCo Training Curricula and Personnel Selection Process will accelerate the training path and increases the productivity of the ATCo operating in the foreseen environment **(Cost-Efficiency and Human Performance)**.

The availability of an **ATCo Psychological Model** would allow establishing the ATCo Mental Workload level that can optimise the level of activation and engagement thus maximising the ATCo productivity within a desired safety level **(Capacity, Cost-Efficiency and Safety)**. This Psychological Model predicts ATCo Mental Workload based on the cognitive resources that the ATCo will require when working in a highly automated environment and allowing risk assessment based on the provided cognitive values.

The **assessment of the automation features** to support future ATCo will contribute to the increment of the ATCo productivity **(Cost-Efficiency)**. This identification also would offer to the industry some advice about the areas to be researched when developing new technology to support the future ATM system. For this reason, the availability of methodologies to estimate the performance benefits of automation increases the effectiveness of their design thus optimising the use of the airspace (Capacity). In turn, a Preliminary Hazard Assessment of AUTOPACE Future Automation Scenarios has supported the identification of a set of automation risks that should be addressed by introducing training or refining the automation design, ensuring that safety can be properly addressed for the automation features expected in future ATM **(Safety).**

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[2]SESAR Performance framework [40] identifies, in addition to the KPAs, two cross-cutting Focus Areas which influence and relate to multiple KPAs and cannot be assigned to simply one. These Focus Areas are Civil Military Cooperation and Human Performance.

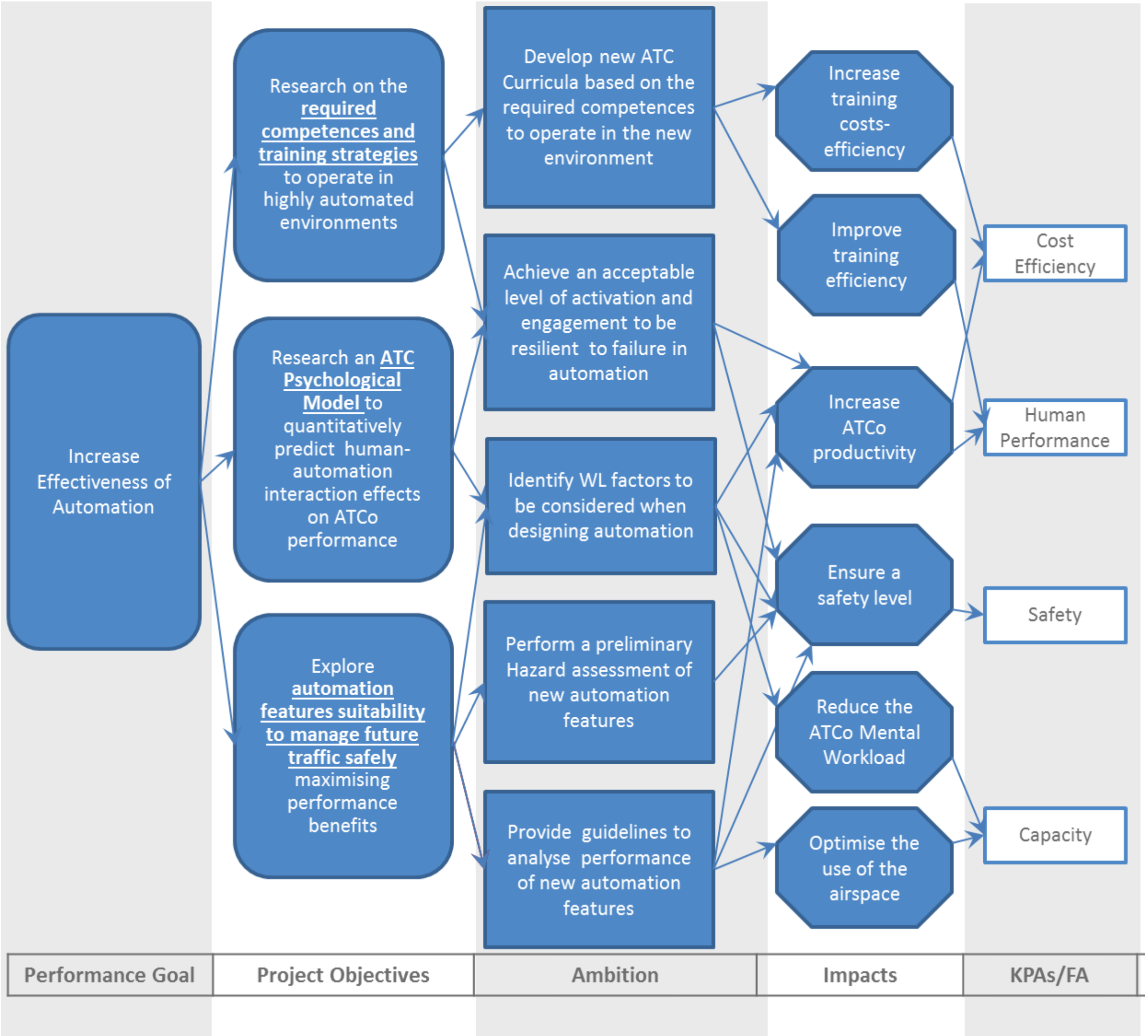

Figure 2: AUTOPACE Benefit Impact Mechanism

2.3 Work Performed

In order to address the research areas and achieve AUTOPACE objectives, an iterative approach where expert judgement, literature research and analytical studies with Fast Time Simulation have been followed.

- **Step1. Definition of AUTOPACE Concept of Operation and Scenarios for 2050 – Literature Research**

The first step has consisted of the development of a 2050 Concept of Operations (ConOps) and scenarios, whose results can be found in deliverable *D2.1 Future Automation Scenarios* (see Table 10). Firstly, the 2035 ConOps is described taking as references SESAR Concept of Operation ([38], [39]). Through a literature research on future operational context defined in Flightpath 2050 Vision [25], ACARE [20], EREA [23] and HALA! Position Paper [26], the expected levels of automation beyond SESAR/NextGen were explored. First, the 2035 ConOps was defined taking as references the SESAR

Step 2 documents. Second, by using the documents above-mentioned and the project expertise, the 2050 ConOps was elaborated.

Due to the uncertainty on ATM levels of automation at 2050, two different future automation scenarios were defined: High and Medium Automation addressing nominal situations, unexpected events and system failures (non-nominal situations). Current tasks and ATCo responsibilities were collected along with the future function allocation between ATCo and system expected in 2050 scenarios (both at High and Medium Automation Levels).

- **Step 2. Research on an ATCo Psychological to predict performance drawbacks – Literature Research, Fast Time Simulations and Cognitive Demand estimations with COMETA**

Once defined the 2050 scenarios, the next step was the research of a Psychological Model for ATCo. This Psychological Model presented in *D3.1 ATCo Psychological Model with Automation* is a representation of the ATCo cognitive system and established psychological attentional theories of Psychology domain. The model has allowed the identification of hypothesis on how the automation would impact the ATCo mental resources (demanded and available resources).

To support this activity, an existing prototype developed by CRIDA called COMETA (Suárez, N. et all, 2014) [41] has provided estimations on ATCo demanded resources. This prototype provides quantitatively the cognitive demand at every cognitive processing stage for a set of control events. The ATC control events were obtained from a fast time simulator (RAMS) where the different AUTOPACE automation scenarios where modelled taking into account the forecast traffic at 2050.

- **Step 3. Preliminary Safety Hazard Assessment – Application of Eurocontrol and ICAO Methodologies**

Based on the performance drawbacks identified in the ATCo Psychological Model Research Area and the Concept of Operation for 2050 a first cycle of the preliminary hazard assessment was done identifying the hazards in Medium and High Automation Scenarios in nominal and non-nominal situations. This cycle was used as an input for competences and training design (Step 4).

Second cycle of the safety analysis was performed accounting for modified competences and training catalogue. The hazard assessment was refined taking into consideration new competences and training strategies defined in Step 4. Hazards not mitigated with training were also identified. Further information can be found in *D4.1 Preliminary Safety Hazard and Performance Assessment.*

- **Step 4. Definition of New Competences and Training Requirements –Literature Research**

Based on Step 1 and Step 2 and literature research for current ATCo Competences and Training, a first set of future competences and new training techniques were identified to cope with needs and issues expected in future automated scenarios. After the first cycle of the Safety and hazard assessment, a refined competences and future training were obtained not only addressing the technical competences but also the psychological aspects.

Further information about the results of these two tasks can be found in their corresponding deliverables: *D3.2 Competences and Training requirements.*

In addition a preliminary performance assessment was also accomplished. This task has proven the usefulness of AUTOPACE Psychological Model to support performance assessment of the automation features along with an initial automation suitability evaluation providing an estimation of the expected benefits of AUTOPACE Future Automation Scenarios. Further information can be found in *D4.1 Preliminary Safety Hazard and Performance Assessment.*

The next Figure 3 shows the research approach followed in AUTOPACE project:

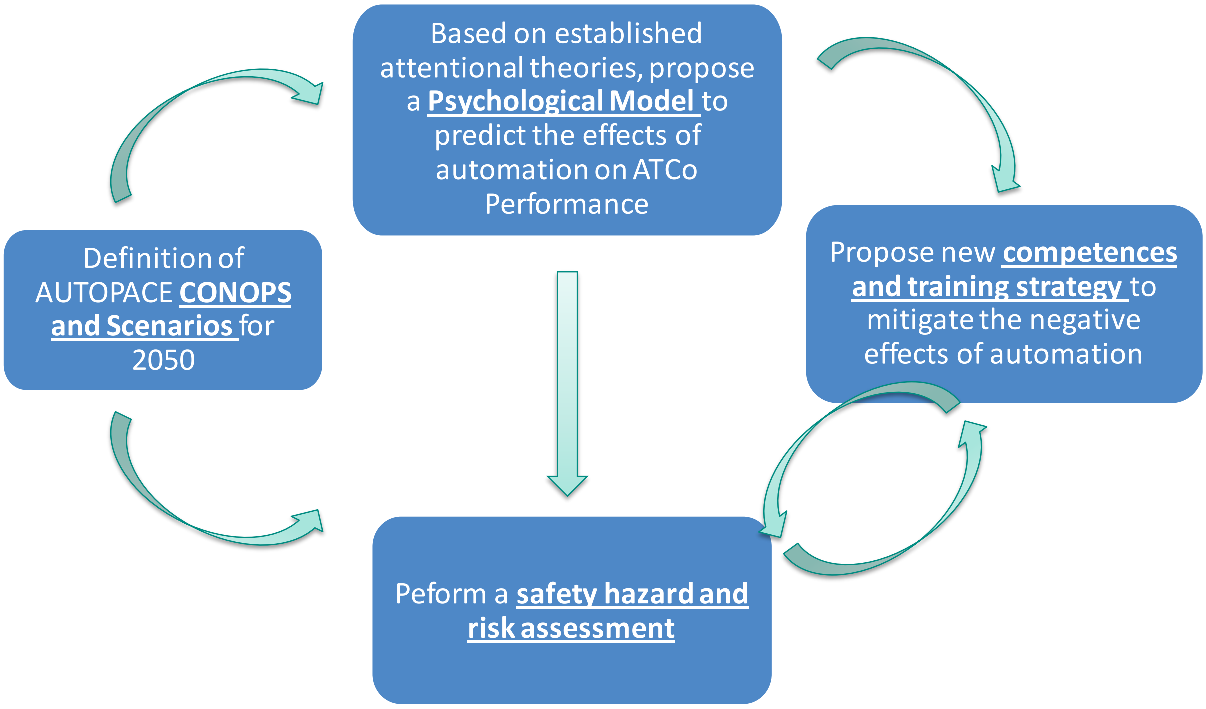

Figure 3: AUTOPACE Research Approach

To address these research areas, AUTOPACE Consortium assembles five organisations with a large experience on the field of ATM psychological modelling and ATM system operations:

- CRIDA, the R&D+i Centre of the Spanish Air Navigation Service Provider (ENAIRE), leads the project who has brought its strong experience on the central topic of the proposal – the **ATCo Mental Workload assessment**.
- University of Granada has provided its experience on the field of the **Human cognition and psychological effects**.
- Polytechnic University of Madrid (Aerospace Systems, Air Transport and Airports Department) have been crucial for the research of the application of the ATC Mental Workload to the **Competences and Training** area.
- University of Bologna has provided a long term experience in **the ATM operational Scenario Analysis** and **the Human Machine Interfaces**.
- University of Belgrade - Faculty of Transport and Traffic Engineering has closed the loop providing its expertise in **Safety assessment** and **ATM System design/operations.**

2.4 Key Project Results

The Key Project results are structures according to the AUTOPACE Research Areas described in 2.2:

2.4.1 AUTOPACE CONOPS and Scenarios Description

2.4.1.1 AUTOPACE CONOPS definition at 2050

In order to define ConOps, AUTOPACE has chosen a two-step approach, comprising the development of 2035 AUTOPACE ConOps prior to the identification of 2050 AUTOPACE ConOps: since 2035 timeframe would help AUTOPACE to capture current R&D trends with regards to ATM and automation, and to evolve them towards 2050 horizon, by taking into account 2050 reference documentation.

The AUTOPACE ConOps definition has been performed on the basis of a literature research. Several documents were considered as relevant to achieve a common understanding on the state of the art on future automation developments in Air Traffic Control. A reference list was identified considering two different time horizons (2035 and 2050):

- 2035 AUTOPACE ConOps has been defined based on SESAR Step 2 deliveries ([38], [39]), as a good picture of what will be in place by this time. It constitutes a robust, well-structured baseline upon which 2050 environment can be developed.
- 2050 AUTOPACE ConOps has been developed upon 2035 AUTOPACE ConOps using as primary references *Flight Path 2050*document; *ACARE SRIA – Strategic Research and Innovation Agenda*, *EREA From Air Transport System 2050 Vision* and *HALA! Position Paper 2014* [19], [23], [25], [26].

2050 AUTOPACE ConOps were derived to Operational Scenarios: they consist in a description of how a future system could work, considering user's behaviour, the interaction between user and future system, and the wider context of use. For each scenario, several use cases describe the set of circumstances, where the user interacts with the system as identified by a group of expert in the matter of study.

AUTOPACE scenarios development has been based on the execution of the ATCo activities during En-route phase.

2.4.1.1.1 Operational Environment, Systems and Personnel role

The prediction of 2050 air traffic is mainly defined on the basis of demography evolution, global economy and the role of Europe on it, the new aviation technologies, the importance of the environmental impact, the expected demand for air travel and its purpose (business, leisure, freight…) and the advance in ground transport. The Regulated Growth theory represents a common view of an extension to the existing environment. Forecast [24]is characterised by moderate economic growth, with regulation reconciling the environmental, social and economic demands to address the growing global sustainability concerns. It exhibits a medium level of growth with 18.6 million IFR movements in Europe by 2050 (2 times more than in 2012 and 1.3 times more than in 2035).

Airspace management will still seek for the optimal airspace configuration adapted to the business and mission preferred trajectory demand. DCB processes will have evolved towards bigger airspace sectors and incorporate the use of dynamically shaped sectors and sectorizations.

Free Routing and flexible use of airspace concepts will be fully implemented in low to high complexity areas. Also, by 2050, **Flight-centred (or 'sectorless')** is expected to be implemented in low, medium and high complexity areas, allowing the assignation of Business Trajectories with less workload. Flight-centred *ATS* implies that the aircraft trajectory remains under the control of the same ATCo throughout the whole or a significant part of its En-route segment. A number of flights are assigned to an ATCo, unconstrained by geographical location, sector or national boundaries including in full Free routing environment.

4D ATM contract is at the basis of the global optimisation of Air Traffic Management. It provides the framework for automatic handling of the flight management of all air traffic participants by a central ATM System, ensuring safe separation and optimisation of all flights, according to global performance criteria. All 4D contracts are generated by the central ATM system (strategic planning). Each contract is issued for the entire flight, including ground operations, and is conflict-free in relation to all other contracts. The aircraft are in charge of executing their contracts and the ground system monitors them. The implementation of a 4D contract-based ATM system will bring significant improvements to ground and on-board systems, both on technology, methodology and conceptual levels.

Novel 2050 ATC concepts will lead to an evolution from a purely tactical intervention model towards a more strategic trajectory management concept. It is expected a progressive introduction of more autonomous and decentralized systems, untill full automation. The implementation of such future ATM system will change the human role and its relationship with the automated processes.

A higher degree of automation is needed to cope with the increasing complexity, thus the **Decision Support System (DSS)** main function will be to support all human decision makers of the ATS in fulfilling their tasks in a safe and efficient way. 2050 DSS will lead to enhancement in data processing and information presentation capabilities; in agent theory, human and DSS would act together as one unique agent towards the environment. MTCDT(Medium Term Conflict Detection Tool) and TCT (Tactical Controller Tool) are improved in order manage false conflicts, missed conflicts and conflicts very close to the loss of separation mainly due to unexpected manoeuvres (e.g. wrong ATC clearance which immediately generate a loss of separation, etc.).

Finally, **new Human Machine Interface technologies** shall be developed in order to allow human participants to perceive and interact with the results of that higher level of information processing. Human Machine Interface technologies must support ATCo Situational Awareness, necessary for his/her role as safety monitor, and for intervening in the situation when necessary. Improved interaction and visualization techniques shall support the operators to execute their functions and allow them to be aware of the systems status at all times.

The new approach is supported by the assumption that considers ATM as a 'socio technical multi agent' controlled/managed process, modelled as a system composed of different interconnected actors and different agents working into a collaborative or orchestrated framework.

The definition of personnel role and responsibilities is connected to the real future automation level, since it is crucial to determine how ATCo do every task and who is (ATCo or ATC system) responsible to do them. Since, there is still much uncertainty about what degree of automation will be deployed, AUTOPACE has considered two different degrees of automation for ConOps definition, that will affected ATCo role in the following way:

- **High automation or Level of Automation 1:**
    - ATC system plays a major active role
    - ATC system is responsible to perform most of the ATC tasks.
    - ATCo remains as a supervisor of the system behaviour and of the implemented solutions.

- **Medium automation or Level of Automation 2:**
  - Tasks are shared between ATC system and ATCo.
  - In order to reduce workload, ATC system proposes a set of actions that the ATCo needs to approve and implement.
  - Some tasks are not fully automated. The ATCo still analyses and decides about the solution to implement with the support of the system, which provides him/her with necessary information.

Depending on the level of automation addressed in 2050, the system, the human or a combination of human action with system support will perform these tasks.

2.4.1.2 Definition of future automation scenarios (High and Medium Automation) in nominal an non-nominal situations)

Since the objectives of AUTOPACE focus on the effect of automation on human factors, two 2050 scenarios considering two different levels of automations have been developed as the main tool to support AUTOPACE research. Upon these two baseline Scenarios a number of non-nominal situations will be identified to support the assessment of automation failures.

- **Scenario 1: High Automation Scenario**

Scenario 1 will have a high degree of automation. The ATC System develops the necessary actions for the orderly and safely traffic management, informing the ATCo of the actions developed if requested. The ATCo maintains a monitoring function.

In order to reduce the workload of the ATCo, the system assumes the major ATCo responsibilities:

  - Manage traffic;
  - Maintains separation;
  - Sequence and synchronize traffic;
  - Receive information from ATC tools;
  - Issue tactical actions;
  - Coordinates with other units;
  - Informs the ATCo about its performances and forecasts.

While the system has an active role, the ATCo remains as the supervisor of the system operation. He/she checks and monitors the actions of the system and ensures that the defined safety and capacity requirements are met.

The ATCo has access to all information received by the 'ATC system', and receives the results of all ATC tools.

- **Scenario 2: Medium Automation Scenario**

Scenario 2 will have a medium degree of automation. The ATC tools will propose actions to be performed, and the ATC controller will decide which action to apply from the set of proposals suggested by the system.

In order to reduce ATCo workload, the system proposes different alternatives and the ATCo has the responsibility to select and implement solutions. Therefore, he/she assumes major ATCo responsibilities such as:

  - Manage traffic;

- Maintains separation;
- Sequence and synchronize traffic;
- Select and issue tactical actions;
- Coordinates with other units.

However, in this scenario the ATC system remains as a support tool for the ATCo and its main actions are:

- Receive information from ATC tools;
- Propose tactical actions;
- Propose coordination actions;
- Support the ATCo on performances and forecasts.

The ATCo has access to all information received by the ATC system, and receives the results of all ATC tools to be able to decide which the best solution is proposed to perform the required actions.

To define AUTOPACE scenario, four elements have been addressed to fulfill every aspect related with the project objective. Those defining elements are (Figure 4):

- Scenario Actors Identification,
- Responsibilities allocation to Scenario Actors,
- Processes and services description and their relationship with systems,
- Human Performance aspects.

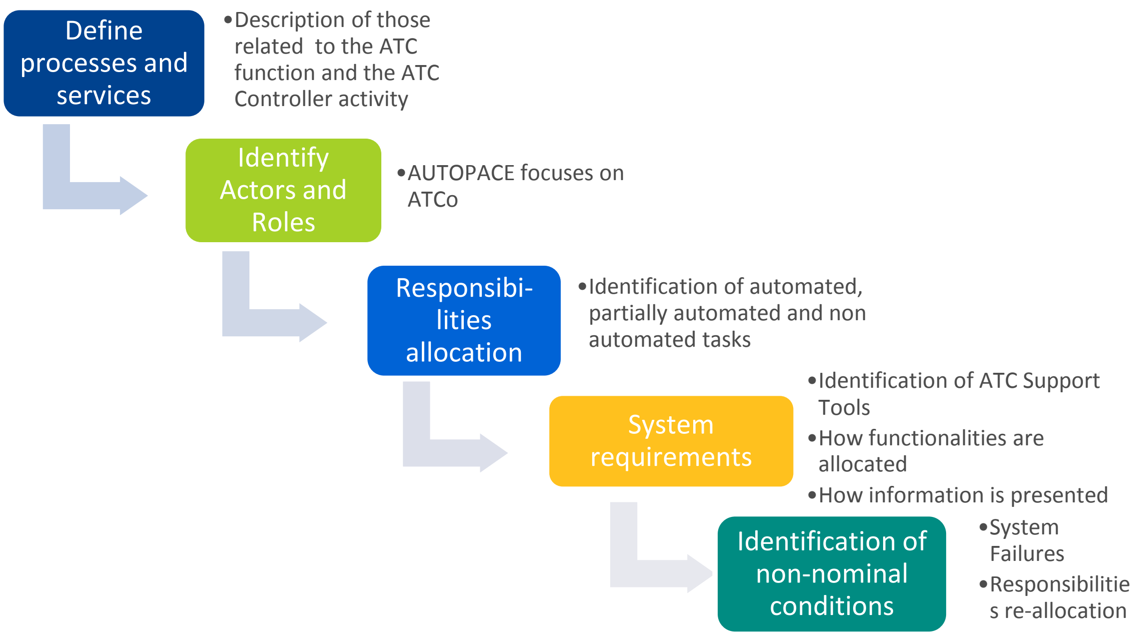

Figure 4: Scenarios Description

Depending on the scenario, responsibility sharing is widely different for each actor, ATC system and ATCo. The reason is that as the degree of automation increases, the ATC system has more capabilities and it is able to perform more tasks and assume more responsibilities. This higher set of actions done by the ATC system implies a reduction in ATCo workload, since he/she remains as a supervisor of the system behaviour.

In case that automation is not enough developed, the system would not be able to perform so certain actions and the ATCo would have to assume them. However, in 2050, systems are expected to be at least capable to propose the ATCo a set of solutions so he/she would only need to choose the right one according to the information obtained from the ATC tools.

In this perspective, three categories of verbs have been defined in order to allocate the distribution of ATCo responsibilities between ATC System and ATCo in different scenarios.

In the case of the ATC System, these verbs are:

- **Apply**: the ATC System analyses the situation, decides and implements the most suitable solution on his/her own according to available information;
- **Propose**: the ATC System proposes to the ATCo a set of actions to implement;
- **Support**: when needed, ATC system supports the ATCo decisions by providing him/her necessary information.

On the other hand, the verbs for the ATCo are:

- **Apply**: the ATCo analyses the situation, decides and implements the most suitable solution from those proposed by the ATC system according to the information from the ATC tools;
- **Approve**: once the ATC system has proposed a solution for the conflict; the ATCo must approve it in order to be implemented;
- **Monitor**: when the ATC system is assuming the major tactical actions; the ATCo has to monitor its behaviour to prevent system deviations.

2.4.1.2.1 Non-Nominal Situations

AUTOPACE Non-nominal situations consider an automation failure or a malfunction in the service provision of one or several ATC tools. As AUTOPACE project is focused on the evaluation of workload and human performance aspects, the identification of non-nominal situations is focused on the lack of functionality to impact on user role and responsibility.

The selection of potential failures in the ATC tools to be considered as Non-nominal situations has been based on two criteria:

- The ATC responsibilities should still be carried out even though some services provided by tools are disabled.
- The ATCo will need to change their mode of operation in order to assume the ATC responsibilities that the ATC system will not take during the failure or to operate with the absence of some system functions such as lack of information, support services, etc.

In this perspective, three system's failures have been identified for AUTOPACE purposes:

- The Conflict Detection and Resolution tool fails.
- The Complexity management tools fails.
- The System supported coordination tools fails.

The occurrence of each of these failures in an automation level 1 environment (Baseline Scenario 1) or in an automation level 2 (Baseline Scenario 2) results in a total of six non-nominal situations.

2.4.1.3 ATCo/System Roles and Responsibilities

In general terms, in nominal situations, the ATCo is expected to have the responsibility of monitoring or monitoring and approving in the provision of the majority of the ATC services in AUTOPACE High Automation Scenario. Nevertheless, in AUTOPACE Medium Automation Scenario the ATCo will be responsible not only for monitoring and approving but also for applying many of the ATC services after analysing the proposals made by the ATC system (therefore monitoring, approving and sometimes applying). Table 1 shows the responsibilities allocation to the ATCo depending on the automation scenario.

Responsibilities	High Automation	Medium Automation
Identify conflict risks between aircraft	Monitor	Monitor
Provide flight information to all known flights	Monitor	Monitor
Provide information on observed but unknown flights that may constitute traffic for known aircraft	Monitor	Monitor
Relay to pilots SIGMETS that may affect the route of a flight	Monitor	Monitor
Provide Alerting Service (ALRS) to all known flights according to the following three different phases (INCERFA, ALERFA, DETRESFA)	Monitor	Monitor
Check flight-plans/RBT/RMTs for possible conflicts and complexity issues within its area of responsibility	Monitor	Monitor
Plan conflict-free flight path through its area of responsibility	Monitor	Monitor
Provide early conflict detection and resolution if the early resolution brings operational benefit (either on the ground side or the airborne side)	Monitor	Approve
Assign specified headings, speeds and levels	Monitor	Approve
Re-route flights to avoid non-nominal or hazardous weather areas	Monitor	Approve
Provide sequencing between controlled flights	Monitor	Approve
Resolve boundary problems by re-coordination	Monitor	Approve
Implement solution strategies by communicating trajectory changes to the aircraft through the concerned ATCo/System via Data Link	Monitor	Approve
Provide separation between controlled flights	Monitor	Apply
Apply appropriate separation to all controlled flights departing his/her area of jurisdiction	Monitor	Apply
Input data into the flight data processing system regarding tactical route modification, modification of flight level, etc.	Monitor	Apply
Transfer control of aircraft to the appropriate ATCo/System when clear of traffic within his/her area of jurisdiction	Monitor	Apply
Co-ordinate with adjacent ATCo/Systems (exit and entry conditions)	Monitor	Apply

Responsibilities	High Automation	Medium Automation
Input tactical trajectory changes into the Flight Data Processing System	Monitor	Apply
Communicate with pilots by data link	Monitor	Apply
Monitor flights regarding adherence to flight plan/RBT/RMT	Monitor	Apply
Monitor the air situation picture	Monitor	Apply
Monitor the weather conditions	Monitor	Apply
Monitor information on airspace status, e.g. activation of segregated airspace Communicate with pilots by data link	Monitor	Apply
Monitor aircraft equipment status as provided by the system	Monitor	Apply
Co-ordinate with adjacent control areas/sectors for the delegation of airspace or aircraft	Monitor	Apply
In coordination with the ATC Supervisory or Local Traffic Management roles determine the need for Complexity Solution Measures in the case of overload situations forecast	Approve	Apply
Issue holding instructions	Approve	Apply

Table 1: ATCo Responsibilities for the High and Medium Automation Scenarios

2.4.2 ATCo Psychological Model for ATCo Performance Prediction

For the purpose of developing an ATCo psychological model to predict the effects of automation on the ATCo MWL in the future scenarios, two sub-models are considered: (a) the *functional structure* of the cognitive also referred as Cognitive Processes and (b) the mental resources needed to ensure its *functioning*.

2.4.2.1 ATCo Cognitive Processes and Mental Workload

The cognitive system has some structural components whose functions are the processing of information from outside, the storing of the results of that processing, and the responding to the environment. AUTOPACE has taken as a reference the model proposed by Histon and Hansman [27] (see Figure 5). This model incorporates the so called Situation Awareness (SA) [22]: perception, comprehension and projection. After the three components of SA, the model assumes that decision making processes are finally put in place leading to the action that is executed.

The information that the ATCo receives and that comes from the traffic situation is processed by combining it with the one that the ATCo has stored in its memory after its learning and experience in the task of air traffic control. That process allows the ATCo to understand the actual situation. Then, the ATCo should project into the future to predict how the traffic situation will be and, finally, make decisions about what to do to correctly perform the tasks (execution).

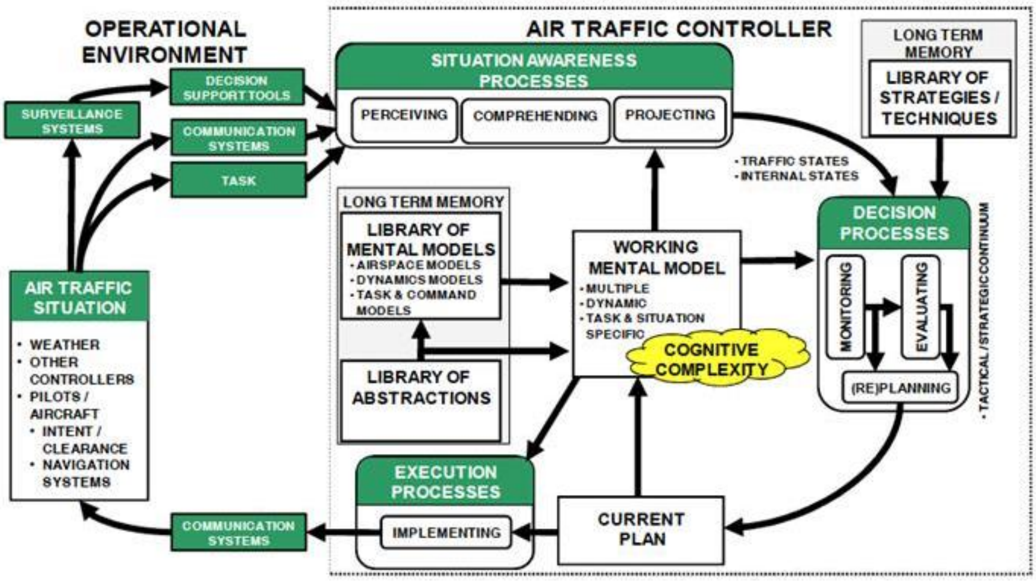

Figure 5: Functional Structure for the ATCo Cognitive System

The cognitive processes associated to the ATCo tasks that underpin the ATCo Cognitive Functional Structure can be classified in five dimensions: Perception, Comprehension, Projection (SA Processes), Decision Making (Decide Process), Execution (Execution Processes). In case of an ATCo, the two main channels for perception are visual and auditory, and the two main channels for execution are manual and verbal.

Psychological models have explained the functioning of the human cognitive system by using mental resources, particularly demanded and available resources. While demanded resources are those required by the task and essentially dependent on the task complexity, available resources are the pool of resources that the ATCo has that could be used to perform the task. This pool could be of different depending on a number of factors such as stress, fatigue, emotions, etc., all being factors that affect the level of activation or arousal. However, a person might decide to use only a set of the whole pool of available resources. Engagement ([22], [44]) with the task might affect the size of the pool of available resources, but more important than that, it would determine how much of those available resources are dedicated to the task.

The relationship between demanded and available resources is called the Mental WorkLoad (MWL). At a certain point three possible situations can occur.

- If the amount of available resources equals the amount of resources required for performing the task can be performed optimally.
- If the amount of available resources is less than the amount of demanded resources, the operator experiments **Mental Overload** and the task cannot be performed optimally and the effort to perform the task will affect their physical and mental health.
- If the available resources are greater than the demanded resources, the operator may want to perform the task in an optimal way and still has spare resources available to devote to another simultaneous task. If the discrepancy were very large it would produce boredom and finally distraction or drowsiness. This situation is called Mental Underload.

2.4.2.2 Automation effect on ATCo Cognitive Processes

For the purpose of evaluating the effects of automation on the ATCo Cognitive System it has been employed the computational prototype developed by CRIDA called COMETA (COgnitiveModEl for aTco workload Assessment) [41].

COMETA foundations share the *functional structure* and the *functioning of the ATCo cognitive system* models of AUTOPACE. COMETA, for being a prototype has some functions not implemented yet but possesses the potential for future developments to implement those. Figure 6 shows the complete functional architecture highlighting in light blue what is currently developed.

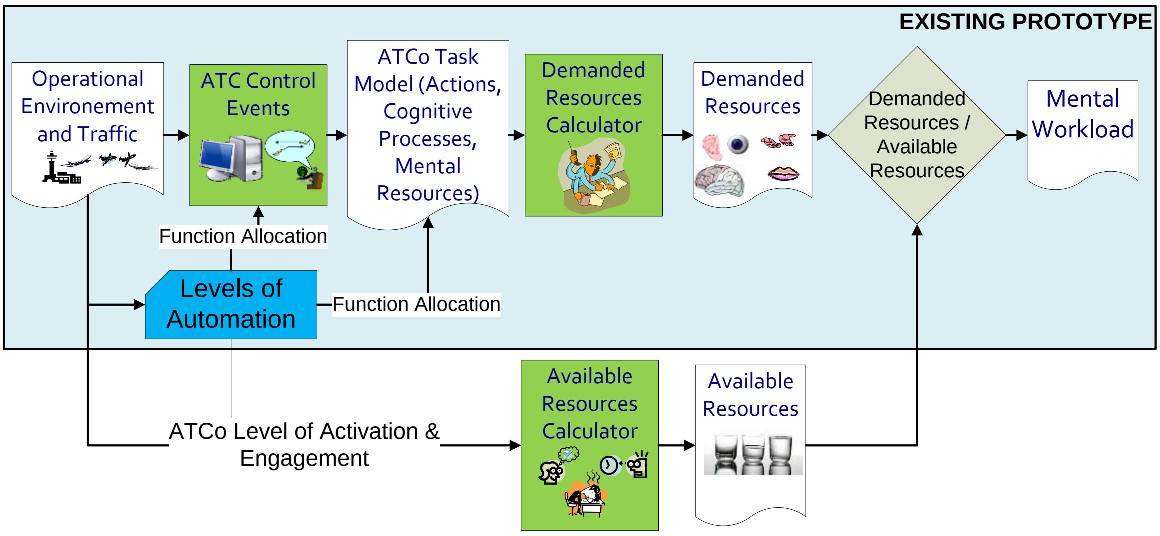

Figure 6: COMETA Functional Architecture

Currently COMETA algorithm estimates the demanded resources of ATCo tasks along with the cognitive processes used by the ATCo. What is not incorporated yet is the available resources calculator that is dependent on psychological factors such as stress, fatigue and emotions and ATCo level of activation and engagement with the task. If assuming that the ATCo has received a proper training to cope with the negative effects of automation (OOTL effect, fears of automation fail), the ATCo level of activation and engagement with the activity is adequate to keep an optimum performance. As a consequence, the available resources would be kept as fixed and the demanded resources estimation would mean MWL estimation.

COMETA needs a description of the ATCo activity structured by conceptual units:

- **Control Events** is the psychological stimulus to which the ATCo responds (e.g. solve conflict). The operational environment and the air traffic under the ATCo responsibility is taken into account through the Control events.
- **Actions:** They are observable behaviours that can be defined as the "behaviour of an actor directed to an objective". The actions are carried out with the implication of cognitive processes that consume mental resources. The actions that the ATCo will need to implement within each Control Event depend on the distribution of responsibilities between the ATCo and the ATC system (function allocation).

In order to link the cognitive processes required to perform ATCo Actions triggered by Control Events, **Behavioural Primitives** are defined to facilitate psychological modelling [42]. The amount of resources required by every cognitive channel depends on the ATCo responsibilities (monitor, apply, approve) and on the degree of automation of the processing by that channel.

It is important to highlight that the ATCo Task Model is tailored according to the acquired competences. Usually the ATCo Model is a representation of a typical ATCo who is fully technically trained. The actions and behavioural primitives are based on historical observations of ATCo activity and operational support for their definition. The estimation of associated cognitive processes and the required mental resources are obtained from expert cognitive psychologists.

The quantification of the cognitive demand resources is calculated using Wickens's Theory [43] that was refined in Wickens's and McCarley's Theory [45]. For the evaluation of the demanded cognitive processes, the methodology followed is detailed in Figure 7.

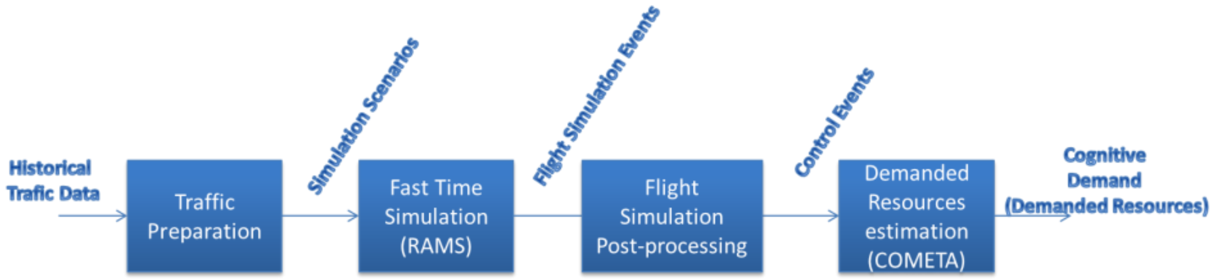

Figure 7: Methodology for laboratory studies

Firstly, a representative day of the year 2015 is selected and three peak hours are identified for simulation. Future traffic is cloned to emulate the increase expected by 2050 [24].

Secondly, automation scenarios are modelled in a FTS tool (RAMS[3]) to reproduce the concept of operations of AUTOPACE. Then, the scenarios are executed to identify the Flight Simulation Events occurred.

Flight Simulation Events are post-processed into Control Events by means of logic (rules) associated to the identification of each type of Flight Simulation Event. For example, the identification of the Control Event "Assume a flight" is usually done some time (offset) before the physical entry of the aircraft within a sector in the simulator.

Finally, the ATCo Task Model (actions triggered by Control Events, behavioural primitives, the associated cognitive processes and mental resources) is detailed reflecting current and future AUTOPACE scenarios. COMETA calculator is then executed. As a result, the cognitive demand (demanded resources) is obtained for each simulated scenario.

[3] RAMS: Reorganized ATC Mathematical Simulator. Is a FTS developed by ISA Software (http://ramsplus.com – taken on 06-03-2017)

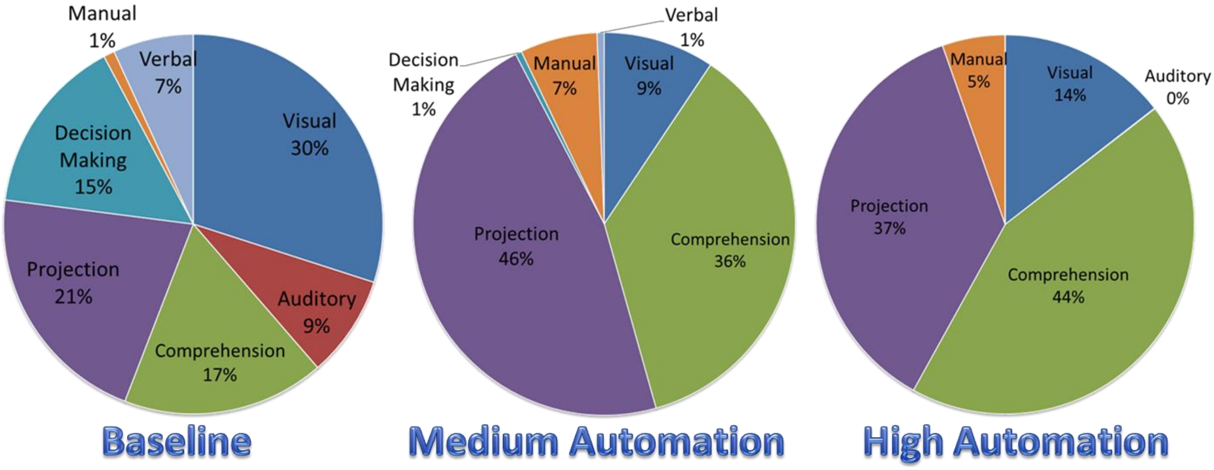

Figure 8: Cognitive Processes evolution in the Current, Medium Automation and High Automation scenarios

Figure 8 shows some results obtained with COMETA related to the functional structure evolution and the expected cognitive process in the future automation scenarios, all of them compared with current ATC paradigm. As observed, the distribution of the functional structure of the cognitive system changes drastically with automation. While current ATCo uses the cognitive dimensions (visual, comprehension, projection, decision making and verbal resources) in a balanced way, the future ATCo shall focus his/her cognitive effort in mainly comprehension and projection. The ATCo needs to project what is going to happen to understand the system performance without missing Situational Awareness. In Medium Automation Scenario where main actions are not only monitor and approve but also apply, Projection is more relevant than Comprehension as ATCo needs to invest more resources on project future pictures to correctly select the options given by the system (approve) and his/her own instructions (apply). In the High Automation Scenario, the contrary occurs as what is important is to have a more robust mental picture of what is occurring to monitor system performance (monitor) and to approve system proposals (approving), namely a better Comprehension than Projection.

2.4.2.3 Automation effect on ATCo Mental Workload

The prediction of the effect of automation on the ATCo MWL depends on the atteentional theories supported by researchers, apparently with contrary effects if the attentional theories are referred to the Level of Activation/Arousal or to the Engagement with the task.

On the one hand, the psychological effects of automation are explained by the classical attentional resource theories [35], by assuming that automatic systems only reduce the demanded resources by the task and, therefore, reduce the mental load and avoid the overload. According to these classical theories, automation does not affect the available resources (Figure 9)

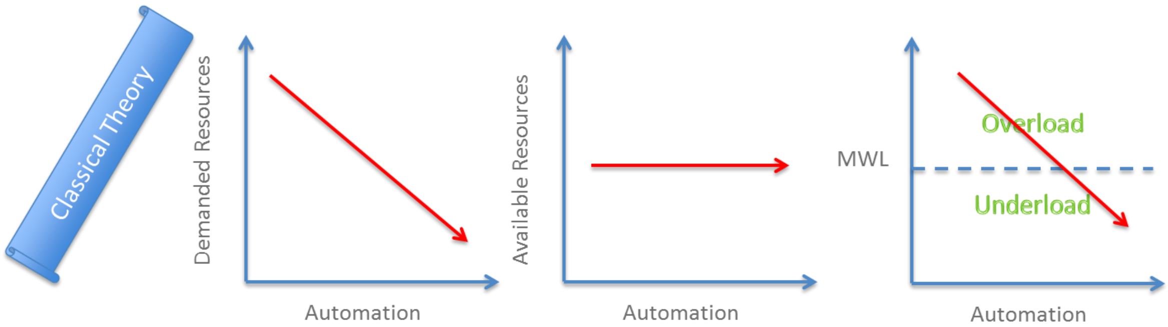

Figure 9: Effects of automation on MWL-ATCo Performance (Kahneman,1973)

On the contrary, there are alternative theories, such as the Malleable Attentional Resources Theory (MART) [46] that assume that the task complexity would affect not only the demanded resources but also the available ones depending on operator's expectations.

This reduction will occur at the same time as a reduction on demanded resources. Then, there would be more risk of overload or no change of MWL at all if the reduction is equal in the demanded and the available resources. Interestingly, this reduction on available resources increments the risk of suffering lack of SA and OOTL.

However, if the ATCo feels fear of automation failures, the stress would increase and then there will be an increase in the amount of available resources due to an extra activation. Therefore, the available resources would be greater than the demanded resources and underload could be observed. In this case the extra resources would be dedicated to the task when they are not needed for performing it. Therefore, when the ATCo feels fear of failure -or untrust the automatic system- underload, disorientation, overacting or erratic behaviour would be observed.

Figure 10 reflects MART Theory on ATCo MWL.

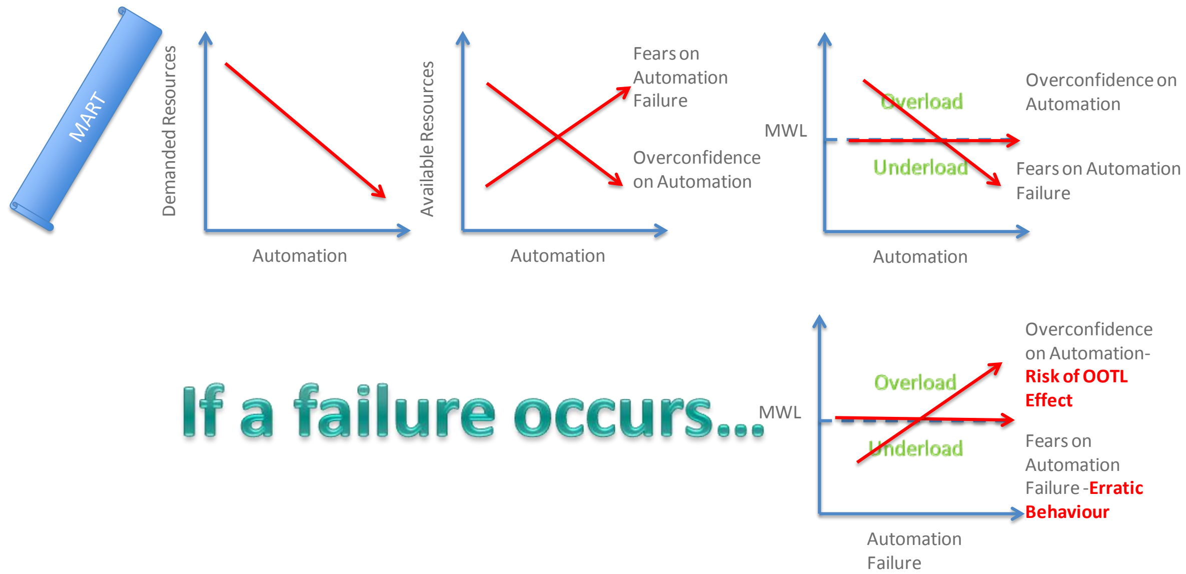

Figure 10: Effects of automation on MWL-ATCo Performance (MART, 2002)

The key factor on the Level of Activation is therefore the ATCo Trust in the system: the more is the trust, the less is the level of activation.

Different new researchers (new different attentional theories apart form MART) claim that no all the available resources that a person has are allocated to the task. Independently on how many available resources the ATCo has (due to activation or arousal), he/she might allocate only one part of the total amount depending on the effort dedicated to the task and how much he/she is engaged in the task [22]

It is assumed that engagement with the task and SA would vary with responsibility [36]. As can be seen in Figure 11, the responsibility for "apply" actions would require more engagement than just "approve" automated decisions and actions. The responsibility that requires less engagement is "monitor". However, each responsibility relates to different amplitude of variability on engagement. For example, when applying an action, the engagement does not suffer a significant variability, i.e. the ATCo has to be engaged with the task. However, "monitor" could vary significantly. The ATCo could decrease his/her level of vigilance during monitoring in the case that nothing occurs during a period of time.

That means that in a High Automation Scenario, where the ATCo mainly performs "monitor" and "approve" actions (see Table 1), he/she would be less engaged with the task than in Medium Scenario. As a consequence he/she would have poorer SA and lower decision making and the performance in detecting a system failure and shifting to the correct course of action would be poorer (more difficult, take longer time). But as the complexity of the task is also lower with automation, the effect on MWL is not clear enough (Figure 12).

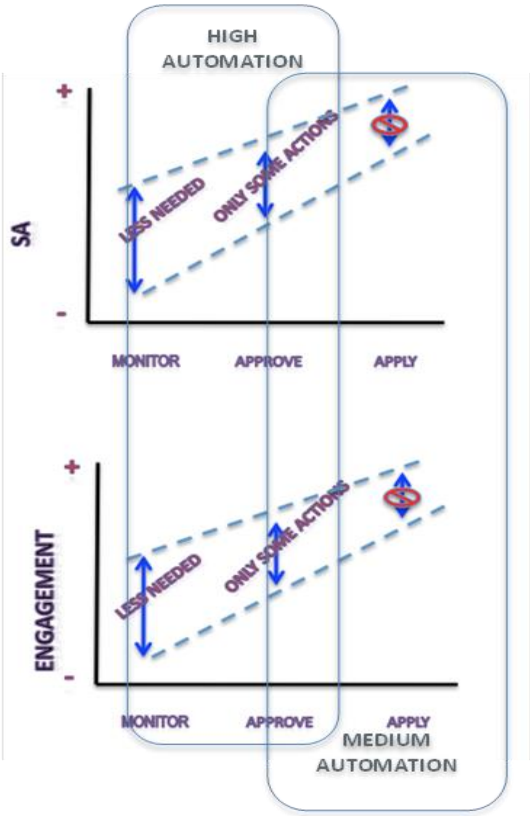

Figure 11: Engagement and situation awareness as a function of the three responsibilities in High Automation versus Medium Automation

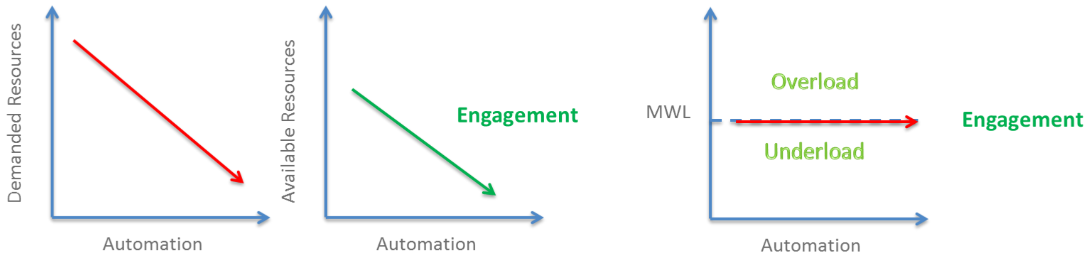

Figure 12: Effects of automation on MWL-ATCo Performance (Engagement)

As the total effect of automation on available resources is a combination of the level of activation (trust) and the ATCo engagement with the task, further research is needed to validate how the combination of these factors will be (see Appendix B)

2.4.3 Preliminary Hazard Assessment

AUTOPACE Preliminary Hazard Assessment (PHA) conducts safety assessment aiming to provide a set of automation risks that should be mitigated by modifying ATCo competences and training or refining the system automation design. The analysis is performed in opposite direction as well, aiming to show an impact of ATCo training strategy on improvement of safety.

Common methodology (as recognized by ICAO and EUROCONTRO) is used (Figure 13). It consists of three steps:

- **Hazard identification**: an identification and qualitative analysis of safety hazards for all scenarios;
- **Risk assessment** i.e. determination of acceptable, tolerable and not acceptable risks (hazards), based on hazard characterisation, i.e. assessment of severity and likelihood for each hazard; and
- **Risk mitigation**: safety recommendations to training designers and identification of mitigation measures for critical risks.

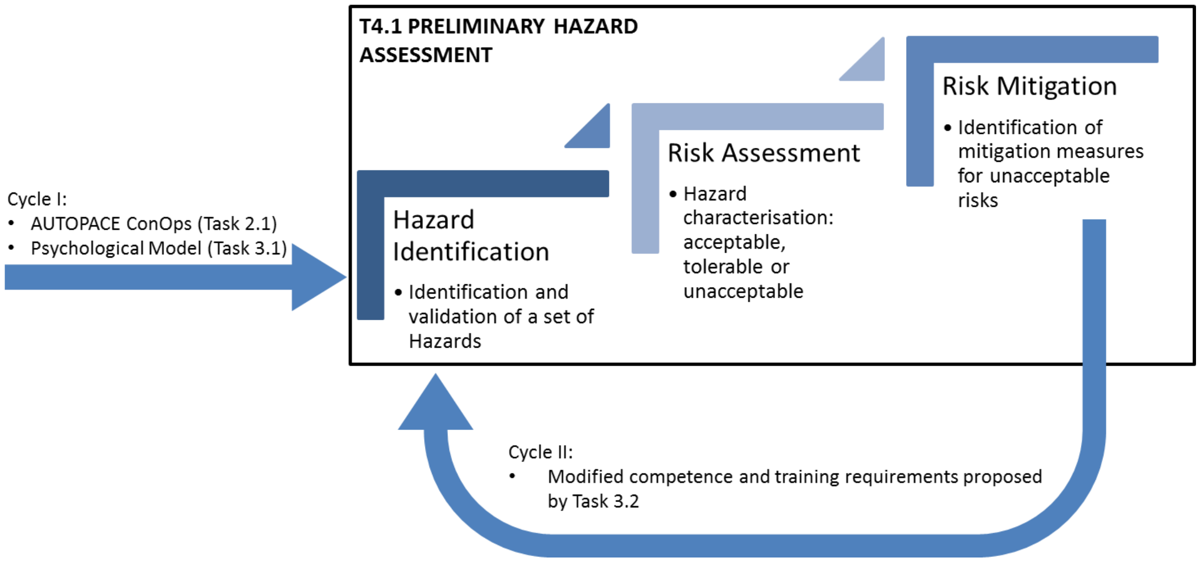

Figure 13: Task 4.1 Methodology

PHA is executed in **two cycles**. In the first cycle, PHA uses AUTOPACE ConOps, nominal scenarios and non-nominal situation, ATCo tasks list (and ATCo and ATC System responsibility shares), and Psychological analysis of ATCo as input. Hazard identification and risk assessment are performed and critical hazards are identified. Safety recommendations for the definition of competences and training requirements are defined (for the given set of critical hazards).

Mitigation of critical hazards through (initial) training strategy is used as an input in the second cycle of PHA. Risk level of critical hazards is reassessed to show how safety improves. Critical hazards that remain after the second cycle can serve to further refine competences and training requirements and/or to propose improvements related to system architecture and/or procedures.

Methodology for safety risk assessment in future automated ATM system is presented at international conference [13].

2.4.3.1 Hazard Identification

Hazard identification (HAZID) is the most critical stage in safety assessment. AUTOPACE project is specific because it looks in a far future – 2050 and beyond. This fact together with fact that details for future automation are uncertain makes hazard identification process very challenging. Two expert

brainstorming sessions (HAZID 1 and HAZID 2) were performed, based on future tasks and description of nominal and non-nominal situations. HAZID 1 was performed with academic experts in the fields of ATM and safety, resulted with initial set of hazards. HAZID 2 was performed with operational experts (experienced ATCo, all with academic MSc/PhD degrees in aviation) together with academic experts in safety and ATM. It provided a validation of the initial set of hazards and enriched it with some additional, complementary hazards.

During HAZIDs, future ATCo environment is observed through two main parts. Internal, core part contains ATCo and ATC System and their relations. External part (environment) gathers Local Traffic Manager, System Wide Information Management (SWIM), other ATC Systems/ATCo and traffic (aircraft/pilot). Also, special attention was paid to the list of tasks (28 of them) and how they are distributed among actors (ATCo and ATC System).

Hazard can be the result of a system or component failure, but it also can exist without anything failing – so, the human errors and mistakes can often lead to hazards. In AUTOPACE project it is assumed that ATC System performs its tasks correctly i.e. its failures are limited strictly to non-nominal situations. Possible corruptions of the functions (such as data link, HMI, ATC support tools) are considered. The main focus should be on ATCo and tasks he/she performs, i.e. the human errors and mistakes, especially in transition from a nominal to a non-nominal situation and in non-nominal situations. During mentioned periods ATCo are dealing with procedures and tasks different from those in regular conditions. Having observed far future ATM system defined on very general level, sources of hazards can also be related to system design, procedures, environment, etc.

The **total number of hazards** identified in two brainstorming sessions (HAZID 1 and HAZID 2) per scenario/situation is summarized in Table 2 (Note: one hazard is counted multiple times if it is assigned to several tasks).

Scenario/Situation	High Automation (S1)		Medium Automation (S2)	
	Task specific hazards	General + Transitional hazards	Task specific hazards	General + Transitional hazards
Nominal situation	101	9	150	12
Conflict Detection and Resolution tools fail	158	16+10	173	13+10
Complexity Management tools fail	88	11+10	133	12+10
System Supported Coordination tools fail	116	13+10	151	13+10

Table 2: Number of hazards (different types) per scenario/situation

Some hazards are related to certain task (**task specific hazards**), while some hazards are relevant for the particular scenario/situation (**operations specific or general hazards**). Special group of general hazards are those that that occur in the transition period (**transitional hazards**) and are typical only for non-nominal situations. Arranging hazards in this way enables easier refinement of the identified hazards once some changes in the ConOps, scenarios or tasks occur.

In order to be consistent and comprehensive in hazard characterisation, for all observed scenarios/situations and types of tasks, hazards are categorized with respect to three criteria:

- **Responsibility share** between ATC System and ATCo: Apply/Monitor, Propose/Approve, Support/Apply;
- **Nature of hazard**: Incorrect input, Incorrect action, Non-performable action, Undefined responsibility, reduced Situation awareness (SA), Tool corruption, Uncertain traffic evolution and Other) and
- **Internal/External part of the system**: ATC System, ATCo performance, Communication, Coordination and Other).

Hazard identification approach and its results are presented at international conference [12] .

2.4.3.2 Risk Assessment

In order to assess risk, hazards are characterized with **severity** (1-5 scale[4]) and **likelihood** i.e. probability of occurrence (also 1-5 scale[5]). Hazard characterization was mainly based on particular task hazard is related to, share of responsibilities between ATCo and ATC System and nature of hazards.

When assigning the severity and likelihood some **high level principles** were used, e.g.:

- In nominal situations, in general, severity is lower in High Automation than in Medium Automation, because in the former case the most of the tasks (almost all) are performed by the ATC System (lower engagement of ATCo).
- Likelihood is independent of the scenario/situations, except for those that involve ATCo - reduced situation awareness (SA) and incorrect action (likelihood for Reduced SA due to boredom or fear of automation is significantly higher in High Automation scenarios; and likelihood is higher when ATCo is required to perform tasks he/she do not perform on regular basis, as everyday routine).
- For non-nominal situation 1 (Conflict Detection and Resolution Tools fail) substantial change in responsibilities is expected. Due to that severity is assumed to be high and should take the same values in both High and Medium Automation. (In High - ATCo is required to take over the tasks for which he/she does not possess routine in performing. In Medium - although ATCo possesses routine with majority of tasks, high severity should remain due to critical task load.) On the other hand, the likelihood can remain the same as it is in nominal situation. Namely, ATCo has higher task load, but once the control is established he/she has more active role and more focused attention, so these two are considered to annul each other.
- In non-nominal situation 2 (Complexity Management Tools fails) and non-nominal situation 3 (System Supported Coordination Tools fails), the responsibilities are not significantly changed

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[4] 1 – No safety effect, 2 - Minor incident, 3 -Moderate incident, 4 - Serious (major) incident, 5 – Accident

[5] 1 – Rare, 2 - Unlikely, 3 -Possible, 4 - Probable, 5 – (Almost) certain

with respect to nominal scenarios, so the severity and likelihood can remain the same in (majority) of tasks that do not require any change in responsibilities.

- Same/similar general hazards should have higher severity in transition phase than in nominal scenario and non-nominal situation with established control.

The criteria adopted for AUTOPACE project to classify risks as acceptable, medium, high or unacceptable are presented in Figure 14 Presented **risk matrix** shows results obtained in the Medium Automation Non-nominal situation 1. Green fields represent **acceptable risks**, considered to be manageable by routine procedures. Two levels of **tolerable risk** area are defined. Yellow represents minor risk and requires development of appropriate procedure for the risk mitigation. Orange requires special, strategic mitigation measures (including ATCo training strategy) to be developed and implemented. **Unacceptable risks** are shown in red, meaning that review of the system functioning (including both ATC System and ATCo, their functioning and inter-relations) is required in this area.

S2.1	S-1	S-2	S-3	S-4	S-5
L-5	2.2, 4.2				
L-4	11.12, 12.13, 13.14, 18.14, 21.4, 21.5	2.1, 4.1, 16.1, 17.1, 18.1, 20.4, 21.1, 23.1, 24.1, 25.1, 26.1	9.1, 9.4, 9.11, 14.1, 18.15, 19.1, 20.2, 23.2	1.1, 11.14, 18.19	
L-3	3.2, 21.6	10.3, 10.12, 11.2, 12.1, 12.3, 13.1, 13.3, 15.1, 15.2, 15.3, 15.5, 16.7, 18.4, 20.1, 21.3, 28.1	**0.3, 0.9, 0.14, 0.27**, 9.6, 9.7, 9.10, 10.1, 10.5, 10.6, 10.10, 10.14, 11.4, 11.5, 11.13, 12.5, 12.8, 12.14, 13.5, 13.8, 13.15, 14.4, 16.3, 16.4, 16.5, 16.6, 18.5, 18.6, 18.18, 19.4, 20.7, 23.3, 23.4, 23.5, 23.6, 24.4, 25.2, 25.3, 25.4, 26.2, 27.1, 28.2, 28.3, 28.4, 28.5, 28.6	**0.10, 0.11**, 9.2, 9.5, 11.6, 11.9, 11.10, 11.11, 12.16, 13.16, 14.2, 14.3, 18.7, 18.11, 18.17, 19.2, 19.3	
L-2		**0.2**, 3.1, 10.4, 10.9, 10.13, 17.7, 21.2, 28.7	**0.5, 0.26,** 1.6, 1.7, 1.8, 5.5, 9.9, 10.2, 10.7, 10.8, 10.11, 11.1, 11.3, 12.2, 12.4, 12.9, 12.10, 12.11, 12.12, 12.17, 13.2, 13.4, 13.9, 13.10, 13.11, 13.12, 13.13, 13.17, 15.4, 16.2, 17.3, 17.4, 17.5, 17.6, 17.8, 18.3, 18.13, 18.16, 20.3, 20.8, 28.9	**0.4, 0.6, 0.7, 0.8, 0.12, 0.13, 0.19, 0.23, 0.24, 0.25, 0.28, 0.29,** 1.5, 5.1, 5.3, 5.4, 9.3, 9.8, 11.7, 12.15, 16.8, 18.12, 18.20, 20.5, 20.6, 20.9, 26.3, 26.4, 28.8	**0.22, 0.30**
L-1				17.2, 18.2, 24.3	3.3, 24.2

Figure 14: Risk acceptability – Results for S2.1

Numbers in the fields are unique hazard identification numbers (X.Y – hazard no. Y related to task no. X). Bold numbers indicates general hazards (prefix 0) and bold underlined – hazards related to transition period.

Results from the first cycle of safety risk assessment performed in AUTOPACE, is accepted to be presented in the conference [14] and it is submitted to journal [15].

2.4.3.3 Safety Feed-back

Bearing in mind that the "object" of this safety assessment is far future system, involving many uncertainties, it was decided to consider as critical, not only hazards with unacceptable risk, but also upper bound of the tolerable area - hazards with high risk (red and orange areas in risk matrix, Figure 14).

Among **critical hazards**, the most relevant for the AUTOPACE project, are the hazards which could be mitigated through appropriate future ATCo training design. Those are hazards related to ATCo performance, reduced SA (due to boredom, fatigue, overload, too much information shown, or tunnelling), human errors (slips, lapses, mistakes and violations), etc.

These hazards are used as input for **third brainstorming session** (HAZID 3) with experts involved with ATCo training (experienced ATCo, instructors, training designers, etc.). The goal of this brainstorming session was to provide safety feedback to training requirements definition and to identify possible measures to mitigate critical hazards related to ATCo performance through newly designed training for the future ATCo.

Generally, appropriate training methodology and competent teachers and instructors involved with training are considered highly important.

Other, more specific, **safety recommendations** resulted from HAZID 3 brainstorming session, are:

- Training should not be based only on technical aspects. It should also contain psychological (cognitive and non-cognitive) training;
- Simulation and theoretical training should be designed to prepare ATCo for transition procedure under various situations;
- Simulating failures are needed to train ATCo for detecting the alert;
- ATCos should be trained for team decision making (needed in Flight Centric ATC) and to recognize the leader and followers in the team;
- Training for the (emergency) procedures should be combined with fatigue and stress management;
- ATCo should be trained for "self-evaluation" - to recognize symptoms of stress and fatigue (heart beating, sweating, etc.);
- Maintaining situation awareness is the key for hazardous situations related to ATCo performance. Interaction with the system (random checks, fake alerts, etc.) should be introduced to check ATCo attention and situation awareness;
- Due to passive role in operations, higher number of training hours in simulation environment is needed. Refreshing trainings should be more frequent.

For several groups of hazards it is not possible to mitigate safety problems with ATCo training only. These hazards are related to system architecture and procedures.

2.4.3.4 Hazard Assessment – Second Cycle

Second cycle of PHA is performed to show the impact of proposed training strategy on critical hazards identified in the first cycle of the PHA.

In the second cycle of PHA initial training strategy is provided as an input. It assumed initial and refreshing trainings. Initial training consists of technical training and psychological and cognitive training. Technical training involves basic training (without automated functions), system logic training (aiming to calibrate trust in automation) and technical simulation training (focused on transition to non-nominal situations; part-task and multi-task). Psychological and cognitive training refers to training to cope with stress in potential challenging situations. ATCo performance will be continuously monitored during operations and based on the performance indicators the decision will be made about refreshing training for each ATCo.

For each general critical hazard related to ATCo skills and competences it was indicated which components of the training can support hazard mitigation as well as whether it impacts severity and/or likelihood (see D4.1, Section 2.6, Table 21, [5]). Proposed training strategy is also expected to influence task specific critical hazards, primarily in category Reduced SA.

After decreasing severity, likelihood or both, some critical hazards are fully mitigated (degraded to acceptable/tolerable area), some remained critical with lower risk (from unacceptable to high risk), and some remained unchanged.

The numbers of critical hazards for High Automation and Medium Automation scenarios after the second cycle are summarized in Table 3 and Table 4, respectively. (Notes: one hazard is counted multiple times if it is assigned to several tasks; some red hazards from cycle 1 changed into orange in cycle 2).

High Automation (S1)SS1	General Hazards				Task Specific Hazards			
	Cycle 1		Cycle 2		Cycle 1		Cycle 2	
Nominal situation	2	0	0	0	7	0	3	0
Conflict Detection and Resolution tools fails	10	11	6	2	20	16	7	12
Complexity Management tools fails	6	1	2	0	4	0	2	0
System Supported Coordination tools fails	8	2	2	1	11	3	8	0
TOTAL	26	14	10	3	42	19	20	12

Table 3: Number of hazards (second cycle) per situation – High Automation

Medium Automation (S2)SS2	General Hazards				Task Specific Hazards			
	Cycle 1		Cycle 2		Cycle 1		Cycle 2	
Nominal situation	2	1	1	0	16	6	14	3
Conflict Detection and Resolution tools fails	12	4	4	0	27	16	22	8
Complexity Management tools fails	7	1	2	0	12	6	11	3
System Supported Coordination tools fails	10	2	2	0	19	7	17	3
TOTAL	31	8	9	0	74	45	64	17

Table 4: Number of hazards (second cycle) per situation – Medium Automation

It is important to note that, under the assumption that no procedures shall remain unidentified and all responsibilities will be clearly defined/known by the time system is implemented, some of the critical hazards disappear in the second cycle. That way, hazard category *Undefined responsibility* is not included (counted) in Table 3 and Table 4. Those hazards can be considered as additional result of the AUTOPACE project that points out to safety hot-spots to system and procedure designers that should be addressed in the stage of system and procedure design before its implementation.

Final training strategy definition is explained in detail in D3.2 - Competence and Training Requirements [4]. It assumes three different training phases: Simulator Training, On-the-Job Training and Refresh Training (2.4.4.2)). Performing third cycle analysis, with final training as input, was not in the scope of AUTOPACE. However it is important to note than some of the remaining critical hazards that can be further mitigated through training are mainly those related to Reduced SA:

- Function failure not detected or detected after longer period of time (only High Automation),
- ATCo SA reduced due to boredom/overload/fatigue (only High Automation),
- ATCo SA reduced due to high taskload (only Medium Automation),
- ATCo confusion about responsibilities over specific flight,
- Omission of ATCo to carry out the prescribed procedure,
- Incorrect input undetected (only Medium Automation)
- Conflict risk not identified between aircraft under the responsibility of one ATCo,
- Both ATCo's not aware of incorrect coordination data applied,
- ATCo continues working in previous sectorization (only Medium Automation)

Vast majority of hazards in category *Incorrect action* are related to unintentional human errors (slips, lapses and mistakes). Such hazards exist in any current/future system that involves human. It is not possible to train humans not to make (unintentional) errors, since they can appear due to various reasons.

Similarly, some hazards categorized as *Other* can be mitigated through adequate training when they are related to ATCo activity, e.g. Skill degradation (wrong evaluation, reaction time too long, procedure mistakes etc.), but severity fixes it in critical area.

In certain categories of hazards insufficient or no improvements can be expected to achieve through training, but it needs to be addressed in the context of system and/or procedures providing adequate safety barriers.

Following system life cycle phases of the future automated ATM (from its definition, through design and implementation, to operations and decommissioning), once more detailed knowledge of tasks/operations is available, future refinement of the results should be performed using the same approach as performed in AUTOPACE.

2.4.4 Training and Competences

2.4.4.1 ATCo Functions and Competences

It is expected that automation will play an important role in the ATM system. However, there is still much uncertainty about what degree of automation will be deployed. The degree of automation is important to determine who will be responsible to do the different functions and how each of them will be performed. Therefore, according to each automation level, the ATCo will perform a set of functions in a different manner and will require different competences. A competence is a combination of skills, knowledge and attitudes required to perform a task to the prescribed standard.

For the definition of 2050 competences required to operate in automated environments, current ATCOs functions and competences are analysed. This allows understanding current framework and changes caused by automation. Then, taking into consideration the new roles and responsibilities assigned between system and ATCo in the AUTOPACE ConOps and scenarios (section 2.4.1), the psychological effects on ATCo due to automation (section2.4.2) and the preliminary hazard assessment (section 2.4.3), future functions and competences for ATCo in 2050 are derived.

2.4.4.1.1 Evolution from Current to Future ATCo Functions

This section analyses the functions which are currently carried out by the ATCo and how they evolve for 2050 timeframe. *Integrated Task and Job Analysis of Air Traffic Controllers (ITA)* (EUROCONTROL, 1999), identifies ten different basic functions for en-route ATCo. Based on the AUTOPACE Automation Scenarios, two new more functions are also identified. Table 9 shows the definitions of these functions along with a colour code meaning:

- Green cells indicate the functions are maintained without changes;
- Blue cells indicate the functions that are maintained but with changes.
- Yellow cells indicate the new functions for future automation Scenarios

Function	Definition
Maintaining Situational Awareness	The ATCo is aware of what is happening in the control position, thanks to his/her experience, knowledge and all the available information. The ATCo is able to understand the traffic current state and to anticipate the aircrafts' behaviour
Checking	A set of operations performed by ATCo in order to obtain information only from external sources about airspace under their responsibility
Searching conflicts	ATCo retrieves relevant aircraft data for the assessment of a potential conflict (level, route and aircraft speed for example) by receiving external information
Issuing instructions	This process is one of the most common actions carried out by the ATCo, which is activated when it is necessary to give instructions or to inform the pilots
Switching attention	This process is essential for the ATCo functions as it is necessary that the ATCo knows which function is the most important at any time and focus on it but without neglecting the rest of actions since it could compromise the safety
Taking over position	This process takes place before the ATCo sits down at the control position and takes over from his/her partner. In the first place, the ATCo builds in his/her mind the sector mental model. From this model and with the current traffic conditions, the ATCo establishes the sector mental image and predicts future traffic developments
Monitoring	The monitoring process consists of a continuous sector observation and the surveillance maintenance in order to detect possible conflicts. This process is constantly repeated while the route ATCos are in position
Managing routine traffic	Standard routine traffic management takes place as long as pilots' normal calls and flight progress information are received currently. It is related to the "searching conflicts", "checking" and "issuing instructions" processes

Function	Definition
Managing requests/ assisting pilots	Something very common in airspace management is that pilots carry out some kind of request to the ATCo. The ATCo will grant the request or not, taking into account the following criteria: safety, own workload and adjacent ATCo workload
Solving conflicts	This process begins when a potential conflict is detected. ATCo will decide if it is necessary to solve it immediately or postpone its solution until a more convenient moment. There are three possible solutions to resolve a conflict: routine solutions, non-routine solutions and backup solutions
De-complexing Process	This function consists of implementing de-complexing measures, which are those activities which include reducing the complexity level of en-route air traffic. However, it will be the LTM (Local Traffic Manager) which will propose the de-complexing measures, so the LTM will be the main actor of this process and not the ATCo. However, the ATCo will need to interact with it.
System supervision	While the ATCo is performing all functions mentioned before, he/she should be able to identify a system malfunction. The ATCo will continuously have to make sure that the system will be working properly. For example, the system could fail identifying a conflict or, the solutions proposed to solve a conflict may not be adequate, complexity level management could fail or, finally, the coordination support system could fail. Any of these cases would trigger non-nominal situations.

Table 5: Evolution from Current to 2050 Functions

As a consequence of the expected new roles and responsibilities allocated to ATCos in the time frame of study (2050**), two new functions are identified:**

- *De-complexing Process* which consist of implementing de-complexing measures, which are those activities which include reducing the complexity level of en-route air traffic. This function is more oriented to LTM ((Local Traffic Manager) actor but the ATCo needs this function as there is a relationship between both actors related to this process.
- *System Supervision* is a key function for future ATCOs. This function implies that the ATCo supervise the system to detect a potential malfunction and is crucial to detect non-nominal situations and be ready to recover the system control if needed.

2.4.4.1.2 Evolution from Current to 2050 Competences

The following Table 6 shows the current competences and how they evolve towards the future competences. It can be seen that as automation increases, there are more changes in the competences.

- Gray cells indicate the competences that will disappear.
- Green cells indicate the competences that will be maintained without changes.
- Blue cells indicate the competences that will be maintained but with several changes.
- Yellow cells indicate the new competences.

Current competences	Medium Automation Competences	High Automation Competences
Situation assessment	Situation assessment	Situation Comprehension
Traffic and capacity management	Traffic management	Monitoring
Communication	Communication	
Coordination	Coordination	Identification
Problem solving and decision making	Problem solving and decision making	
Management of non-routine situations		
Workload management	Workload management	Workload management
Cooperation and teamwork		
Individual aspects of performance	Individual aspects of performance	Individual aspects of performance

Table 6: Evolution from Current to 2050 Competences

The competences in the Medium Automation Scenario are more similar to the competences currently required for the ATCo. This is because the system does not perform most of the actions, but it provides the ATCo a set of proposals that he/she has to approve and implement using the system as a support. For this reason, the "*Problem Solving and Decision making*" is a key competence in this scenario.

However, in the High Automation Scenario the competences are especially different as the system performs all most actions automatically. In consequence, the ATCo's main role is to monitor and to supervise the system actions and to evaluate if they are correct. For that reason, the ATCo key competence is "*Monitoring*", which is essential and necessary for all the other competences. Although the system is the main actor, it is also very important that the ATCo has a great understanding of the operational situation. AUTOPACE has taken into account unusual situations in which the system could fail. In these non-nominal situations, the ways in which the ATCos have to perform the different functions changes during the duration of the non-nominal situation. Therefore, the ATCos need a different set of competences to take charge of the new situation (Table 7 and Table 8).

MEDIUM AUTOMATION SCENARIO	Conflict Detection and Resolution fail	Complexity management tools fail	System supported coordination fail
New competences	------------	------------	------------
Changes in the competences scope	Problem solving and decision making	Traffic management	Communication
	Traffic management		
	Communication		Coordination
	Coordination		
Competences to be strengthened	Situation assessment	Situation assessment	Situation assessment
	Workload management	Workload management	Workload management
	Individual aspects of performance	Individual aspects of performance	Individual aspects of performance

Table 7: Competences allocation for Medium Automation in non-nominal situations

HIGH AUTOMATION SCENARIO	Conflict Detection and Resolution fail	Complexity management tools fail	System supported coordination fail
New competences	Problem solving and decision making	Traffic management	Communication
	Communication		Coordination
	Coordination		
	Traffic management		
Changes in the competences scope	------------	------------	------------
Competences to be strengthened	Identification	Identification	Identification
	Situation comprehension	Situation comprehension	Situation comprehension
	Workload Management	Workload Management	Workload Management
	Individual aspects of performance	Individual aspects of performance	Individual aspects of performance

Table 8: Competences allocation for High Automation in non-nominal situations

2.4.4.1.3 Competences Classification

The competences are classified in order to organise the training phases and to define the more useful exercises to develop competences acquisition. Taking into consideration the ATCo Psychological Model, the competences can be classified in technical, psychological cognitive and psychological non-cognitive.

- Technical Competences will help ATCos to resolve the Control Events applying the correct actions and procedures depending on the ATCo competences (experience) the way to resolve the Control Events will be different.
- Psychological Cognitive Competences will strengthen the use of appropriate cognitive processes that in High and Medium Automation are Comprehension and Projection.
- Psychological Non-Cognitive Competences: The Psychological-ATCo trust on the system depends on how the ATCo perceives the system complexity and the previous experiences with the system (trust). In turn the ATCo engagement is dependent on the responsibility (the responsibility for applying actions would require more engagement than just approving automated decisions and actions). Psychological Non-Cognitive Training will help ATCo to trust the system and to detect and cope with the negative effects of automation such as OOTL and panic to system failures. In turn as long as the ATCo is acquiring these psychological non-cognitive competences the ATCo will be more responsible to be committed (engaged) with the control activity.

For Medium and High Automation Scenarios, the classification of competences is shown in Table 9. For High Automation Scenario, in Nominal Situations, the ATCo just would need to acquire psychological competences. But as the ATCo needs to be prepared for system failures (non-nominal situations), technical competences to recover control and manage the traffic will be also necessary as described in Table 7 and Table 8.

	Technical Competences	**Psychological Cognitive Competences**	**Psychological Non-Cognitive Competences**
High Automation Scenario	*Traffic Management (NN)*	Situation Comprehension Monitoring Identification *Communication (NN)* *Coordination (NN)* *Problem solving and Decision Making (NN)*	Workload Management Individual aspects of performance
Medium Automation Scenario	Traffic Management	Situation Assessment Communication Coordination Problem solving and Decision Making	Workload Management Individual aspects of performance

Table 9: Competences Classification: Nominal and No-Nominal (NN) Scenarios

2.4.4.2 Training strategy overview

For defining the AUTOPACE Training proposal it has been taken into account how the strategy could deal with the acquisition of 2050 Competences, but also how the training program helps to cope with the preliminary hazards assessment. Training contributes in the hazards mitigation by two ways. On the one hand, training can reduce the probability of some hazards. For example, hazards related with lack of SA are mitigated thanks to the reduction of the probability of suffering lack of SA through the introduction of techniques to calibrate automation trust.

On the other hand, some hazards are related to external factors beyond the ATCo. With appropriate ATCo training for such situations ATCo can only be better prepared to deal with such situations thus severity of these hazards can be decreased. However, full mitigation of those hazards is dependent to system design, equipment, environment and/or procedures.

The training strategy has been designed in order to be flexible to the needs of each applicant, so that every applicant reaches a common level at the end of the training. Nowadays, training strategies have a fix structure. That means ATCo which could be better qualified than others. With the flexible training scheme proposed, this issue can be reduced since the training strategy is designed to be adapted for each applicant, fitting to his/her needs in order to reach a common level of qualification.

The objective of the ATCo Psychological Model researched and described in D3.1 is to predict how automation affects the ATCo Mental Workload. The ATCo Psychological Model chases to behave as an “ideal” and an ordinary future ATCo as it represents the cognitive processes expected for an ATCo in the 2050 environment including the relevant tasks and responsibilities to cope with the expected traffic forecasts keeping an acceptable MWL level. The model could be used to support a training design plan. The final goal for the trainee ATCo would be to be able to manage the traffic within acceptable MWL levels as the model does (always assuming that the ATCo Psychological Model is calibrated). The main inputs of the Psychological Model to predict in a quantified way the impact on the MWL and the relationship with the Training are shown in Figure 15.

For its nature, Technical & Psychological Cognitive Training will be handled separately from the Psychological Non-Cognitive Training. From the Psychological Model point of view, the former training is just affecting on the Demanded Resources while the latter is on the Available Resources. It is assumed that psychological non-cognitive training helps ATCo to keep the Situational and Trust in an optimum and therefore the negative effects of automation (OOTL and panic) will not occur. The same for the engagement as the ATCo training will make operator be always engaged with the task.

The final goal of the Training is to ensure that for the traffic levels expected in the future (traffic complexity), the ATCo can safely manage the traffic without experimenting Mental Overloads.

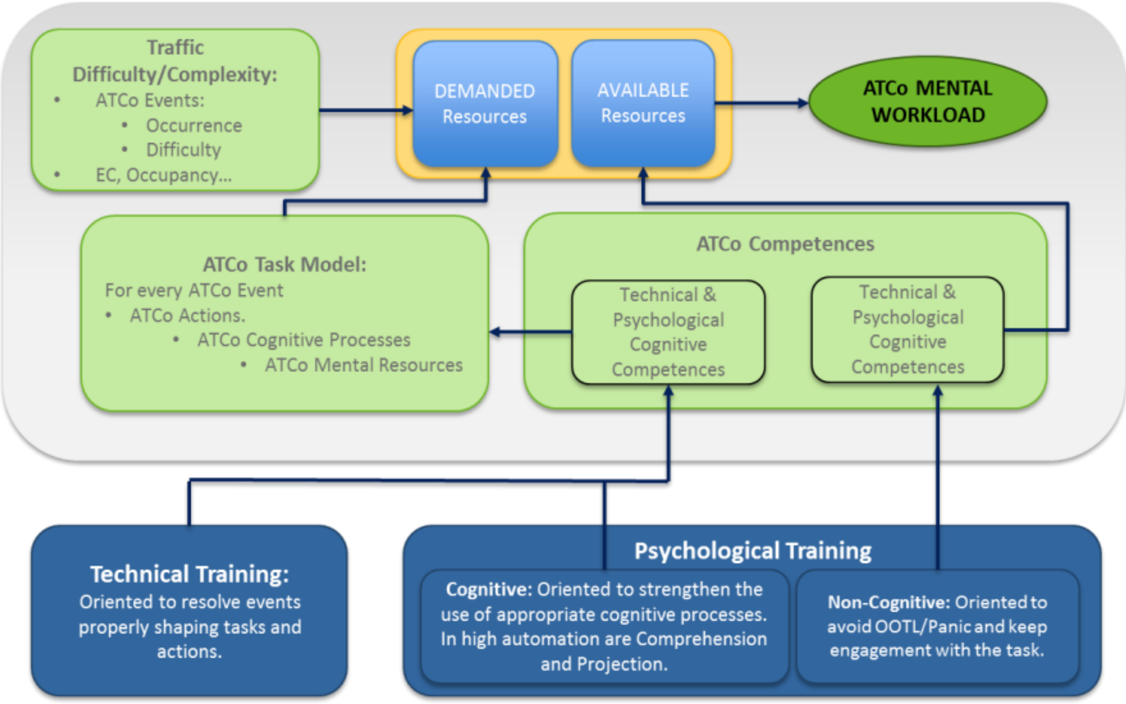

Figure 15: ATCo Psychological Model and relationship with training

The training program has been divided into three different phases (Figure 16). The first phase, called Simulator Training, supposes the main part of the training strategy and allows the students acquiring the competences for providing ATC in automated environments. Following, the student shall pass an On-The-Job Training in order to put in practice knowledge and competences acquired along the training program in a life traffic situation. In addition to training for acquiring the ATCo license, it is also necessary to provide Refresh Training along the professional life of ATCo in order to maintain their competences in an appropriate level for providing ATC.

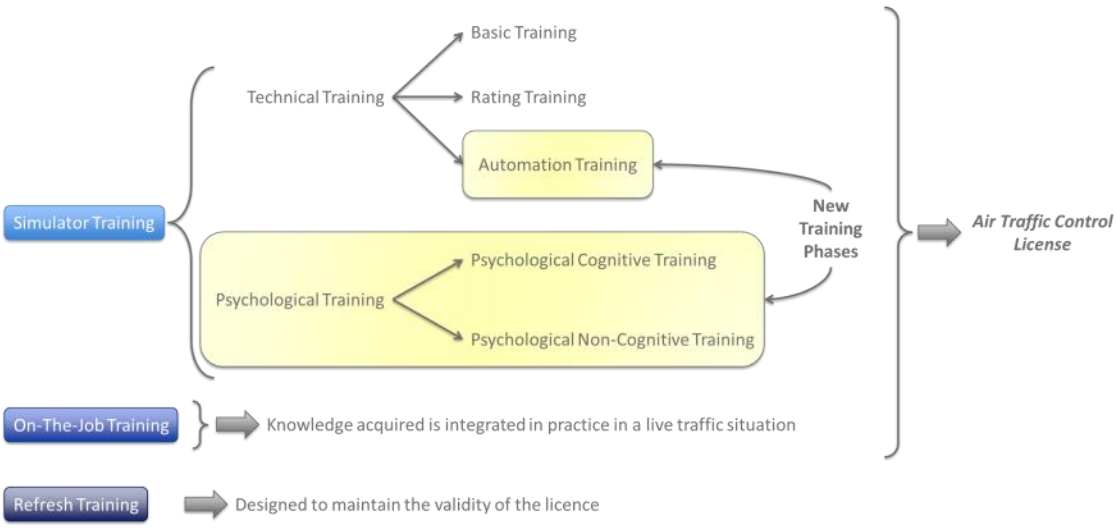

Figure 16: AUTOPACE Training Scheme proposal

The Simulator Training covers two different areas, Technical Training and Psychological Training. Technical Training could be divided into three phases:

- **Basic Training**: Theoretical and practical training to provide basic knowledge needed to operate without automation assistance.
- **Rating Training:** Theoretical and practical specific knowledge related to the rating in which ATCos are qualified, Area Control Surveillance in case of AUTOPACE project scope.

  Basic and Rating Training are proposed to train ATCo without any automation support as it is done today. With this proposal, the ATCo will be ready to control in case a system failure might occur (non-nominal situations), particularly, if all automated systems failed.
- **Automation Training**: Practical knowledge focused on the acquisition of Technical Competences within the automated framework, that is, with the ATC System assistance.

Psychological Training is an innovative training phase which is divided into two parts:

- **Psychological Cognitive Training**: Specific training phase to cope with the development of Psychological Cognitive Competences, especially those related with *Comprehension* and *Projection*.
- **Psychological Non-Cognitive Training**: Focused on Psychological Non-Cognitive Competences. This training phase is based on techniques for coping with stress in order to respond to any potential challenging situation, as well as to improve the identification of symptoms of lack of situational awareness. One proposed way to improve the attention level of the ATCo and keep the Situational Awareness in an optimum, is to make him/her to keep a more active role with the system, especially in High Automated scenarios, where his/her main responsibility is to monitor the system performance. In Medium Automation scenarios, the ATCo is supposed to be in an active role since he/she has to choose the solutions performed between the proposed ones. However, in High Automation scenarios, the operator does not have to take decisions, so it must be introduced a new way to make the ATCo to be involved with the performance of the ATC System. One possibility is that ATCo is randomly asked about the system performance and he/she has to evaluate it with his/her own criteria.

  On the other hand, another way to increase the arousal level proposed in AUTOPACE is through the employment of Biofeedback techniques. These techniques allow determining when an ATCo is suffering OOTL/lack of SA thanks to his/her own evaluation or an alarm system. Therefore, as the ATCo acquire experience along their professional life, they will improve progressively understanding his/her arousal behaviour to detect low level of attention or, also, this identification could be carried out by the own system, warning with an alarm.

2.4.4.3 Competence assessment

The evaluation methodology of the technical competences is carried out through the called ATCo Performance Monitoring. This methodology identifies if a ATCo has suffered a significant loss of competences along the Training Program and if he/she shall pass a Refresh Training to recover the appropriate level. Then, based on this methodology, the system evaluates the ATCo performance by filling automatically a series of templates. The ATCo performance monitoring will be different depending on the scenario.

- In the High Automation scenario, the ATCo have to evaluate the performance of the ATC System through questions that will appear randomly. These ATCo answers to the ATC System questions in order to evaluate its performance will be used by the ATC System to fulfil the templates and to evaluate if the ATCO is losing his/her competences.
- In case of Medium automation scenarios, the system uses the chosen solution from the three different plausible ones when a decision is needed. If the ATCo chooses systematically the less suitable option or does not choose the most suitable one, it could mean he/she is losing his/her technical and cognitive capacities and may need further training, that is, a Refresh Training.

To evaluate the mental and cognitive workload, AUTOPACE has taken as a reference a mental workload assessment tool developed by EUROCONTROL which is called AIM – Assessment of the Impact of Change in Automated ATM Systems on Mental Workload. The operator is asked about the effort that requires performing the task, the difficulty that he/she considers the task has and factors that has more influence in the mental workload.

The methodology proposed maintains the same philosophy, but with the purpose of replacing the questionnaires by objective measures that allow to evaluate the effort that the person has to employ in order to perform certain actions. Then these measures are compared with an "ideal effort" (estimated by the ATCo Psychological Model) that the fully trained ATCo would have in the corresponding training phase.

Applying this kind of techniques, it could be obtained a continuous distribution of the ATCo effort. At the same time, in each training exercise, it is possible to dispose the actions that the ATCo is performing, so a relationship between the actions performed by the ATCo and the effort level required at each moment can be established.

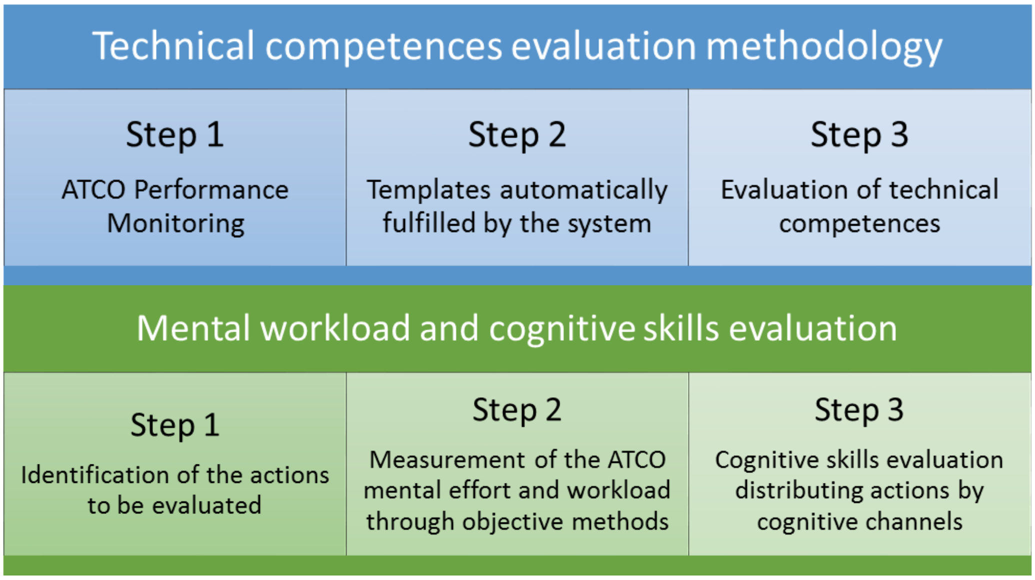

Figure 17: Progress Assessment Methodology

The evaluation of the progress is done employing a common methodology (Figure 17) to evaluate the cognitive competences and the mental workload.

The objective of the Training Program is to make the students evolve with a constant level of effort. This implies that they have an optimum level of learning load which makes them able to acquire competences progressively, avoiding the possibility of collapse due to the excess of concepts to be assimilated.

This is how a Training Program is created, which is adapted to the learning needs of each ATCo student. The application of the Training Program is intended to be the much adjusted as possible, selecting exercises with a difficulty level that the student is able to handle employing a Progress Assessment methodology. The Progress Assessment methodology allows incorporating personal parameters based on learning load experienced to the objective evaluation results, giving a complete approach to the exercises selection.

2.4.4.4 Training simulation platform

Some of the concepts and models developed in AUTOPACE are in a first level of development, and it will be necessary to check them in later phases of the research, and to calibrate the model for the different phases of the ATCo training.

To accomplish with this objective it is necessary to dispose of a simulation tool which allows creating exercises with different scenarios and to validate the hypothesis defined. The current simulation and the ATC training tools are operative environments, which are really expensive to maintain and difficult to adapt them to new concepts.

For this reason AUTOPACE has worked on the creation of a simulation environment. Among its application, the simulation platform can be used to demonstrate if these future scenarios are reliable or not, without the necessity of creating a complex and complete automation program.

This simulation platform allows continuing with different project tasks:

- Calibrating the ATCo model for each training phase.
- Validating the hypothesis of the traffic and events distribution for each defined phase.
- Checking the difficult scales which are defined in the training.
- Validating the performance assessment methodology that has been proposed in the different training phases as well as the hypothesis defined for the continuous training processes.

2.5 Technical Deliverables

According to AUTOPACE Work Breakdown structure ([1]), the Technical Work packages are WP2, WP3, WP4 and WP5, being WP1, WP6 and WP7, Management and Support WPs. The table below (Table 10) contains the deliverables produced under the above-mentioned Technical WPs.

Reference	Title	Delivery Date[6]	Dissemination Level[7]
Description			
D2.1	Future Automation Scenarios	01/09/2016	Public
Deliverable D2.1 presents the Concept of Operations and the Scenarios that have been identified in the AUTOPACE WP2, Future Automation Scenarios. The Concept of Operations (ConOps) will serve as an input to establish the future operational scenarios in which AUTOPACE research is framed. It considers changes in operations and procedures, systems and personnel to define the Future Automation Scenarios The document defines the automation features that should be analysed according to automation needs and trends expected for 2050, with the description of nominal and non-nominal situations. Considering the specific requirements of the study in relation to ATC perspective, the deliverable describes three steps to define the AUTOPACE Scenarios: • 2035 AUTOPACE ConOps definition; • 2050 AUTOPACE ConOps definition; • AUTOPACE Scenarios identification and description. A preliminary identification of required skills and human performance aspects is also presented			
D3.1	ATCo Psychological Model with Automation	07/03/2017	Public
Deliverable 3.1 collects the main research on the psychological model that will serve to investigate the required new competencies and training strategies to ensure that the mental load of ATCo is adequate to ensure a safe operation. To achieve the objective of evaluate the effect of automation; the research begins with the definition of the ATCo Psychological Model based on the functional structure of the cognitive system and the cognitive functioning of a human. AUTOPACE applies new attentional theories proposing that automation not only affects the demanded resources but also the available ones. The last part of the deliverable indicates consequences for training competences drawn during the analysis carried out in the work package. Some new training strategies to cope with “out-of the loop” effect and those coping with stress are pointed out.			
D3.2	Competences and Training Requirements	31/10/2017	Public
This activity will use D3.1 and D4.1 outputs to research the new competences and a catalogue of training requirements to effectively operate in the foreseen scenarios for 2050 described in D2.1. A competence based training and assessment methodology approach will be followed. The development of competency-based training and assessment is based on a systematic approach whereby competences and their standards are defined. Training is based on the competences identified to cope with new function allocation between ATCo and system (technical and psychological cognitive training) and the potential negative psychological effects of automation (psychological non-cognitive training) being either out-of-the-loop/overconfidence that might create overload in case of system failure as the ATCo has not the necessary situational awareness to cope with high complexity tasks or disorientation, overacting or erratic behaviour/ fears of failure (creating an underload due to high levels of arousal) . Assessments are developed to determine whether these competences have been achieved.			
D4.1	Preliminary Safety Hazard and Performance	31/07/2017	Public

[6] Delivery data of latest edition

[7] Public or Confidential

	Assessment		

Deliverable 4.1 provides preliminary findings regarding the automation benefits as well as the safety hazards in order to support the refinement of the competence and training requirements.

First part of the document describes the safety assessment conducted to provide a set of automation risks that should be mitigated by modifying ATCo training or refining the automation design. Preliminary Hazard Assessment – PHA is performed in two cycles. The main outcome of the first cycle is a safety feedback to training designers who modified competences and training catalogue including some of the safety recommendations adopted based on that outcome. Second cycle shows improvement in safety - some of the critical hazards were resolved and their risks reduced by new training strategies proposed in D3.2. It also summarizes critical hazards which cannot be resolved by training, because they relate to procedures and system design that are not defined to enough detailed/mature level.

Second part of the document evaluates the usefulness of the Psychological Model researched in D3.1 to support the benefit assessment of the automation features. AUTOPACE psychological model supports the performance assessment in several KPAs such as CAP, CEFF and HP that are strongly linked with Mental Workload.

D5.1	**Final Project Results Report**	**31/01/2018**	**Public**

Deliverable 5.1 presents an outline of the researched solutions to mitigate the ATCo performance drawbacks in high automation environments providing a better understanding on how cognition and automation live together and how new ATCo competences and training mitigate likely foreseen hazards.

The main project results with a presentation of conclusions and recommended next steps are presented in this document. The solution feasibility is substantiated with a positive maturity assessment that demonstrates that AUTOPACE is ready to move from Basic Research to Applied Research.

A preliminary experimental plan for next R&D phase is also included.

Table 10: Technical Project Deliverables

3 Links to SESAR Programme

3.1 Contribution to the ATM Master Plan

AUTOPACE objective is not to propose new ATM Solutions but to collect the most likely expected OIs for 2050 time horizon and to analyse how having being deployed all these OIs, the high automation is affecting ATCo performance. Although the OIs expected to be deployed for 2050 time horizon are not yet available in the ATM Master Plan ([19]), the most likely concept of operation and operational scenarios have been defined. AUTOPACE proposes new ATCo roles and responsibilities and task allocation between system and ATCo according to these defined operational scenarios. AUTOPACE identifies how these new responsibilities affect on ATCo performance from a psychological point of view and proposes new competences and training strategies to mitigate those performance drawbacks. Besides, AUTOPACE performs a preliminary hazard and safety assessment resulting in safety requirements. Most safety requirements have derived on refinement of competences and training strategies, but others not mitigated by training, have derived to system and procedural recommendations.

As a consequence what AUTOPACE is mainly proposing are new HUMAN Enabler Categories linked to a generic OIs that covers AUTOPACE Concept of Operation. AUTOPACE support the enabling of a probable future concept where ATCo tasks are focused on monitoring and supervision of the system actions keeping the tactical interventions to a minimum.

Code	Name	Project contribution	Maturity at project start	Maturity at project end
AUT-01	Facilitating the Automation Pace	Proposal of a Concept of Operation for 2050 time frame with two possible levels of automation (medium and high automation)	TRL0	TRL1
HUM-01	New Function allocation between System and ATCo	Definition of new roles and responsibilities for ATCo and system in nominal and non-nominal situations	TRL0	TRL1
HUM-02	New ATCo Competences and Training	New ATCo Competences and Training for system and psychological needs	TRL0	TRL1

Table 11: Project Maturity

3.2 Maturity Assessment

AUTOPACE Maturity Assessment serves for three main purposes:

- To assess the actual maturity of the content developed by the project based on the results obtained and the deliverables produced by the project. To assess the
- To assess the potential ATM benefits that the topics researched by the ER project could bring.
- To assess the conclusions and recommendations for future R&D activities on the topics researched by the ER project

The SESAR Maturity Assessment Criteria are based on material from E-OCVM version 3.0 and Technology Readiness Levels provided by Horizon 2020, adapted to the specificities of SESAR 2020 programme.In case of AUTOPACE SESAR Maturity Criteria cover the maturity transition From fundamental Scientific Research to Applications-Oriented Exploratory Research: from TRL-0 to TRL-1.

In order to provide evidence on this transition, the SESAR Maturity Assessment Criteria require the project to address 12 criteria giving a rationale per every criterion based on AUTOPACE results and deliverables.

Table below shows the AUTOPACE Maturity Assessment indicating the level of satisfaction according to the criteria of each TLR, as well as the evidences that allow stabilising the corresponding level of satisfaction.

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
TRL-1.1	Has the ATM problem/challenge/need(s) that innovation would contribute to solve been identified? Where does the problem lie?	**Achieved**	AUTOPACE has identified that ATM system moves towards an increasingly high level of automation which will provide higher capacity at high standards of efficiency and predictability. Automation will unavoidably change the ATCo work environment and the role of the human will move towards tasks focused on monitoring and supervision of the system actions keeping the tactical interventions to a minimum. However, human-automation interaction in highly automated environments presents serious performance drawbacks due to the risk of the "out of the loop" effect (OOTL) especially in case of automation fail or fears of automation when a fail might occur. Future ATCos should be trained not only to acquire new technical competences but also to acquire psychological cognitive and non-cognitive competences for keeping attention to avoid the OOTL effect and for coping with stress or fear. Safety assessment should take into consideration these psychological effects on ATCo due to automation. AUTOPACE proposes investigation to better understand those effects of automation on ATCo psychological aspects and proposes mitigation with new competences and training strategy. **References:** AUTOPACE D3.1 ATCo Psychological Model with Automation
TRL-1.2	Has the ATM problem/challenge/need(s) been quantified?	**Partial – Non Blocking**	The problem/challenge/need(s) should always be quantified to better understand the severity of the problem if nothing is done but when the timeframe of study is far beyond (2050), the high level of uncertainties on how the concept of operation will be, leads to analyse the problem from a qualitative perspective instead of quantitative. AUTOPACE has qualified the problem/challenge/need by assessing Safety KPA, Cost-Efficiency KPA (CEFF), Capacity KPA (CAP) and Human Performance Focus Area (HP) first on a reference scenario. This means the assessment of the abovementioned KPAs on a "business as usual scenario that for AUTOPACE means the analysis on scenarios where no solution in terms of new competence and training

			are applied to manage the increase of traffic in high automation environments. **References:** AUTOPACE D4.1 Preliminary Safety Hazard and Performance Assessment
TRL-1.3	Are potential weaknesses and constraints identified related to the exploratory topic/solution under research? - The problem/challenge/need under research may be bound by certain constraints, such as time, geographical location, environment, cost of solutions or others.	**Partial – Non Blocking**	Although clearly stated in the Grant Agreement, the project weakness is the execution of validation within the project timeframe. The project researches in literature and expertise and proposes hypothesis to be validated but not in the project due to the scope, time and budget. **References:** AUTOPACE D2.1 Future Automation Scenarios
TRL-1.4	Has the concept/technology under research defined, described, analysed and	**Achieved**	AUTOPACE Concept proposes three main solutions to face up to high levels of automation: (1) A Psychological Model to predict the effect of Automation on ATCo Human Performance, (2) New Training and Competences for future ATCos to cope with the expected highly automated systems and (3) Automation Suitability Assessment to safely manage future traffic: the expected high levels of automation are analysed to ensure the traffic is safely managed by

	reported?		maximising performance benefits with the training strategies support. **References:** • AUTOPACE D3.1 ATCo Psychological Model with Automation • AUTOPACE D3.2 Competence and Training Requirements • AUTOPACE D4.1 Preliminary Safety Hazard and Performance Assessment
TRL-1.5	Do fundamental research results show contribution to the Programme strategic objectives e.g. performance ambitions identified at the ATM MP Level?	**Partial – Non Blocking**	ATM Master Plan Performance Ambitions are foreseen for 2035 on Cost-Efficiency, Operational Efficiency, Capacity, Environment, Safety and Security.AUTOPACE brings benefits beyond 2035 (2050 timeframe) on: *Cost-Efficiency as the identification of the required new competences and training to operate in a future highly automated environment will allow the European Community to effectively implement advanced automation features. Moreover, the delivery of an effective ATCo Training Curricula and Personnel Selection Process will accelerate the training path and increase the productivity of the ATCo operating in the foreseen environment. *Safety: New Competences and Training Strategies for future ATCo are designed ensuring adequate safety level. A Preliminary Hazard Assessment of AUTOPACE Future Automation Scenarios supports the identification of a set of automation risks that should be addressed by introducing training or refining the automation design, ensuring that safety can be properly addressed for the automation features expected in future ATM. *Capacity: The availability of an ATCo Psychological Model allows establishing the ATCo Mental Workload level that can optimise the use of the airspace within a desired safety level. AUTOPACE is not addressing Operational Efficiency, Environment and Security. **References:** AUTOPACE D4.1 Preliminary Safety Hazard and Performance Assessment

TRL-1.6	Do the obtained results from the fundamental research activities suggest innovative solutions/concepts/ capabilities? - What are these new capabilities? - Can they be technically implemented?	**Partial – Non Blocking**	AUTOPACE Concept proposes three main solutions to face up to high levels of automation, maximising the automation effectiveness and traffic management safety: - A Psychological Model to predict the effect of Automation on ATCo Human Performance through Mental Workload Assessment. An existing prototype to measure cognitive demand provides evident of the feasibility to complement it with further research to validate other psychological factors that affect the MWL such as the ATCo Level of Activation and the Engagement with the task. - New Training and Competences for future Controllers to cope with the expected highly automated systems. ATCO should be trained not only on technical aspects but also on psychological aspects (cognitive and non-cognitive) to master the concentration and alertness in case the controller has overconfidence on automation, or to keep the stress levels acceptable in case the ATCo has fears of automation failing. This solution is not validated in AUTOPACE and therefore its technical feasibility is not analysed yet. - Automation Suitability Assessment to safely manage future traffic maximising performance benefits, The expected high levels of automation are analysed under a preliminary safety assessment to ensure the traffic is safely managed by maximising performance benefits with the training strategies support. **References:** • AUTOPACE D3.1 ATCo Psychological Model with Automation • AUTOPACE D3.2 Competence and Training Requirements • AUTOPACE D4.1 Preliminary Safety Hazard and Performance Assessment • AUTOPACE D5.1 Final Project Results Report
TRL-	Are physical laws and assumptions	Not	AUTOPACE investigates about psychological theories not psysical so the criterion TRL1.7 is not

1.7	used in the innovative concept/technology defined?	Applicable	applicable.
TRL-1.8	Have the potential strengths and benefits identified? Have the potential limitations and disbenefits identified? - Qualitative assessment on potential benefits/limitations. This will help orientate future validation activities. It may be that quantitative information already exists, in which case it should be used if possible.	**Achieved**	AUTOPACE brings benefits on the following Key Performance Areas and Focus Areas: - Safety: Preliminary findings regarding the safety hazards are provided, analysing which could be addressed by training. - Capacity: The number of ATCo required to safely provide the ATC service, keeping the workload at an acceptable level from a HP perspective, decreases with the level of automation. AUTOPACE Psychological model improves the estimation of this performance improvement as a tool to better predict the MWL implied by the implementation of new automation features. AUTOPACE solution addresses the potential reduction of Capacity in contingency situations through training design. - Cost Efficiency: AUTOPACE estimates that training time for future automation scenarios shall not necessary be longer than for current scenarios. Training cost can be reduced thank to the employment of simulators (reducing hours of training in the working position). Also, the model improves the estimation of the count of flights handled divided by the number of ATCo-hours applied by ATCo on duty - Human Performance: Evaluation of the Functional Tasks allocation description, Hierarchical Tasks analysis description and the Cognitive Tasks analysis description have been fully addressed. Hypothesis about the expected variation of Mental Workload are provided. Training strategies have been defined to increase trust in automation and, also, changes in competences have been fully evaluated. Limitations are about the assumptions taken during the Concept of Operation definition and the assignation of ATCo/System Roles and Responsibilities due to the uncertainty of 2050 timeframe.

			References: • AUTOPACE D2.1 Future Automation Scenarios • AUTOPACE D3.2 Competence and Training Requirements • AUTOPACE D4.1 Preliminary Safety Hazard and Performance Assessment
TRL-1.9	Have Initial scientific observations been reported in technical reports (or journals/conference papers)?	**Achieved**	Based on the work developed in AUTOPACE Project, consortiums members have participated in several conferences and have presented papers: • **FRAMily**, 24-26th May 2017, Rome. A presentation named "Understanding the impacts of enhanced automation in future ATM" is given. • **SAFE 2017**, 6-8th September 2017, Rome. A paper named "Hazard identification approach for future highly automated air traffic management concept of operation: experiences from AUTOPACE project" was presented. • **SYMOPIS 2017**, 25-28th September 2017, Zlatibor. A paper named "Methodology for safety risk assessment in future air traffic management concept of operations" was presented. • **7th EASN International Conference**, 26-29th September 2017, Warsaw. The paper titled "An ATCo Psychological model with automation" was presented. • **7th SESAR Innovation Days 2017**, 28-30th November 2017, Belgrade. In the SID 2017, two papers based on the Safety and the Competences and Training achievements (Task 4.1 and Task 3.2) on the one hand, and on the Psychological Model (Task 3.1) on the other hand were submitted but not accepted. For presentation: ○ "Identification of Safety Critical Hazards to Support Future Air Traffic Controller Training Program"

			○ "Quantitative prediction of automation effects in Human Performance" Instead, one poster was submitted and accepted related to WP2 and the definition of the different scenarios titled: ○ "Analysis on Future Automation Scenarios in the Framework of 2015 ATC" • **TRB 2018**, 7-11th January 2018, Washington. A paper named "Safety Risk Assessment in Future Automated Air Traffic Management System" was presented. • An article named "Safety Risk Assessment in future highly automated air traffic management concept of operations" was submitted in July 2017 to the **Safety Science** journal. Paper is currently under review. **References:** AUTOPACE D6.2 Exploitation and Dissemination Report
TRL-1.10	Have the research hypothesis been formulated and documented?	**Achieved**	AUTOPACE defines an Experimental Plan to validate how automation impacts on ATCo Mental Workload according to different Attentional Theories. Basically the different attentional theories coincide on the effects of automation on the demanded resources. The more automation, the less task complexity and therefore, the less demanded resources. But in case of the available resources, the automation effect on the level of activation (dependant on operator trust on the system) and the engagement with the task, is predicted in a different way depending on the attentional theory. As a consequence, AUTOAPCE has identified scientific hypothesis to be validated in further research. As the total effect of automation on available resources is a combination of the level of activation (trust) and the ATCo engagement with the task, further research is needed to validate how the combination of these factors will be. On the other hand, a catalogue of new training strategies are proposed and documented and sets hypothesis to be validated to explore which training technique is the most suitable to be

			applied in the future automated scenarios. **References:** • AUTOPACE D3.1 ATCo Psychological Model with Automation • AUTOPACE D3.2 Competence and Training Requirements • AUTOPACE D5.1 Final Project Results Report
TRL-1.11	Is there further scientific research possible and necessary in the future?	**Achieved**	AUTOPACE has demonstrated that the solutions proposed are mature enough to follow the investigation to Applied Oriented Research. ATM moves towards higher levels of automation and to mitigate the ATCo performance drawbacks until succeeding with the full automation where the human might not be necessary, it is mandatory to train the human to ensure that those performance drawbacks do not arise to ensure unsafe situations. AUTOPACE not only has proposed an ATCo Psychological Model that could be computerised to quantify the ATCo Mental Workload depending on the level of automation but also a training strategy to ensure that future ATCo acquires the required competences. The focus on non-nominal situations must be the objective to prepare the ATCo to recover control in case the system fails. Until the human cannot be “removed” from the system, the human will be the only one to be able to manage the situation. Training on these non-nominal situations becomes mandatory and therefore it is worth keeping on with the paved research. • **References:** AUTOPACE D5.1 Final Project Results Report

TRL-1.12	Are stakeholder's interested about the technology (customer, funding source, etc.)?	**Achieved**	Measuring this criteria with the different stakeholders attending AUTOPACE Workshops, the interest have been shown by all stakeholders identified in the Dissemination and Exploitation Plan: SJU Technical Officer, Potential ATCo Students (Croatia Control Ltd), Universities (Zagreb, Delft, Cranfield, Linköping, Trento, Fraunhofer), ANSPs (LFV, Croatia Control, BULATSA, DFS, SkyGuide, Naviair, ENAIRE, MUAC, DSNA), ATCos (ECTRL, AEROTHAI, SMATSA, Croatia Control, ENAIRE, IFATCA, APROCTA), Industry (Airbus, SOPRASTERIA, LEONARDO, Thales), Research Centres (ONERA, ENAC, DLR, Deep Blue, INNAXIS), ATCo Training Centres (ENAC, UPM, NELSO AEROFORMACIÓN), EUROCONTROL, Safety Agencies (AESA, IFATSEA). **References:** AUTOPACE D6.2 Exploitation and Dissemination Report

Table 12: ER Fund / AO Research Maturity Assessment

4 Conclusion and Lessons Learned

4.1 Conclusions

- From human factors analysis, the operational scenarios where the future ATCo will work in, the tasks he/she will perform and his/her role new roles and responsibilities are key to know, understand and research on the interaction between ATCOs and high automation. Therefore, the more detailed the concept of operation is, the better the analysis is. AUTOPACE has defined a solid methodology for the definition of a 2050 Concept of Operation. First a concept for 2035 was defined based on SESAR mature documents and the concept for 2050 was built upon based on primary references Despite of this approach, a high uncertainty exists for 2050. The issue has been mitigated with the definition of two different levels of automation: High Automation and Medium Automation where in general terms and in nominal situations, in High Automation Scenarios the ATCo is expected to have the responsibility of monitoring or monitoring and approving in the provision of the majority of the ATC services. Nevertheless, in Medium Automation Scenario the ATCo will be responsible for applying many of the ATC services after analysing the proposals made by the ATC system as well.
- The definition of operational scenarios when the system might fail (non-nominal situations) is also relevant to analyse the feasibility for the ATCo to recover control. Due to effort limitations and project duration, three non-nominal situations have been analysed (Conflict detection and resolution system fail, Complexity management system fail and Communications support system fail), but total fail or other possible levels of failures are not addressed in the project. Preliminary results from a cognitive demand point of view reflect that in High Automation Scenarios, a Conflict Detection and Resolution failure should be declared as not feasible, not being possible to be assumed by an ATCo. Training could mitigate these situations but validation is needed. In medium Automation Scenarios where the ATCo tasks do not change so drastically from what is today, the situations are more feasible with training.
- The application of different psychological theories allowed the definition of a Psychological Model for an ATCo. This has been the key for a better understanding on how cognition and automation live together. The research has shown that the cognitive processes implied for information processing by ATCo are perception, comprehension, projection, decision making and execution. Today, the use of these processes are balanced but preliminary results have shown that, not only in high but also in medium automation scenarios, processes such as comprehension and projection are the most demanding ones as they are the key to build the correct mental picture of the situation (appropriate channels in tasks focused to monitoring and system supervision).
- Curiously, the theories to analyze how the automation impact on the ATCo Mental Workload, and therefore on his/her performance, do not predict the same effect on MWL with automation. This does not mean that any of the analyzed theories are incorrect, but that each of them analyses different influencing factors that affect differently on ATCo MWL due to automation. The influencing factors are: task complexity, level of activation (arousal), confidence in the system (trust) and engagement with the task. The results of this particular

research derived a set of hypothesis, where the contribution of every influencing factor needs to be analyzed along with their cross-effect (combination effect).

- The computerization of the psychological model proposed by AUTOPACE would provide a powerful tool to quantify the benefits and weaknesses of different levels of automation not only in terms of Human Factors, but also in terms of Capacity and Cost-Efficiency. The estimation of ATCo MWL is an indicator that enables to calculate a sector throughput or the number of needed ATCos to control sector. The potential of having a model like this is proven with an existing prototype (COMETA) which provides the demanded mental resources.
- Acquisition of appropriate Competences for future ATCos are mandatory to ensure a safe operation. With the difference from today's competences, the future requires, not only technical training, but also psychological training. The psychological training is divided in: (a) cognitive training - to boost the use of appropriate cognitive processes, to ensure a proper mental picture and to be able to detect system deviations; and (b) non-cognitive training - to master the concentration and alertness, in the case ATCo has overconfidence in automation, or to keep the stress levels acceptable in the case ATCo has fears of automation failing.
- Training on psychological aspects is wide open to further validation, as the proposed training strategies have not been covered yet in the ATM domain. Old techniques such as biofeedback is proposed to be used in ATC to teach ATCo to detect by his/her own when the performance is failing and reacts consequently.
- In turn, AUTOPACE proposes to tailor the training to the student needs, focusing the bulk of training hours on running exercises in a simulator. The advantage to train in a high fidelity simulator is the infinite casuistic of non-nominal situations that can be emulated to prepare ATCos for potential system failures and for recovering control. Also the confrontation to situations with different levels of automation would allow tuning and validate the most appropriate training strategies.
- The Safety Assessment provides a preliminary identification of potential hazards expected for 2050 timeframe, categorized mainly based on: particular task hazard is related to, share of responsibilities between the ATCo and the ATC System, and the nature of hazards. The details of the operational scenarios in High and Medium Automation and the Task Model for the ATCo allowed performing thorough hazard identification. Refinement of the concept of operation would also allow a refinement of hazard identification and categorization. It is important to note that, having observed far future ATM system defined on very general level (early stage of system development), sources of hazards were also related to system design, procedures, environment, etc.
- The risk assessment assumes assigning a severity and likelihood to all hazards. Although the number of hazards is higher in Medium than in High automation scenarios, likelihood is independent of the scenario/situations, except for those that involve ATCo (reduced situation awareness and incorrect action). As the reduction of SA due to boredom or fear of automation is significantly higher in High Automation scenarios than in Medium, the likelihood is also higher in High than in Medium. The severity is lower in High Automation than in Medium Automation, because the most of the tasks (almost all) are performed by the ATC System (lower engagement of ATCo). For all scenarios risk matrices are produced – containing distribution of hazards to different risk levels, based on their severity and likelihood bearing in mind this is qualitative analysis, scenarios cannot be directly compared

one to another i.e. it cannot be easily stated which level of automation scenario is safer by the moment. But, it is evident that Conflict Detection and Resolution failure in High automation is the most critical scenario (also shown as unfeasible in psychological analysis).

- Among critical hazards, the most relevant for the AUTOPACE project are the hazards which could be mitigated through appropriate future ATCo training design. Those are hazards related to ATCo performance, reduced SA (due to boredom, fatigue, overload, too much information shown, or tunnelling), human errors (slips, lapses, mistakes and violations), etc. Second cycle of Safety Assessment proves improvement in safety with adequate training design, through decreased number of critical hazards in all scenarios.

New tasks and responsibilities coupled with new competences will impose the research of new ATCo curricula that will detail the course of study required to learn and develop the required competences. In coordination with the new ATCo curricula, the **personnel selection processes** should be re-evaluated to ensure that the **potential ATCos have the ability to acquire the required new competences through training.** Appendix C and Appendix D collect findings for the previous skills and abilities from trainees and recommendations for personnel selection process.

Furthermore, since for certain categories of hazards, insufficient or no improvements can be expected to achieve through training, **some recommendations related to other components of the system (equipment, procedures and environment) and operational procedures** are included in section 4.2.1 debajo de.

Finally, a preliminary exploration modelling with **Functional Resonance Analysis Method (FRAM)** has been done within AUTOPACE. Although not foreseen within AUTOPACE description work, it was considered a relevant contribution to enhance the understanding of the potential impacts of automation throughout the different sequences of actions and within overall ATC operations (Appendix E).

4.2 Technical Lessons Learned

Technical Lessons learnt are here referred to those technical aspects of the project that shall serve as starting point for related projects. In AUTOPACE the technical solution proposed to mitigate the ATCO performance drawbacks suffered in high automated environments is the research on future ATCo Competences and Training Techniques.

Safety hazard assessment has proven that not all critical hazards can be mitigated through training so other solutions or combination of them should be necessary to address the automation issues. In this sense, AUTOPACE has identified some System and Procedure Recommendations to complement the training requirements not addressed with training (section 4.3.1). Furthermore, AUTOPACE jointly with the ER Projects MINIMA and STRESS has analysed how the different solutions under research in the three projects respectively can be complemented to solve the automation issues (section 4.2.2).

4.2.1 System and Procedure Recommendations

In the process of PHA, hazard identification was performed thoroughly (covering all four components of the system – equipment, procedures, people and environment). The main emphasis was on the group of hazards related to ATCo skills and competences, aiming to support training strategy definition, and to show to what extent it is possible to improve safety by mitigating critical hazards through adequate training.

As already briefly mentioned in section 2.4.3 for certain categories of hazards, insufficient or no improvements can be expected to achieve through training. Although some of those hazards are related to ATCo performances (mainly *Incorrect action* category), majority are related to other components of the system (equipment, procedures and environment).

Some hazards are related to system functioning and data accuracy, so it is not possible to mitigate safety issues, possibly caused by those hazards, with ATCo training solely. Selected examples are:

- Incorrect/incomplete input data,
- Incorrect weather forecast,
- Data link corrupted (information not received; incomplete information received)
- 4D trajectory of ATC System and aircraft FMS differ,
- Inflexibility with negotiation of entry/exit conditions (System resilience),
- Impossibility to take over control from the ATC System.

Hazards related to some non-regular situations, with low probability of appearance, indicate safety issues that can simply appear in the system, but there are no special measures to prevent their appearance. Some of these hazards are:

- Existence of unknown flights,
- Lack of procedure for interception of aircraft,
- Message sent by pilot is not in standard format,
- Cockpit disagrees with system solution (not able to perform suggested change),
- Sector boundaries cannot be adapted to traffic routes,
- Insufficient capacity of an ATC centre.

Also some regular situations in Flight centric ConOps (e.g. Conflicts between aircraft under the responsibility of two different ATCos), are considered as hazardous due to significant divergence between future and current concept of operations.

All abovementioned hazards (associate to system functioning, data accuracy, regular and non-regular situations) should be given special attention not only in training ATCos, but also in designing supporting equipment and procedures.

One of the most important hazards are related to unknown aspects of the future ConOps, that are not defined at all or not defined to enough depth. They primarily assume undefined responsibilities when solution requires communication between various ATC Systems/ATCos, like:

- Lack of "master ATCo" within the same area of responsibility (sector),
- Lack of "master ATCo" (lack of or delayed communication regarding responsibility),
- Lack of "master system" for supervision of the ATC System coordination,
- Lack of clear responsibility for final decision (LTM or "master" ATCo),
- Coordination with military undefined,
- Unclear responsibility share between ATCo and ATC System.

Related to unknown aspect the most critical is lack of procedure, e.g. Lack of contingency procedure, related to transition period from nominal to non-nominal situations.

Due to the nature of hazard origin, no improvements can be expected through training, in hazards categories Incorrect input and Non-performable actions (e.g. Incorrect/incomplete data, Sector boundaries cannot be adapted to traffic routes), but their mitigation mainly relies on supporting equipment and double-checks for data accuracy.

Hazard category Tool corruption cannot be affected by training except when ATCo is actively involved with decision making and giving the instructions, when severity of the hazard can be affected i.e. reduced. These are hazards related to support functions corruption/temporary failure, or increased task-load due to unpredicted circumstances (e.g. Data link corrupted - information not received or incomplete information received, Air situation picture not provided, etc.). Likelihood can be affected only by designing more reliable tools in terms of their failure, or providing backup tools.

Those hazards, related to system functioning and data accuracy, should be resolved by building enough safety barriers in terms of equipment and data exchange reliability that will keep the likelihood of hazard appearance as low as possible.

Hazards related to some non-regular situations indicate safety issues that can simply appear in the system, but there are no special measures to prevent their appearance (e.g. Existence of unknown flights, Lack of procedure for interception of aircraft, Message sent by pilot is not in standard format, Insufficient capacity of an ATC centre, etc.). If ATCo is trained for such situations severity of the hazards can be decreased. However, full mitigation of those hazards is related to environment and/or procedures.

It is similar with hazards categorized in uncertain traffic evolution. These hazards cannot be prevented to happen. They are related to pre-tactical decisions that can evolve in an undesired way due to various circumstances (e.g. ATCo accepts to be overloaded despite the fact that conditions for issuing some measures exist). With appropriate training ATCo can only be better prepared to deal with such situations on tactical level, thus reducing the severity of these hazards. But, full mitigation of this group of hazards should take into account impact of ATCo environment and its characteristics (LTM, weather, other traffic, etc.).

Hazards related to Undefined responsibility when solution requires communication between various ATC Systems/ATCos represent serious safety issues. Those hazards should be resolved by clear pre-defined procedure design concerning responsibility between ATCo(s) and/or ATC System and by ATCos properly trained to handle such situations in the scenario implementation. By applying this recommendation those hazards will not be relevant any more, i.e. will not be the characteristic of the system that endangers safety. Brainstorming session on safety feedback suggested that no hierarchy should exist among ATCos, but they need to be trained as a team to handle any conflicting situations that involve various ATC Systems/ATCos i.e. that they can always recognize who is follower and who is leader in decision making in Flight Centric ATC environment involving CDM in pre-tactical stage. In that context no "master" ATC System or ATCo need to be defined and hazards from this category can be replaced with different one, that is "ATCo is confused about the responsibility ...", meaning the responsibility is clearly defined, but ATCo does not recognizes it appropriately. Such hazards would certainly have lower safety significance than undefined responsibility, and should be possible to mitigate through adequate training by affecting SA.

Similarly, as a result of HAZID 3, some additional hazards are also excluded from the initial list, like: Cockpit disagrees with the system solution (it is considered that final decision is always with the pilot, so ATC System and/or ATCo need to revise their instruction if cockpit disagrees with it); and

Impossibility to take over control from the ATC System (it was suggested that exactly the opposite would jeopardize safety in the future environment - to allow ATCo to take over control of the ATC System). It means that as the system definition and design evolve and more details are known, some of the hazards will disappear from the list with no need for their mitigation.

After including partial impact of ATCo training on mitigation of critical hazards related to equipment, procedures and environment and revising the list by excluding majority of procedural hazards, some critical hazards still remained:

- Insufficient capacity of an ATC centre,
- Conflicts between aircraft under the responsibility of two different ATCos,
- ATCo accepts to be overloaded despite the fact that conditions for issuing some measures exist,
- Incorrect/incomplete data,
- ATCo cannot determine separation due to incorrect aircraft position information,
- Existence of unknown flights,
- Segregated airspace not shown,
- Segregated airspace shown but not accurate,
- Sector boundaries not updated on ATCo working position.

First two are related to future ConOps itself, third is related to environment (communication with LTM), fourth and fifth are data exchange/update, sixth on non-regular situation, and last three on equipment (reliability of the tools) and information exchange/update. Those hazards should be given special attention in designing system, supporting equipment and procedures.

4.2.2 Combination of AUTOPACE, MINIMA and STRESS Solutions

AUTOPACE, MINIMA and STRESS Projects are all SESAR Exploratory Research projects, addressing the first research call on Automation, being all of them fundamental scientific research projects, to identify the opportunities for common areas of further investigation given by their complementarities.

The general objective of *MINIMA* project is to improve the comprehension of the OOTL performance problem especially according to a future air traffic scenario. Further, in MINIMA tools have been developed in order to detect and compensate the negative impact of this phenomenon and a carefully selected allocation of tasks between the human agent and the automated system for the use case of a highly automated Terminal Manoeuvring Area (TMA) is proposed.

In *MINIMA,* The vigilance and attention observer has been developed in order to be able to measure both vigilance aspects, which refer to the alertness component of attention, and the selective aspects, which refer to the capacity of controlling the focus. To this aim, the measure of the loss of vigilance and attention is performed by means of psycho-physiological recording, such as EEG (ElectroEncephaloGraphy) and Eye tracking. *STRESS* wants to enhance the comprehension of the human response to this role changing, in order to generate knowledge able to support the design of the technologies which will be used by ATCos to manage the future air traffic scenario. Specifically, the project will **provide guidelines to be followed to design future systems that are compatible with human capabilities and limitations**, ensuring that the right balance between humans and automations is obtained.

So far, STRESS has developed:

- Future ATM scenarios and related human factors issues based on the SESAR expectation in terms of traffic type and implemented concepts. The project identified **highly automated operational scenarios, featured by technologies able to support in a semi or totally automated way ATCo's decision making** (e.g. how to solve conflicts) and action implementation tasks (e.g. giving orders to aircraft). Stress, vigilance, attention and workload have been recognized to be the human factors issues mostly impacted by the transition to higher automation levels.

- **Neurophysiological indexes of stress, vigilance, attention, cognitive control on tasks and workload**. The indexes have been tested in an ecological environment and validated against usability and ATM suitability.

These indexes will be used in the next phase of the project to assess the impact of high automation on the human performance in air traffic control tasks and derive optimal automation design strategies.

AUTOPACE, MINIMA and STRESS projects present strong commonalities and complementarities as summarised in the following bullets and in Figure 18:

- All projects deal with long term automation.
- All projects are focused on the human/system relationship in highly automated scenarios.
- All projects try to reduce the risks of the negative effects of automation.
- All projects identify different levels of automation but for different purposes.

Furthermore, the complementarities identified are:

Complementarity #1: HF assessment

- AUTOPACE provides a model to predict the mental workload as a relationship between demanded resources and available resources with some hypothesis to be validated regarding the effects of automation on available resources (Level of activation/arousal and engagement with the task);
- MINIMA provides tools and methods to measure the available vigilance and attentional resources (available resources);
- STRESS provides a neurophysiological toolbox for human performance assessment.

Complementarity #2: Prevention and mitigation of automation drawbacks

- AUTOPACE focused on Training Strategies for future ATCo to mitigate ATCo performance drawbacks with automation;
- MINIMA is focused on system adaptation to mitigate the abovementioned performance drawbacks;
- STRESS supports a better design of technologies by ensuring the consistency between automation support and human capabilities and limitations.

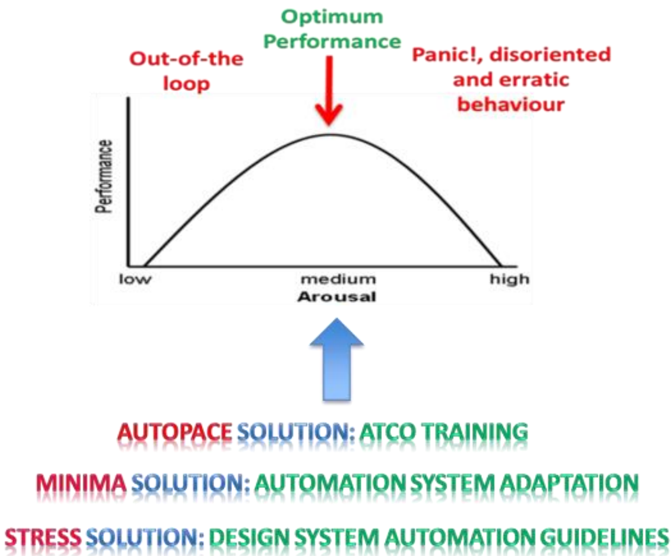

Figure 18 AUTOPACE, MINIMA and STRESS Solutions

Complementarity #3: Support to the innovation process

- AUTOPACE provides a catalogue of training techniques for future ATCo addressing not only the technical aspects but also the psychological ones;
- MINIMA develops a method for mitigating the negative effects of automation regardless the ATCO Competencies and Strategy;
- STRESS delivers automation guidelines for achieving the highest possible level of automation and for supporting safe transitions from higher levels of automation to lower levels of automation, and vice versa.

Complementarity #4: Experimental setting

- AUTOPACE provides the requirements for a simulation platform and an experimental plan to validate hypothesis on psychological aspects and training strategies;
- MINIMA provides a simulation platform and an experimental plan;
- STRESS provides a simulation platform integrating the neurophysiological measurement tools for the analysis of human performance during the execution of ATM tasks at different level of automation support.

Complementarity #5: Envisioning of future scenarios

- AUTOPACE considers a complete ConOps for en-route, the nominal and non-nominal situations for 2050 along with the roles and responsibilities expected for future ATCo;
- MINIMA focuses on a simulation platform of TMA that includes aspects of the AUTOPACE ConOps, such as the AMAN in a dense traffic airport;
- STRESS considers current expectations of ATM stakeholders towards automation, which are related to the introduction of innovative concepts and increased automation levels and as a consequence, to a change in the roles and tasks of ATCo

4.2.2.1 Further objectives built upon the complementary areas

Research opportunity #1: Automation drawbacks mitigation

Main area to keep on researching is the validation of combined solutions (training and system design and adaptation) to mitigate ATCo performance drawbacks at high automated environments. These validations should cover not only the nominal situations but also the cases of system failure where ATCo has to recover the active control.

Among the catalogue of training techniques to keep the level of activation (arousal), biofeedback technique could be validated by using psychophysiological measures to train ATCo to maintain a high attentional level.

To reach a higher level of maturity of the concept of mitigating the negative effects of automation through:

- A combined approach based on a system adaptation and a training/competences control.
- The demonstration of the applicability to a number of key areas in the SESAR 2050 ConOps through the already selected in the AUTOPACE 2050 ConOps.

Research opportunity #2: Training design

As the context and the tools change, ATCo training should adapt. The training techniques and strategies developed could be validated using Human Factors neurophysiological indexes in realistic future scenarios simulation environments, not only testing envisioned technological concepts but also expected future roles and procedures.

Research opportunity #3: Validation of future technological and organisational concepts

Simulation environments are available which are able to simulate in a realistic way future technologies, procedures and roles. These concepts can be tested and validated through the use of Human Factors neurophysiological indexes to assess their impact on human and system performance.

Research opportunity #4: Adaptive automation

Knowledge is available among the three projects to propose and validate adaptive automation concepts (e.g. able to prevent/reacts to performance degradation or anticipate errors) and tools able to provide different support depending on ATCo status (e.g. more automation in high workload conditions).

4.3 Recommendations for future R&D activities (Next steps)

After the Workshop held on the 27th of November, 2017 at Belgrade and the Dissemination Event on the 5th of March, 2018 at Madrid, both organised by AUTOPACE and dedicated to disseminate project results, some areas were identified for further research.

Following sections cluster the research areas according to the key project results (section 2.4) providing also the potential stakeholders whose participation in that research area would be relevant.

4.3.1 Further Research on Future Automation Scenarios

RA#1: Future ATC System Development: In the Future Automation Scenarios context, the Research Area focuses on a description refinement of future concept of operation and scenarios for 2050 time horizon. The level of uncertainty at this timeframe supposes many assumptions for roles and responsibilities for ATCo and system along with system requirements and the identification of non-nominal situations.

Definition of different levels of automation apart from High or Medium Automation as AUTOPACE poses is also necessary to be covered. Some options proposed at Madrid were: (1) ATCo takes the action of each situation and system is monitoring the ATCo. In case of failure the system assumes automatically the control, (2) Cooperation between the system and the ATCo in the function allocation. For example: more complex tasks could be done by the system and the simplest by the ATCo, (3) Gradual transitions from current situations to full automation are needed to be identified (this option is also in line with 2).

For the different levels of automation and ATC Tasks, the "Apply – Approve – Monitor" responsibilities for ATCo activity would be identified

Potential stakeholders: ANSPs, Research Centres/Universities and Industry

RA#2: Definition of different non-nominal scenarios: The selection of potential failures to be considered as non-nominal situations has taken two assumptions: (1) the ATC responsibilities should still be carried out even though some services provided by tools and (2) the ATCo will need to change their mode of operation in order to assume the ATC responsibilities that the ATC system will not take during the failure or to operate with the absence of some system functions such as lack of information, support services, etc. New assumptions might be needed to refine the existing non-nominal scenarios considering different severity of failures. Also new different system failures or other circumstances could be analysed for non-nominal situations.

Potential stakeholders: ANSPs, Research Centres/Universities and Industry

RA#3: Investigate on regulation and standardization issues related to new responsibilities allocation in high automation scenarios: The new function allocation between system and human implies substantial changes in current regulation and standardization frameworks. This research area proposes to investigate how to tackle with these changes to ensure the feasibility of the new roles and responsibilities for ATCo.

Potential stakeholders: Safety Agencies, Regulatory Bodies, ECTRL and Deployment Managers

4.3.2 Further Research on ATCo Psychological Model

RA#4: Validation the combination effect of automation on the level of activation (overconfidence, fears of automation) in simulated environments: The available resources depend on the level of arousal and the engagement of ATCo while performing the task. Level of activation and engagement modifies the pool of available resources but it is unknown how and how much these two factors modify the available resources. The research area proposes to get empirical data from medium and high fidelity simulations with ATCo (Real Time Simulations).

- <u>Level of activation</u>: Experimentally, the level of activation would be easily manipulated by changing the trust in the reliability of the system. For example, different frequency of system failures could be introduced in the simulation.

- Engagement: Engagement comes from the allocation of responsibilities in the automation scenario. However, it should be kept in mind that each responsibility can be performed within a variable range. For example, monitor is a responsibility with a high variability in its execution and is a responsibility that can more easily lead to OOTL. As independent variable, it could be manipulated by instructions.

The hypotheses about the effects of automation on the available resources and the level of activation and engagement would have to be tested by observing the dependent measures relevant to each hypothesis. These dependent measures are:

- Performance Measures (Time to detect the system failure, how to go back in control)
- Psycho-physiological Measures (e.g. hart rate, pupil measures)
- Subjective Measures (ISA – Instantaneous Self-Assessment - methodology)

Potential stakeholders: Research Centres/Universities and ATCo

RA#5: Investigation on computerization of ATCo Psychological Model to quantify the automation effects on ATCo Performance: The modelling of demanded resources is a reality (COMETA prototype is already developed) but in case of the available resources, first it is necessary to validate the total effect of automation on available resources (previous research area). At this point a development of a computerised model to be used for prediction of automation on ATCo performance will be closer to reality. This would give the potential to quantify ATCo performance for any level of automation and new concepts of operation.

Potential stakeholders: Research Centres/Universities and ATCo

RA#6: Research on the input from the Psychological Model to systems design approaches (automated systems and work systems – sociotechnical systems). The research on an ATCo psychological model has served to better understand how automation is affecting the ATCo MWL. This information should be used as guidance for system design. For example, the estimation of cognitive demand (demanded resources) in high and medium automation scenarios for 2050 has shown that the use of comprehension and projection cognitive processes are more demanded than Perception, Decision Making and Execution. A good acquisition of Situational Awareness is key to monitor/understand what the system is doing and therefore to detect if the system is making errors. Supporting tools for the ATCo to improve the acquisition of a good SA are proposed for research.

Potential stakeholders: Research Centres/Universities, Ergonomists, Industry

4.3.3 Further Research on Training Strategies

RA#7: Validation on the use of ATCO Model as a reference for the ATCo Trainee: The ATCo Psychological Model chases to behave as an “ideal” and an ordinary future ATCo since it represents the cognitive processes expected for an ATCo in the 2050 environment considering the relevant tasks and responsibilities necessary to cope with the expected traffic forecasts keeping an acceptable MWL level. The model could be used not only for checking system features suitability but also to support a training design plan. The final goal for the ATCo trainee would be to manage the traffic within acceptable MWL levels as the model does (always assuming that the ATCo Psychological Model is calibrated). The Model would be calibrated for every training phases and the trainee target would be to behave as the model does.

The validation could be done through the use of Fast Time Simulation and COMETA to adapt the ATCo Task Model to the different training phases. To measure the ATCo WL at different training phases, RTS is proposed to collect WL data and use them to calibrate the ATCo Task Model.

Potential stakeholders: Research Centres/Universities, ATCo, ATCo Training Centres

RA#8: Development of platforms to simulate exercises for the different degrees of automation: AUTOPACE proposes that training on a simulator is the most important phase to acquire the technical and psychological competences. The main risks due to high automation are related to system failures (non-nominal situations) and therefore the more exhaustive training covering all possible failures modes can be done on a simulator. On the Job-Training and Refresh Trainings are still necessary for acquiring the ATCo license and maintaining ATCo competences but the development of platforms to emulate different levels of automation and failure become essential to prepare future ATCos to be ready to recover back control.

Potential stakeholders: Research Centres/Universities, Ergonomists, Industry

RA#9: Review of future ATCo Competences: Following the RA#1 where it is proposed to define different levels of automation for the future system with clear transitions between ATCo and System roles, a review of Competences defined in AUTOAPCE should be performed.

Potential stakeholders: Research Centres/Universities, ANSPs, ATCo, ATCo Training Centres

RA#10: Validation of psychological non-cognitive training strategies such as biofeedback techniques: Biofeedback is a technique in which one or more psychophysiological parameters (heart rate, respiratory rate, brain waves ...) are recorded using sensors placed in different parts of the body. These registers are automatically displayed on screens to be scanned by the ATCo trainees. The hypothesis is to say that it is possible to train the ATCo to identify and to relate body signals to high or low levels of activation.

The Validation should be a RTS with ATCo where different psycho- physiological measures captured during the RTS would be displayed to the ATCo. In the Reference Scenarios, these psycho-physiological measures wouldn't be shown to ATCo. If during OOTL situations the ATCo come back quicker to optimum level of activation when displaying these measures, the usefulness of this biofeedback technique would be proven.

Potential stakeholders: Research Centres/Universities, Psychologists, ATCo

RA#11: Research on how assess and monitor ATCo performance during ATCo technical and psychological training: Following with the previous research area, it is necessary to research on how the competences (technical and psychological) are already acquired. The identification of the right measure to estimate objectively the mental workload that the ATCo has, the level of activation or the stress that the ATCo is feeling is key to determine if the ATCo has acquire the right competences to safely manage the air traffic in high automated environments.

Potential stakeholders: Research Centres/Universities, Psychologists, ATCo

4.3.4 Further Research on Safety and Risk Assessment

RA#12: Research on new system features and new operational procedures where training does not mitigate critical hazards: In certain categories of hazards insufficient or no improvements can be expected to achieve through training. Although some of those hazards are related to ATCo performances (mainly *Incorrect action* category), majority are related to other components of the system (equipment, procedures and environment). It is recommended to use remaining critical hazards (that could not be mitigated by training) as a basis for further research on new system features and operational procedures in high automation environment.

Potential stakeholders: Research Centres/Universities, ANSPs, ATCo

RA#13: Third (Fourth, etc.) cycle analysis – accounting more details about system architecture, i.e. details on equipment and tools: AUTOPACE has performed two cycles of preliminary hazard assessment (PHA). Using AUTOPACE ConOps, i.e. task-lists and responsibilities (ATCo vs. ATC System) for selected scenarios, first cycle of PHA provided a set of critical hazards that were used as additional guideline to training design for future ATCo. Second cycle used proposed training as input aiming to show impact of training on system safety, for the same scenarios. Once the Concept of Operation is refined, new cycles are proposed to reassess safety by considering details on equipment, tools and procedures (see previous point #13), but also technical and psychological training, roles and responsibilities, as well as different nominal and non-nominal situations.

Potential stakeholders: Research Centres/Universities, ATCo

RA#14: Further improvements of Safety Assessment approach steps: The Safety Assessment approach consists of three steps (Hazard identification, Risk assessment and Risk mitigation). Hazard Identification is based on brainstorming sessions, considered to be the most suitable of available methods. Possible direction for further research is proposing new method(s) that would enable more systematic approach and wider coverage in hazards identification process. Related to risk assessment, further research should be focused in finding a stronger connection between mental workload model and severity/likelihood. And finally, the risk matrices have mathematical and logical limitations to be amended, primarily related to defining borders of acceptable, tolerable and unacceptable risk areas.

Potential stakeholders: Research Centres/Universities, ECTRL

RA#15: Development of new methodology for Safety Assessment of future ATM: The best available methodologies which exist today, recognized by ICAO and EUROCONTROL, are used in AUTOPACE. They are commonly used for safety assessment not only of the current system, but also of the future systems (no matter how far that future is – it is important to have a notion the system definition). Anyway, it is worthy research on new methodologies or adaptation of current ones to be applied in high automation environments on long term horizon that is associated with high uncertainties. Suitability of the methodology for such cases could be improved.

Potential stakeholders: Research Centres/Universities, ECTRL

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Appendix A

A.1 Acronyms and Terminology

Term	Definition
ACARE	Advisory Council for Aviation Research and Innovation in Europe
AIM	Assessment of the Impact of Change in Automated ATM Systems on Mental Workload
ALERFA	Alert Phase
ALRS	Alerting Service
ANS	Air Navigation Service(s)
ARES	Airspace REServation
ATC	Air Traffic Control
ATCO	Air Traffic Control Operator
ATM	Air Traffic Management
ATS	Air Traffic Services
BT	Business Trajectory
CAP	Capacity
CDM	Collaborative Decision Making
CEFF	Cost-Efficiency
COMETA	COgnitive ModEl for aTco workload Assessment
CONOPS	Concep of Operation
DCB	Demand Capacity Balancing
DFS	Deutsche FlugSicherung
DSS	Decision Support System
ECAC	European Civil Aviation Conference
ENAC	Ecole Nationale de l'Aviation Civile
ER	Exploratory Research
EREA	Association of European Research Establishments in Aeronautics

Term	Definition
FMS	Flight Management System
FRAM	Functional Resonance Analysis Method
FTS	Fast-Time Simulation
HAZID	Hazard Identification
HF	Human Factors
HMI	Human-Machine Interface
HP	Human Performance
ICAO	International Civil Aviation Organization
ID	Identification
IFR	Instrumental Flight Rules
ISA	Instantaneous Self-Assessment methodology
ISBN	International Standard Book Number
KPA	Key Performance Area
KSA	Knowledge, Skills, Abilities
LFV	Luftfartsverket
LTM	Local Traffic Management
MART	Malleable Attentional Resources Theory
MIDAS	Man-machine Integration Design analysis System
MP	Mental Picture
MTCDT	Medium-Term Conflict Detection Tool
MWL	Mental Workload
NN	Non-Nominal situations
OCVM	Operational Concept Validation Methodology
OJT	On-the-Job Training
ONERA	Office National d'Étude et de Recherche Aéronautique
OOTL	Out-Of-The-Loop

Term	Definition
PHA	Preliminary Hazard Assessment
PMP	Project Management Plan
RAMS	Reorganised ATC Mathematical (Model) Simulator
RBT	Reference Business Trajectory
RMT	Reference Mision Trajectory
SA	Situational Awareness
SAP	Skills, Abilities, Personality characteristics
SESAR	Single European Sky ATM Research Programme
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SRIA	Strategic Research and Innovation Agenda
SWIM	System-Wide Information Management
TCT	Tactical Controller Tool
TRB	Transportation Research Board
TRL	Technology Readiness Level
USA	United States of America
WAC	World ATM Congress
WP	Workpackage

Table 13: Acronyms and technology

Appendix B AUTOPACE Experimental Plan

For the elaboration of plans to continue with further research, AUTOPACE has produced a preliminary experimental plan to validate main hypotheses identified in the project (Section 2.4.2.3).

Furthermore, as AUTOPACE is a project tightly related with other Exploratory Research Projects addressing the same call on Automation, namely MINIMA and STRESS, coordination activities have been performed with these two projects. As a result of this coordination, their complementary areas have been identified and further objectives have been built upon (Section 4.2.2).

B.1 Setting Hypothesis and Experimental Plan

Fundamental scientific research should start by proposing scientific hypotheses based on the basic sciences. These hypotheses should be derived from empirically developed theories and knowledge in these basic sciences and, then, must be validated empirically according to an experimental plan designed for this purpose.

The experimental plan to validate scientific hypotheses must fulfil several requirements. Firstly, the concepts on which the hypotheses are raised must be well defined in the context of the scientific theories relevant to the research domain and, also, to the context of application of the research. Then, once the concepts have been theoretically well defined, they should be operationalized in order to allow being measured as well as being manipulated and observed according to a standard experimental procedure. Without this operationalization it would had not been possible to measure the effects of automation hypothesized in AUTOPACE.

Following these requirements, the theories of attentional resources employed in the ATCo Psychological Model have served not only to define the hypothesis of automation effects on ATCo performance but also to describe the competences that must be trained in the future scenarios of automation supported by a preliminary hazard assessment

Therefore, in the methodology employed, the procedures to manipulate the complexity of the task (the demanded resources) have been addressed as well as the level of arousal and engagement (the available resources) in order to set the hypotheses. Then, they have served to measure the predicted probabilities of observing OOTL, erratic or panic behaviour in the future automation scenarios. These measures are also useful to check if with appropriate training the risk to observe these effects is reduced.

Finally, it must be pointed out a difficulty presented in designing an experimental plan to test the hypotheses described in AUTOPACE. This difficulty stems from the fact that the proposed hypotheses about future scenarios are not well defined. For example, there is some uncertainty about which features of the automatic systems will be designed in the future.

B.1.1 Objectives of the experimental plan

In AUTOPACE, the effects of automation refer fundamentally to the concept of Mental Workload. This concept is defined as the relation of the mental resources demanded by the task and the mental resources that the ATCo has available to perform it. The resources demanded are calculated from the cognitive processing of traffic parameters and the operational environment in which ATCo performs its task. On the other hand, the available resources depend on the level of arousal and the engagement of ATCo while performing the task. The objective of the experimental plan is to develop the hypothesis needed to predict this Mental Workload in order to determine the effects of automation in the control task. Since demanded resources depend on the environment, these hypotheses have been developed considering the available resources employing psychological theories of attention. In this way, the hypotheses are related to:

- Demanded mental resources;
- Level of activation; and
- Engagement

Besides, the objective of the experimental plan is to check if with the different training strategies to acquire the required competences for future ATCo, the negative effects of automation on the ATCo performance are at least mitigated. During the preliminary hazard and safety assessment, some risks were said not to be mitigated with training. Therefore, these hypotheses are related to Training. As the catalogue of possible training strategies (technical and psychological is extent, the hypothesis are high level to ensure they cover major training solutions.

B.1.2 Definition of main elements of the experimental plan

Technical infrastructure/Validation Platform supporting the experimental plan

Ideally, to improve the significance of the measurements, the platform should be a High fidelity platform to run a Real Time Simulation where an ATCo position would be implemented having the possibility to activate or deactivate functions depending on automation capabilities (High, Medium Automation). As the development of such a high fidelity platform could be unaffordable, other medium fidelity platforms could be used for measurement emulating the degree of automation with external instructions or interactions from a different position.

Human resources requirements for the experimental plan

The sample for the experimental research must be built of professional ATCo. The potentially different levels of seniority of ATCo are expected to have a significant impact on performance and influence experimental outcome. It can be assumed that higher expertise and experience of the ATCo may positively affect performance. However, when considering the response to new automated systems, senior ATCo may not necessarily show more significant performance improvements than less experienced ATCo.

The number of years of working experience as an ATCo is likely to be an experimental factor worth to be investigated throughout the duration of the project. However, high number of variables already involved in the experimental design, in first steps of the future experimental plan, seniority is controlled by sampling ATCo with a pre-established or average number of years of working experience.

Planning of test and exercises

The hypotheses about the effects of automation on the available resources and the level of activation and engagement have to be tested by observing the dependent measures relevant to each hypothesis. These dependent measures are:

- Performance Measures (Time to detect the system failure, how to go back in control)
- Psycho-physiological Measures (e.g. hart rate, pupil measures)
- Subjective Measures (ISA – Instantaneous Self-Assessment - methodology)

The demanded resources depend on the complexity of the task. Therefore, anything that affects task complexity would affect the amount of demanded resources. The more prominent factors are occupancy, uncertainty, time pressure and traffic complexity. However, the available resources depend on the level of activation that the ATCo has and on his/her engagement with the task. The following ways of manipulating these two independent factors in the experimental design are proposed:

- Level of activation: Experimentally, the level of activation would be easily manipulated by changing the trust in the reliability of the system. For example, different frequency of system failures could be introduced in the simulation.
- Engagement: Engagement comes from the allocation of responsibilities in the automation scenario. However, it should be kept in mind that each responsibility can be performed within a variable range. For example, monitor is a responsibility with a high variability in its execution and is a responsibility that can more easily lead to OOTL. As independent variable, it could be manipulated by instructions.

Following Table 14 shows a summary of the hypotheses to be validated in further researches with their relevant measures that can be used to validate them.

The validation should be designed to identify the total combined effect: *What factor has more impact on performance, the Level of Activation or the Engagement?*

	Hypothesis to Validate	How	Relevant Measures
Level of Activation	H1: In nominal situations and if the operator **fully trusts** the system, the performance is not affected (MWL constant). Therefore, automation doesn't affect the performance.	Checking if ATCo MWL is stable/constant in both scenarios (High and Medium).	• Performance Measures • Psycho-physiological measures • Subjective Measures
	H1a: **If a failure occurs (H1),** the demanded resources increases, and also the MWL. As a consequence, the ATCo will have higher MWL in High Automation than in Medium and will experiment an Overload.	Analysing if system failures have worse negative impact in High Automated Scenarios than in Medium Automated with the same operational environment.	• Time to detect the system failure • How to go back in control
	H2: In nominal situations and the operator **does not trust** the system, the MWL is reduced with automation. The MWL in High Automation will be lower than in Medium.	Comparing the ATCo MWL in both scenarios	• Performance Measures • Psycho-physiological measures • Subjective Measures
	H2a: **If a failure occurs (H2),** the demanded resources increases, and	Analysing if system failures have worse	• Time to detect the system

	Hypothesis to Validate	How	Relevant Measures
	also the MWL but this MWL will be lower that when feeling overconfidence. Apparently, in High Level Automation Scenarios, it is better to feel some fear of automation than overconfidence.	negative impact in High Automated Scenarios than in Medium Automated with the same operational environment.	failure • How to go back in control
Engagement	H3: The engagement reduces the available resources with automation but also the demanded resources decrease with automation, then, the performance is not affected (MWL constant). Therefore, automation doesn't affect the performance.	Checking if ATCo MWL is stable/constant in both scenarios (High and Medium).	• Performance Measures • Psycho-physiological measures • Subjective Measures
H4: The most influencing factor on ATCo performance is the engagement with the task meaning no increase of MWL with automation		Comparing results from H1, H2 and H3 and checking if MWL is constant in both Scenarios.	• Performance Measures • Psycho-physiological measures • Subjective Measures
H5: Technical and Psychological Training Strategies will help ATCo to keep the performance in an optimum (optimum level of MWL).		Per training strategy, comparing ATCo MWL before and after the training	• Performance Measures • Psycho-physiological measures • Subjective Measures

Table 14: Hypothesis to validate and relevant measures

The hypothesis should be tested in experiments with within-subject designs in which all participants go through all experimental conditions in order to achieve better control for individual differences. However, due to the large number of conditions AUTOPACE suggest using an incomplete balanced design in which it would not be needed all factorial conditions while still controlling for order and transfer effects.

	Future Automation Scenarios	Current Automation Scenarios
High Automation Scenario	• Nominal and non –nominal without training; • Nominal and non –nominal with training	• Baseline Scenario • Reference Scenario

	Future Automation Scenarios	Current Automation Scenarios
Medium Automation Scenario	• Nominal and non –nominal without training; • Nominal and non –nominal with training	

Table 15: Scenarios and situations for experimental plan

The experimental plan must be developed in line with the structure of this document. ATM operation under both automation scenarios, taking also into account nominal and non-nominal situations, must be investigated within the scope of the conceptual framework previously described. ATCo performance should be evaluated according to baseline and reference ATM simulated scenarios, for both automation levels (high and medium) and under nominal and non-nominal situations. Besides, different training strategies need to be implemented to validate its appropriateness.

B.2 Identification of risks associated with the experimental plan

Issues to be carefully addressed when designing an experimental study are well described in literature. From the wide range of such issues, the following ones are considered particularly relevant for the setting up and execution of the AUTOPACE experimental plan:

- Sample size: experimental studies tend to become unfeasible when considering large samples, mainly due to time availability and costs. A trade-off must be achieved between such limitations and the need for scientific robustness and in particular statistical validity. The factors being tested under this study, namely human psychological and physiological parameters are prone to a particularly significant variability, both between two different individuals and for one given individual throughout time. This means that samples sizing must take into account the different types and ranges of the relevant human "intra" and "inter" variability.
- Sampling method: Human diversity must also be taken into account when planning the study sample. The sampling method should aim to include in the study the different levels of training and expertise, as well as the wide diversity of behavioural traits and health related aspects that could impact on performance, thus potentially introducing a bias in the experiment outcome.
- Trustworthiness of dependent variables: AUTOPACE is grounded on numerous assumptions regarding the foreseeable technological components to be introduced in ATC. At this stage of development, many operational aspects can only be approximately estimated. Most of the factors addressed in the experimental plan have been considerably explored under previous experimental research, and are well documented in literature in terms of their relation to specific human behaviours and performance aspects. This means that the variables at stake here be said to have scientific validity towards the scope and objectives of plan defined. However, the numerous assumptions that are at base of the experimental scenarios could raise issues in terms of the trustworthiness of the variable being measured. This means that particular care should be taken to ensure that the factors being measured are in fact related to performance aspects that are relevant within the foreseeable ATC scenarios and operational processes.

Appendix C Skills, Abilities and Personality Characteristics for selection of future ATCo

AUTOPACE has researched on the future competences needed for an ATCo to comply functions identified in future automation scenarios along with the training strategy to achieve these competences. The basis for the training success is the previous trainee abilities and personality, that helps to achieve the training objectives [37], represented in Figure 19.

1. The bases for acquiring competences are the individual characteristics and abilities that are required to become an ATCo.
2. Next, the fundament is extended by acquiring the knowledge, skills and attitudes learned during Simulation Training and results in basic competences.
3. These basic competences are a combination of technical, cognitive and non-cognitive capabilities.
4. These basic competences are further expanded in Unit Training (simulator training and on-the-job training) into operational competences, accompanied by additional knowledge where needed and continuous training.

So, to develop the competences for handling a variety of situations in air traffic control, some prerequisites have to be met. These prerequisites refer to the required basic competences, the previous skills and the personal characteristics and abilities.

The personal characteristics and abilities needed for ATC are part of selection criteria. The knowledge, basic competences and basic skills that are needed can be divided into three areas:

- **Previous Skills**: Previous Skills are developed capacities that facilitate learning and acquiring competences.
- **Abilities**: Abilities are enduring attributes of an individual that influence performance for training.
- **Personality**: Personality is personal characteristics that can affect how well someone performs the ATCo functions.

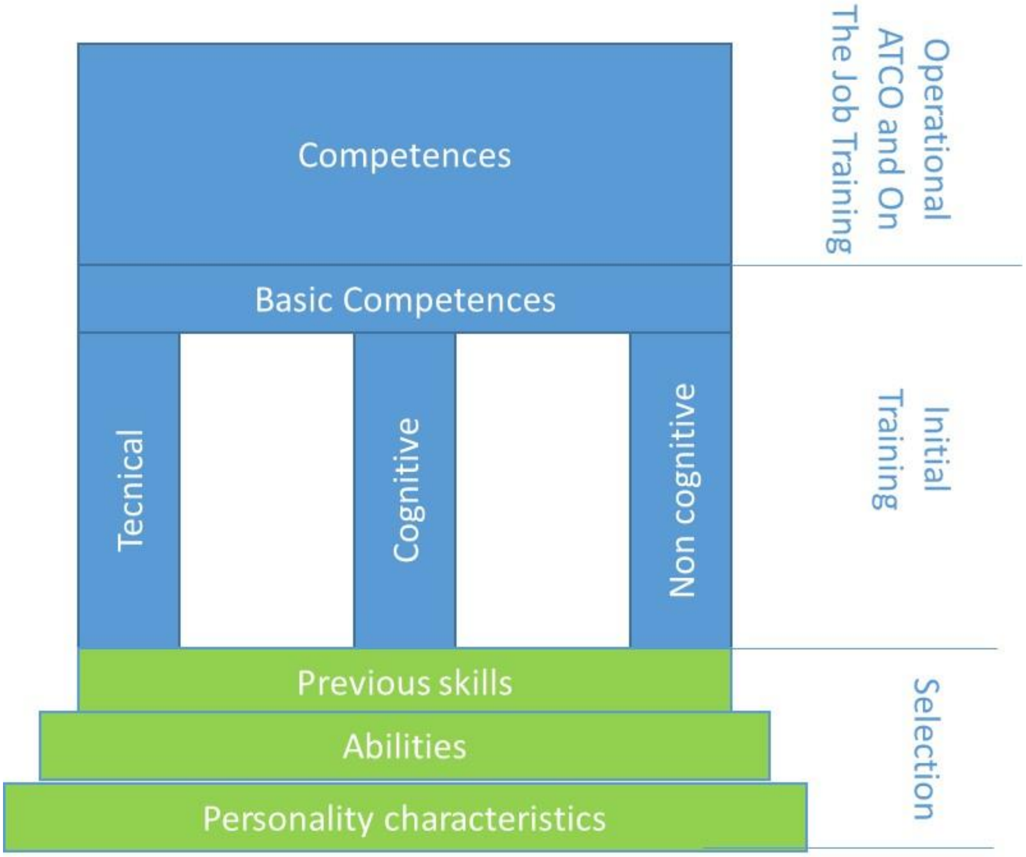

Figure 19: ATCo Psychological Model and relationship with Training

Prerequisites analysis involves determining the Previous Skills, Abilities and Personality characteristics (SAP) defined as conditions for the trainee. To successfully complete de training program there are certain Previous Skills, Abilities and Personality characteristics (SAP) that a person requires.

SAP can be described as enduring skills or abilities and/or trait-like features. The prerequisites competences and characteristics help identify which applicants are most likely able to perform a successful training process.

Taking into account results from D3.2, AUTOPACE identifies the next KSA for the trainee candidate. For the next paragraphs, first it is defined the complete set of prerequisites, and after it the relation with the future competences.

C.1 Previous Skills

Previous Skills are developed capacities that facilitate learning and acquiring competences. They consist of:

- **Active listening**: Giving full attention to what other people are saying, taking time to understand the points being made, asking questions as appropriate, and not interrupting at inappropriate times.
- **Speaking**: Talking to others to convey information effectively.

- **Critical Thinking**: Using logic and reasoning to identify the strengths and weaknesses of alternative solutions, conclusions or approaches to problems.
- **Judgment and Decision Making**: Considering the relative costs and benefits of potential actions to choose the most appropriate one.
- **Complex Problem Solving**: Identifying complex problems and reviewing related information to develop and evaluate options and implement solutions.
- **Monitoring**: Monitoring/Assessing performance of yourself, other individuals, or organizations to make improvements or take corrective action.
- **Coordination**: Adjusting actions in relation to others' actions.
- **Active Learning**: Understanding the implications of new information for both current and future problem-solving and decision-making.
- **Reading Comprehension**: Understanding written sentences and paragraphs in work related documents.
- **Time Management**: Managing one's own time and the time of others.
- **Social Perceptiveness**: Being aware of others' reactions and understanding why they react as they do.
- **Operation Monitoring**: Watching gauges, dials, or other indicators to make sure a machine is working properly.
- **Systems Analysis**: Determining how a system should work and how changes in conditions, operations, and the environment affect outcomes.
- **Instructing**: Teaching others how to do something.
- **Learning Strategies**: Selecting and using training/instructional methods and procedures appropriate for the situation when learning or teaching new things.
- **Service Orientation**: Actively looking for ways to help people.
- **Systems Evaluation**: Identifying measures or indicators of system performance and the actions needed to improve or correct performance, relative to the goals of the system.
- **Writing**: Communicating effectively in writing as appropriate for the needs of the audience.

C.2 Abilities

Abilities are enduring attributes of an individual that influence performance for training. They consist of:

- **Problem Sensitivity**: The ability to tell when something is wrong or is likely to go wrong. It does not involve solving the problem, only recognizing there is a problem.
- **Oral Comprehension**: The ability to listen to and understand information and ideas presented through spoken words and sentences.
- **Oral Expression**: The ability to communicate information and ideas in speaking so others can understand.

- **Selective Attention**: The ability to concentrate on a task over a period of time without being distracted.
- **Deductive Reasoning**: The ability to apply general rules to specific problems to produce answers that make sense.
- **Flexibility of Closure**: The ability to identify or detect a known pattern (a figure, object, word, or sound) that is hidden in other distracting material.
- **Inductive Reasoning**: The ability to combine pieces of information to form general rules or conclusions (includes finding a relationship among seemingly unrelated events).
- **Speed of Closure**: The ability to quickly make sense of, combine, and organize information into meaningful patterns.
- **Far Vision**: The ability to see details at a distance.
- **Near Vision**: The ability to see details at close range (within a few feet of the observer).
- **Perceptual Speed**: The ability to quickly and accurately compare similarities and differences among sets of letters, numbers, objects, pictures, or patterns. The things to be compared may be presented at the same time or one after the other. This ability also includes comparing a presented object with a remembered object.
- **Speech Clarity**: The ability to speak clearly so others can understand you.
- **Time Sharing**: The ability to shift back and forth between two or more activities or sources of information (such as speech, sounds, touch, or other sources).
- **Information Ordering**: The ability to arrange things or actions in a certain order or pattern according to a specific rule or set of rules (e.g., patterns of numbers, letters, words, pictures, mathematical operations).
- **Speech Recognition**: The ability to identify and understand the speech of another person.
- **Written Comprehension**: The ability to read and understand information and ideas presented in writing.
- **Category Flexibility**: The ability to generate or use different sets of rules for combining or grouping things in different ways.
- **Auditory Attention**: The ability to focus on a single source of sound in the presence of other distracting sounds.
- **Visualization**: The ability to imagine how something will look after it is moved around or when its parts are moved or rearranged.
- **Fluency of Ideas**: The ability to come up with a number of ideas about a topic (the number of ideas is important, not their quality, correctness, or creativity).
- **Originality**: The ability to come up with unusual or clever ideas about a given topic or situation, or to develop creative ways to solve a problem.
- **Written Expression**: The ability to communicate information and ideas in writing so others can understand.

- **Memorization**: The ability to remember information such as words, numbers, pictures, and procedures.
- **Number Facility**: The ability to add, subtract, multiply, or divide quickly and correctly.
- **Visual Colour Discrimination**: The ability to match or detect differences between colours, including shades of colour and brightness.

C.3 Personality

Personality is personal characteristics that can affect how well someone performs the ATCo functions. They consist of:

- **Attention to Detail**: To be careful about detail and thorough in completing work tasks.
- **Stress Tolerance**: To accept criticism and dealing calmly and effectively with high stress situations.
- **Dependability**: To be reliable, responsible, and dependable, and fulfilling obligations.
- **Adaptability/Flexibility**: To be open to change (positive or negative) and to considerable variety in the workplace.
- **Persistence**: Persistence in the face of obstacles.
- **Achievement/Effort**: To establish and maintain personally challenging achievement goals and exerting effort toward mastering tasks.
- **Analytical Thinking**: To analyse information and using logic to address work-related issues and problems.
- **Self-Control**: Job requires maintaining composure, keeping emotions in check, controlling anger, and avoiding aggressive behaviour, even in very difficult situations.
- **Cooperation**: Job requires being pleasant with others on the job and displaying a good-natured, cooperative attitude.
- **Initiative**: Job requires a willingness to take on responsibilities and challenges.
- **Integrity**: Job requires being honest and ethical.
- **Independence**: Job requires developing one's own ways of doing things, guiding oneself with little or no supervision, and depending on oneself to get things done.
- **Leadership**: Job requires a willingness to lead, take charge, and offer opinions and direction.
- **Concern for Others**: Job requires being sensitive to others' needs and feelings and being understanding and helpful on the job.
- **Innovation**: Job requires creativity and alternative thinking to develop new ideas for and answers to work-related problems.
- **Social Orientation**: Job requires preferring to work with others rather than alone, and being personally connected with others on the job.

The prerequisite identified in AUTOPACE are related with future competences. Some of the prerequisite apply over more than one competence, and others are specific prerequisite for a particular competence. Based on previous research on future competences and training strategies and the operational expertise of AUTOPACE partners, an assignation of prerequisites and future competences have been done, distinguishing between medium and high automation scenarios.

Based on the different competences expected for Medium and High Automation Scenarios and the different prerequisites demanded for the selection of future ATCo, Table 16 and Table 17 show a comparison between both scenarios for Previous Skills, Abilities and Personality Characteristics Categories.

MEDIUM AUTOMATION SCENARIO		COMPETENCES						
		SITUATION ASSESSMENT	TRAFFIC MANAGEMENT	COMMUNICATION	COORDINATION	PROBLEM SOLVING AND DECISION MAKING	WORKLOAD MANAGEMENT	INDIVIDUAL ASPECTS OF PERFORMANCE
PREVIOUS SKILLS	Active listening			x	x			x
	Speaking			x	x			
	Critical Thinking	x	x			x		
	Judgement and Decision Making	x	x			x		
	Complex Problem Solving	x	x			x	x	
	Monitoring	x	x	x	x		x	x
	Coordination	x	x	x	x		x	x
	Active learning	x	x			x	x	x
	Reading Comprehension	x	x			x	x	x
	Time Management						x	x
	Social Perceptiveness			x	x			x
	Operation Monitoring	x			x			
	System Analysis	x			x			
	Instructing			x	x		x	x
	Learning Strategies						x	
	Service Orientation				x		x	x
	System Evaluation				x			
	Writing			x	x			
ABILITIES	Problem Sensitivity	x	x				x	x
	Oral Comprehension	x		x	x			
	Oral Expression	x		x	x			
	Selective attention		x				x	
	Deductive Reasoning		x			x		
	Flexibility of Closure	x	x			x	x	x
	Inductive Reasoning	x	x			x	x	x
	Speed of Closure	x	x				x	x
	Far Vision	x						
	Near Vision	x						
	Perceptual Speed	x	x			x		
	Speech Clarity			x	x			
	Time Sharing						x	
	Information Ordering						x	x
	Speech Recognition			x	x			
	Written Comprehension	x		x	x			
	Category Flexibility		x	x	x	x	x	
	Auditory Attention							
	Visualization	x	x					
	Fluency of Ideas	x						
	Originality					x		x
	Written Expression			x	x			
	Memorization					x		
	Number Facility					x		
	Visual Colour Discrimination	x						
PERSONALITY	Attention to Detail		x					
	Stress Tolerance							x
	Dependability							x
	Adaptability/Flexibility			x	x			
	Persistence		x					
	Achievement/Effort							x
	Analytical Thinking	x	x					
	Self-Control			x	x			x
	Cooperation			x	x			x
	Initiative		x	x	x			x
	Integrity			x	x			x
	Independance				x			x
	Leadership			x	x			x
	Concern for Others			x	x			x
	Innovation							x
	Social Orientation			x	x			x

Table 16 ATCo prerequisites and future competences for Medium Automation Scenario

HIGH AUTOMATION SCENARIO		COMPETENCES				
		IDENTIFICATION	MONITORING	SITUATION COMPREHENSION	WORKLOAD MANAGEMENT	INDIVIDUAL ASPECTS OF PERFORMANCE
PREVIOUS SKILLS	Active listening	x				x
	Speaking	x				
	Critical Thinking		x	x		
	Judgement and Decision Making		x	x		
	Complex Problem Solving		x	x	x	
	Monitoring	x		x	x	x
	Coordination	x			x	x
	Active learning	x		x	x	x
	Reading Comprehension	x		x	x	x
	Time Management				x	x
	Social Perceptiveness			x		x
	Operation Monitoring		x	x		
	System Analysis		x	x		
	Instructing				x	x
	Learning Strategies				x	
	Service Orientation				x	x
	System Evaluation		x	x		
	Writing	x				
ABILITIES	Problem Sensitivity	x	x	x	x	x
	Oral Comprehension			x		
	Oral Expression			x		
	Selective attention		x		x	
	Deductive Reasoning		x			
	Flexibility of Closure	x	x		x	x
	Inductive Reasoning	x	x	x	x	x
	Speed of Closure	x	x	x	x	x
	Far Vision			x		
	Near Vision			x		
	Perceptual Speed	x	x	x		
	Speech Clarity					
	Time Sharing				x	
	Information Ordering				x	x
	Speech Recognition					
	Written Comprehension	x	x	x		
	Category Flexibility		x		x	
	Auditory Attention					
	Visualization		x	x		
	Fluency of Ideas			x		
	Originality				x	x
	Written Expression					
	Memorization		x	x		
	Number Facility	x	x			
	Visual Colour Discrimination	x	x			
PERSONALITY	Attention to Detail		x			
	Stress Tolerance				x	x
	Dependability				x	x
	Adaptability/Flexibility			x		
	Persistence		x			
	Achievement/Effort				x	x
	Analytical Thinking	x		x		
	Self-Control				x	x
	Cooperation					x
	Initiative					x
	Integrity					x
	Independance					x
	Leadership				x	x
	Concern for Others				x	x
	Innovation				x	x
	Social Orientation				x	x

Table 17 ATCo prerequisites and future competences for High Automation Scenario

Pre-requisites for future ATCo on Previous Skills category are similar in Medium and High Automation Scenarios (Figure 20). In both scenarios, pre-requisites related with Monitoring, Coordination, Active Learning and Reading Comprehension have, in average, more relevance than the other Previous Skills pre-requisites. Slight differences can be found in Coordination skill as it is more relevant in medium than in high automation. On the contrary, System Evaluation is more relevant in high than in medium scenario.

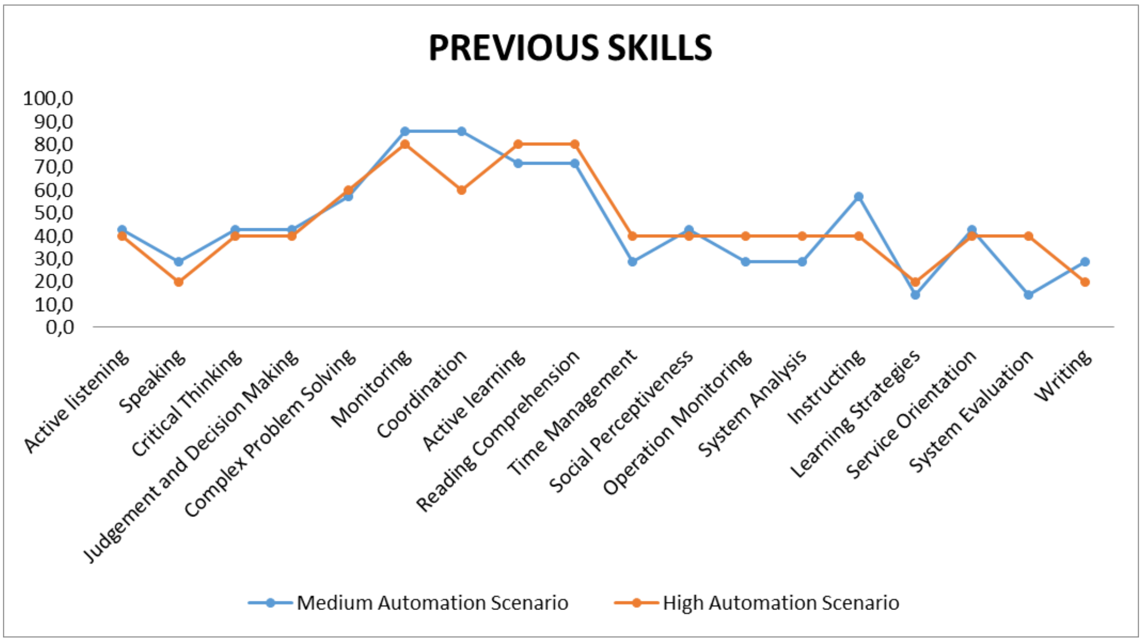

Figure 20 Previous Skills prerequisites for future ATCo in Medium and High Automation Scenarios

Regarding Abilities demanded for the selection of future ATCo (Figure 21), there are Abilities that are not needed to acquire any competences for High Automation Scenarios, namely Speech Clarity, Speech Recognition, Auditory Attention and Written Expression. Auditory Attention is not needed in Medium Automation either.

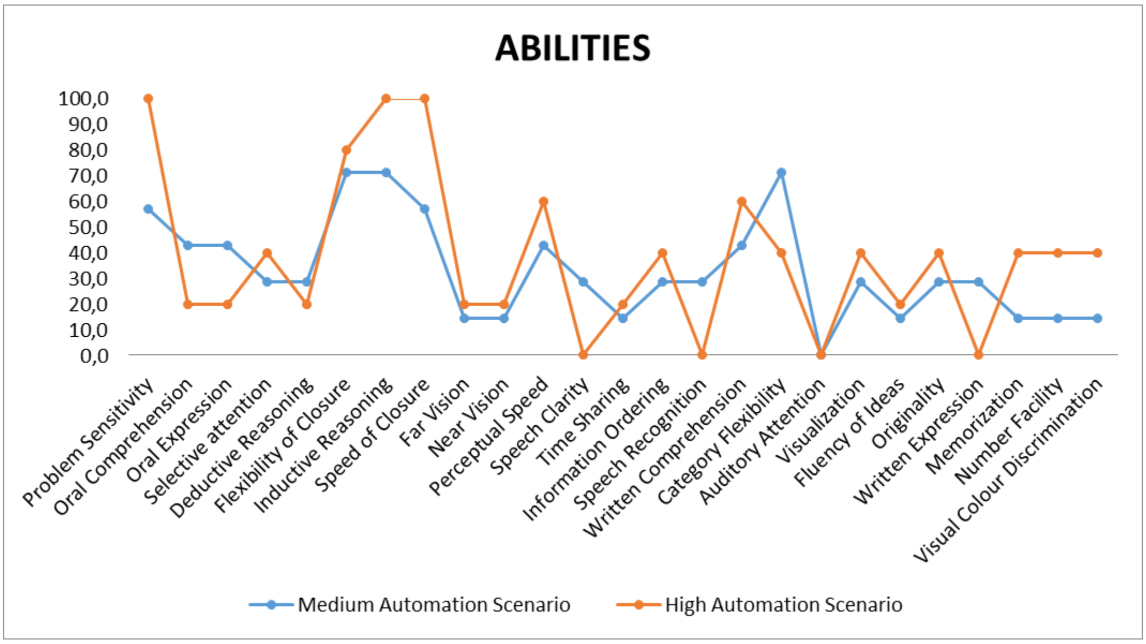

Figure 21 Abilities prerequisites for future ATCo in Medium and High Automation Scenarios

In general terms, except those related with Oral Comprehension and Expression and Category Flexibility, Abilities are pre-requisites more relevant in High than in Medium Automation scenario. Problem Sensitivity, Inductive Reasoning and Speed of Closure are more significant for the acquisition of competences in High Automation Scenario.

With respect to pre-requisites related with Personality Characteristics (Figure 22), for Medium Automation Scenarios, pre-requisites related with teamwork and decision making processes such as Cooperation and Initiative have more relevance that in High Automation. This is consequence of the responsibilities that involve the concept of operation of this scenario, which implies a more active role both with the ATC System and other ATCo. On the contrary, for High Automation Scenarios, the most relevant Personality Characteristics pre-requisites are related to Psychological Non-Cognitive characteristics like Stress Tolerance.

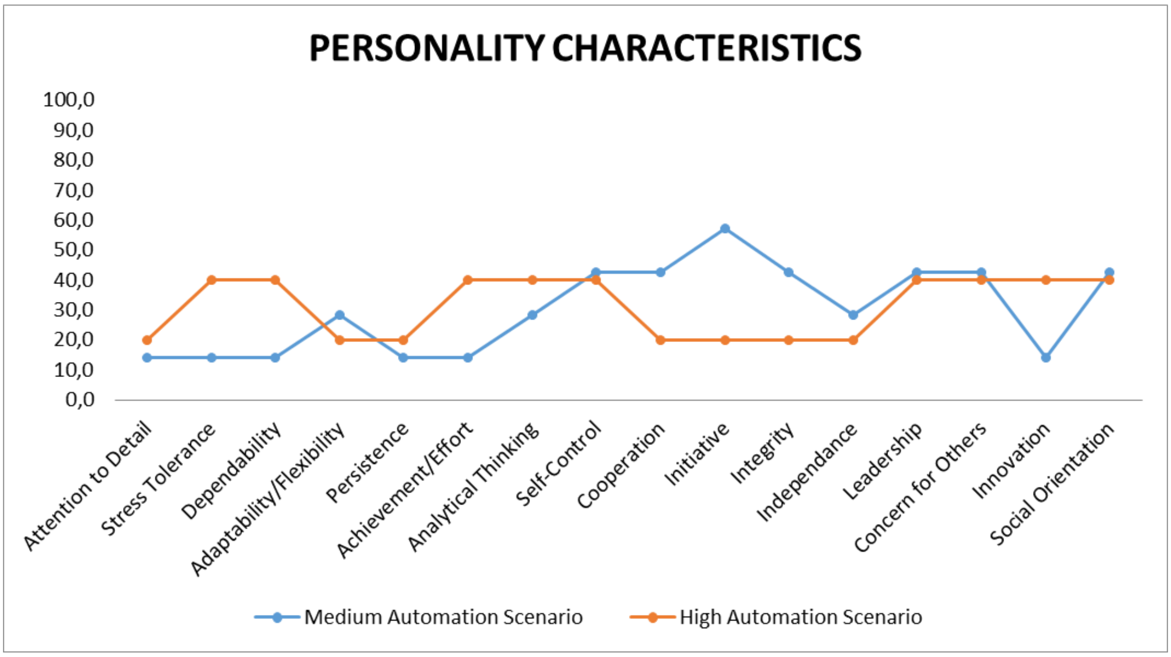

Figure 22 Personality Characteristics prerequisites for future ATCo in Medium and High Automation Scenarios

Appendix D ATCo Personnel Selection

The object of recruiting processes is to attract, screen and recruit suitable ATCo trainee candidates. A clearly defined methodology for recruitment selection processes helps to ensure that all necessary elements are given to consideration and occur in a timely and efficient manner to support an effective and swift selection process.

The selection process is based on a correct function analysis. This is a recruitment activity that occurs prior to assessing candidates for selection: Undertaking functions analysis to determine the recruitment criteria and developing selection criteria and position descriptions based on the functions analysis.

Table 18 depicts the steps to the functions analysis process.

	Step 1	Step 2	Step 3	Step 4
Processes	**Identify future competences**	**Understand the prerequisites**	**Develop Test selection & Test selection criteria**	**Review prerequisite description**
Activity	Develop a list of competences required for the future ATCo position: – defining future functions. – reviewing of current competences.	Develop a list of SAP for the trainee by: – Identifying characteristics related with future competences; – using the capability framework.	– Develop clear and unambiguous ST to assess the degree to which applicants possess the requisite capabilities. – Select or develop recruitment selection techniques that measure the selection criteria.	Develop or modify prerequisite descriptions to reflect the training process results

Table 18: Functions analysis process steps

The key steps are as follows:

1. Identify future competences defined in AUTOPACE.

AUTOPACE has defined the final competence framework for the ATCo

Functions analysis is critical to selection best practice because it is the foundation of a high quality selection process. Functions analysis informs the position description and identifies the selection criteria. A poor functions analysis may adversely affect the quality of outcomes, irrespective of how well the rest of the selection process is executed.

2. Understand the Prerequisites

To have a successful initial training process, the trainee needs previous skills and abilities that are related with the future competences, the Previous Skills, Abilities and Personality characteristics (SAP). These capabilities are the basis for the competences acquisition process.

3. Turn the Previous Skills, Abilities and Personality characteristics into Selection Test (ST)

From the SAPs that have been identified as necessary as the basis for the future competences, develop clear and unambiguous Selection Test (ST), and related selection criteria to assess the degree to which applicants possess the prerequisite.

4. Review prerequisite description

Develop or modify prerequisite descriptions, if needed, after analysing the degree of success of students in the training process. It will be training performance assessment results, and selection results and Selection criteria identified.

D.1 Definition of evaluation process in the selection

Information obtained from undertaking the activities of the functions analysis process is used to develop the selection tests (ST) that is to be used to assess whether applicants have the Previous Skills, Abilities and Personality characteristics (SAP).

ST are used to assess applicants on past behaviours and experiences in order to determine whether they have demonstrated they have the requisite SAP, as opposed to simply saying they meet the criteria. Key considerations in developing ST include:

- Is the ST critical to the trainee (i.e. a must have)? Or is the ST just a bonus if the applicant has it (i.e. a nice to have)?
- ST should be stated in clear and unambiguous language.
- All types of candidates should be able to understand the language being used.
- The criterion should be worded so that the applicant is encouraged to recount a past experience where they have demonstrated a particular SAP.

To define the selection process it could be used two different characteristics:

- Assessment techniques.
- Measurement objective

D.1.1 Assessment techniques

The use of different assessment techniques significantly enhances the selection process and increases the likelihood of a successful hire. The type of tests that could be used for selection purposes are personality, cognitive ability, work styles and motivation. Research indicates [21] that combining cognitive ability tests with a personality test measuring conscientiousness provides a better prediction of work performance than cognitive ability alone.

Cognitive ability

Research indicates [28] that cognitive ability or general mental ability is well-established as the most important predictor of work performance. Testing for cognitive ability is important because it has a direct effect on job knowledge acquisition – individuals who have higher cognitive ability acquire more job knowledge, are able to acquire it faster and are able to compute complex information quickly and accurately.

Generally, the recommended cognitive ability tests are those that test for numerical and verbal reasoning.

Personality assessment

Personality assessment provides insight into an applicant's personal style i.e. how conscientious they are, how well they cope with stress, how they cope with frustration and anger, etc.

It can be an important assessment for evaluating skills related with leadership and management. This is due to the unique insight it provides into how a person is likely to lead others.

Work sample and job knowledge assessment

Work sample tests and job knowledge tests can be used to ascertain specific skill levels required before beginning a position (i.e. skills that cannot be learnt on the job). These two types of tests are quite similar in nature. Job knowledge tests measure critical knowledge areas needed to perform a job effectively and are generally used to assess specific skill sets i.e. technical skills such as IT programming. Work sample tests assess the actual execution of the critical knowledge i.e. they are practically based rather than knowledge based.

Given the work sample or job knowledge test is unique to the role, there is generally no 'off-the - shelf' solution. Tests of this nature need to be specially developed Scoring work sample tests involves trained experts observing and rating behaviour, whereas job knowledge tests are written tests that have right/wrong response options.

D.1.2 Measurement objective

Measurement objective refers to a measurement or assessment process whereby one obtains a quantifiable estimate of some aspect of current performance. Most tests consist of constructed tasks, i.e. specifically designed test items upon which performance is measured. An important distinction between tests relates to the measurement situation where there are two broad categories:

Tests of Maximum Performance

The test takers are expected or instructed to do their best in the test. This category of tests is further sub-divided into:

1. Speed Tests where test takers are requested to work as fast (and accurate) as possible sometimes for a very short period of time. Some ability tests are speeded because a 'true' speed test consists of items which, if given in a longer period of time, would be correctly answered by virtually everybody. Typical test examples are concentration tests, perception speed tests and some tests in an intelligence test battery, etc. The performance measured is typically the number of correctly solved test items. Most ability tests used in an initio trainee selection are speed tests.
2. Power Tests where test takers are requested to solve more complex problems and find the correct answer for them. Power tests are usually untimed and over a longer period of time, where test takers are given as long as they need to complete the test. However, the overall time limits normally allow that all items of the test can be tackled. The performance in the test depends on the knowledge and skills of test takers. Normally, the number of correct

solved items is counted, taking into account guessing. Most achievement tests are power tests. This category of tests is also used in selection of initio trainees (e.g. English knowledge tests, tests for technical understanding).

Habitual Performance Test

The test takers are requested to report or otherwise indicate what they believe or feel, or how they would habitually act in a given situation (e.g. described in a personality questionnaire or inventory).

D.1.3 Selection Test vs Prerequisites

The selection process described in the previous points allows selecting the best applicants with the individual characteristics and abilities needed that allows acquiring the basic competences in a more efficient and quickly manner. These basic competences will be further expanded in the training strategy until they become the operational competences required to become an ATCo. Therefore, the selection process will be important in order to allow that a trainee achieves the future competences required to comply the future functions.

The selection process identifies the appropriate selection text to evaluate every prerequisite. Depending on the prerequisite characteristics, different techniques for assessment can be used (Table 19).

	Cognitive ability	Personality assessment	Work sample and job knowledge assessment
Speed Tests	Reading Comprehension Flexibility of Closure Speed of Closure Far Vision. Near Vision Perceptual Speed Speech Recognition Auditory Attention Visualization Number Facility Visual Colour Discrimination	Monitoring Coordination Time Management Social Perceptiveness Service Orientation Selective Attention Time Sharing Leadership Concern for Others	Operation Monitoring Systems Analysis Problem Sensitivity Information Ordering Attention to Detail Stress Tolerance Self-Control Cooperation Initiative
Power Test	Active listening Speaking Writing Oral Comprehension Oral Expression Inductive Reasoning Speech Clarity	Critical Thinking Active Learning Selective Attention Fluency of Ideas Adaptability/Flexibility Achievement/Effort Leadership	Judgment and Decision Making Complex Problem Solving Systems Evaluation Problem Sensitivity Stress Tolerance Analytical Thinking

	Cognitive ability	Personality assessment	Work sample and job knowledge assessment
	Category Flexibility Memorization	Social Orientation	Integrity Independence Innovation
Habitual Performance Test	Active listening Speaking Instructing Writing Oral Comprehension Oral Expression Deductive Reasoning Memorization Written Comprehension	Critical Thinking Active Learning Learning Strategies Dependability Persistence Originality Written Expression	Judgment and Decision Making Complex Problem Solving Systems Evaluation Problem sensitivity Integrity Independence

Table 19: Relationship between selection tests and prerequisites

Appendix E FRAM Modelling

Understanding the impacts of automation throughout the different sequences of actions and contexts becomes critical to produce meaningful and precise guidance for the future of automation in ATC. To this end, the potential interdependencies between actions and processes were investigated. In particular the availability of information (as a critical resource) and process controls was investigated. A modelling of ATC was produced based on AUTOPACE medium and high automation scenarios. This was then used to produce hypothesis on potential impacts across the network of interdependent actions. This section outlines the methodology used and the outcome produced within the scope of AUTOPACE objectives.

E.1 The Functional Resonance Analysis Method

The Functional Resonance Analysis Method - FRAM [29] is essentially a modelling tool that focuses on system interdependencies, their dynamics and complexity. This tool is grounded on resilience engineering [30] principles and within recent years, has shown to provide an innovative support to the understanding of complex operations and activities. FRAM can be used for both retrospective (i.e. accident and event analysis) and prospective analysis (i.e. systems and operations design). It is based on a description of real work (work as is) based on functions (what must be carried out to achieve a given goal), which then can be used to produce various operational scenarios as instantiations of the model. It is an "abstraction" tool in the sense that it focuses on **what must be carried out** and what is needed (i.e. what resources) to achieve an operational goal, and not so much on how things are carried out. These characteristics of FRAM were considered useful for the pursuit of AUTOPACE objectives, as it, not only provided a basis for comparison between the different scenarios and events under study, but also established a robust relation between the analysis of cognitive aspects based on COMETA lab simulations, and the risk analysis to be carried out in subsequent project tasks. The following subsections elaborate on the key concept of functional resonance, introduce the fundamental of the method, and describe the use of FRAM within the scope of AUTOPACE.

E.1.1 The concept of functional resonance

The theoretical foundations of functional resonance were firstly introduced by Hollnagel (2004) [31]. This concept was developed within the scope of a non-linear and dynamic approach to the safety of complex sociotechnical systems. Rather than the static analysis of processes or components and their sequences in time, the concept of function used conveys aspects of system performance. For the purpose of this discussion a function is regarded as a set of actions that a system performs towards the achievement of a given aim [32].

The phenomenon of resonance in system operations is related to the fact that performance in complex environments is inherently variable in time. Variability can either be the result of short-term fluctuations on resources, demands or working conditions, among others, or slower and longer-term changes such as those depending on economic and commercial relations. Within this context, Hollnagel (2004) [31] describes the slow drifts of systems towards "new norms and emerging tacit standards" and refers as an example the NASA processes of drift into failure [33].

Operations in complex systems are normally underspecified. Thus, carrying out tasks requires tools and formal procedures to be adapted to meet unforeseen (or unforeseeable) operating conditions. Approximate adjustments that are made by people at all levels of organisations (aiming to match operating conditions) must also be considered as sources of variability. In the large majority of cases, these adjustments lead to successful outcomes and only rarely result in undesired events such as incidents and failures. This is clearly demonstrated by most accident rates in complex sociotechnical systems, which are typically beyond 10^{-6} occurrences per number of events [34]. Hence, performance variability must be regarded as a useful resource, as it normally leads to success and only rarely, to failure. The processes that lead to success and failure are essentially the same, only their outcome is different, as “failure is the flip side of success” [30]. While the negative impacts of performance variability have been amply described in relation to many industry domains, the way in which it most frequently encompasses a critical resource is often poorly addressed. Within many industrial domains, in particular those where automation has been acquiring a progressively more prominent operational role such as the aviation industry, this is increasingly recognised as critical area for analysis.

Failure emerges when local variability produces insufficient or inappropriate adjustments to the variability of the environment. The variability of a number of functions may reinforce each other (resonate) and exceed limits of system capacities, which are also subject to variability. Functional resonance results from unforeseen interactions between the normal variability of functions. Normal variability of functions are weak signals and the resonance effect they may produce is the detectable signal, which may or may not exceed system capacities [31].

Functional resonance emphasises the dynamic nature and non-linearity of performance in complex systems. Based on this concept, accident analysis derives from an understanding of both “normal” and unusual functional relations in the system. Rather than aiming to eliminate variability, safety is built around the control of its sources and preventing it from assuming harmful proportions. A system is in control if it is able to minimise to a manageable degree or eliminate undesired variability, or at least, that which is expected to exceed system capabilities. The challenge then resides in providing people and organisations with tools to monitor not only sources of variability from within the system and its environment, but also changes of performance conditions that can lead to variations of system capabilities.

E.1.2 The method

A FRAM model is built based on the description of functions. A system function is something of either a human, technological or organisational nature, which transforms the state of the system towards fulfilling the operational purpose of this system. This introduces in the modelling a diversity of factors relating to system dynamics, which frequently are unobserved within models based on organisational structures or process flows, in particular aspects relating to the types and amplitudes of operational variability.

FRAM takes into account the non-linear nature of performance in complex systems, as opposed to building cause-effect sequences of events in time. FRAM supports risk management by providing an understanding and steering option towards controlling (damping) sources of variability. FRAM is based on four basic principles:

- **Success and failure are equivalent** in the sense that they both emerge from performance variability.
- Variability becomes necessary as a way for people to **adjust** tools and procedures to match operating conditions.

- **Emergence** of either success or failure is not the direct result of variability within a given task or function, but rather to the unexpected combination of variability from multiple functions.
- The unexpected "amplified" effects of interactions between different sources of variability are at the origin of the phenomenon described by **functional resonance**.

The fundamental step in the use of this method is the identification and description of functions. Figure 23 illustrates the functional unit of a FRAM. Each function is defined by six descriptors (time, control, output, resource, precondition and input).

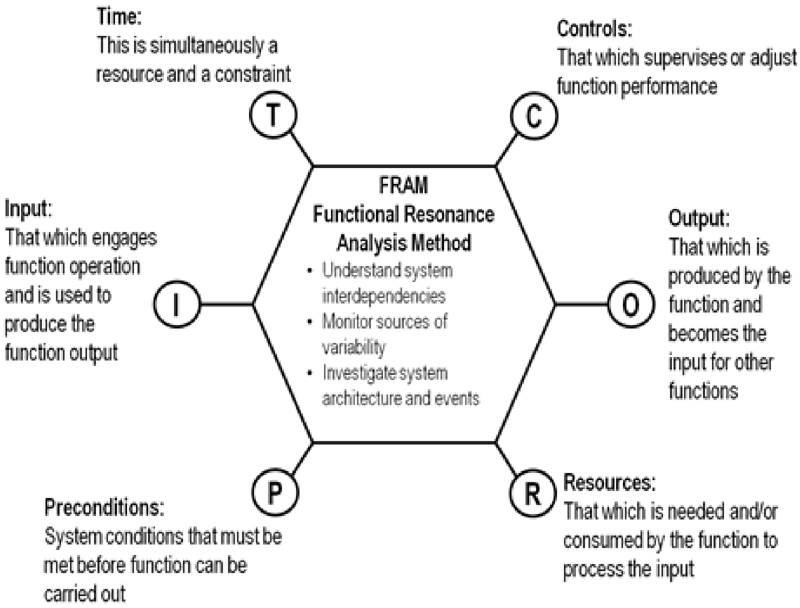

Figure 23: Functional unit of FRAM

Potential sources of variability are then investigated, guided by the identification of context dependent human, technological and organisational aspects. This can then support the assessment of system capacities to cope with variability in view of both expected and unexpected variability emerging from system operation. Variability is mainly assessed according to two dimensions and based on the output of the functions:

- Variability in time: the output is on time or within an acceptable timeframe, too early, too late…
- Variability in quality: the output is up to expected standards, out of expected standards but adequate, unsuitable...

The graphical representation of functions as hexagons becomes useful for the remaining steps of FRAM. Using the six aspects of functions (time, control, output, resource, precondition and input), system interactions are studied, aiming to identify potential sources of resonance. For instance, the output of a function may be the input, a precondition or even enforce a control aspect of another function in the system. This process may also lead to the identification of possible dampening sources for undesired variability. As an example, if resources for a given function are rated as "more than necessary", it could indicate the existence of a "spare capacity" that could operate as a damping barrier.

The process of investigating possible connections between functions, for the identification of both potential undesired variability sources and barriers, is referred to as an instantiation of a FRAM model. These instantiations are essentially a given sequence of activation of all or some of the functions modelled. When functions are activated, it should be because their input became available as an output of other upstream functions. This means that a coupling between this latter upstream function and the former downstream function became effective.

Given its flexible and open nature, FRAM modelling may be used under many different analysis scopes and to respond to a wide diversity of needs. This renders the definition of modelling objectives particularly important, as the obtained model will be closely related to them. Objectives tend to be reflected in the level of detail attributed to certain operational areas of the system being modelled, namely by describing the functions in that area and their aspects in more depth. According to FRAM terminology, these areas are designated as the foreground of the model, whereas the background functions of the model are those for which no input was identified. Hence, the way in which modelling objectives is defined and made explicit, will bear weight on the definition of foreground areas.

FRAM is currently supported by the FRAM Model Visualizer (FMV). The FMV provides the means to build and work with FRAM models, and supports the investigation of different types and sources of variability. A version of this tool is available at “http://www.functionalresonance.com/”.

E.2 FRAM in AUTOPACE

The FRAM model (Appendix C) was developed based on an in-depth understanding of current ATC scenario, and of the transformations that are foreseen as a result of the increased automation, in line with both AUTOPACE automation scenarios. The descriptions of scenarios and the non-nominal situations to be investigated and given in Deliverable D2.1 were used together with the description of actions provided by the AUTOPACE Concept of Operations (ConOps), and the Typical Control Situations (TCS). The impacts of the three non-nominal situations investigated by AUTOPACE were also taken considered. Special attention was given to the need to ensure an alignment between the FRAM analysis process and the AUTOPACE ConOps, as this constitutes the basis for the investigation of automation impacts in ATC. This alignment was fundamental to ensure the validity and coherence of results throughout the various project stages.

The FRAM model that supports the analysis here developed is based on a limited understanding of the profound transformations that enhanced and progressive automation are likely to introduce into ATC processes. As new knowledge arises, this model may be updated in order to support the development of more accurate predictions. The ability to produce a prospective analysis of operational impacts emerging from new automated features may be improved by further knowledge on the design of such features and on the foreseeable changes to the role and responsibilities of the ATCo. On the one hand, the nature of already identified functions may change and with that, new couplings between functions may be identified, or already known couplings may change. On the other hand, new functions may be considered. For instance, the analysis process described in this document did not take into account the transition processes that may be foreseen when a non-nominal situation occurs. As a system failure is detected, ATCo will have to engage in degraded operational modes. Although this was addressed by AUTOPACE under the description of ATCo actions in Deliverable 3.1, the development of the FRAM model did not address in detail these possible degraded operational modes.

Despite the limitations, the following main issues may be anticipated:

- The ATCo capability to monitor and supervise relies on having access to information and data that can support the understanding of traffic situation and of the decisions that are at its origin. To some extent, having knowledge on the criteria and rules that are embedded into system's decision making may be sufficient. In particularly complex cases, knowledge on the actual decision processes may be needed. However, the ability of the system to process information and to handle large volumes of traffic naturally exceeds human ones. The challenge then becomes to provide the ATCo with a flexible access to data and information. Rather than the system providing a pre-defined set of information and data, enabling the ATCo to pull from the system the resources he/she considers meaningful may prove more relevant for the foreseen monitoring and supervisory responsibilities.
- Regarding non-nominal situations, the key issue resides in the ability of ATCo to take over from the failed system feature, whilst ensure the necessary level of response to the remaining system features that remain operational, despite the given failure. On the one hand, system elements must be capable of operating as independent modules, rather than as a fully integrated single unit. On the other hand, these independent system modules must be flexible enough, so as to be capable of operating with, either the remaining system modules, or the ATCo that may take over when one of the modules fails.
- Although the document describes the investigation of non-nominal situations independently, the potential impacts were considered across all three situations. The iterative nature of decision making processes described under conflict detection failure may emerge under different situations. Under a system failure, the supervisory and monitoring capabilities of the ATCo become ever more critical, so as to ensure the decision processes that must be undertaken to take control over the failed system features. If the failure that occurs affects the resources needed for an effective monitoring and supervision, then the decisions that must be made by the ATCo are likely to be more "approximate" rather than "optimal", thus introducing the need for iterations in the process.
- The failure of conflict detection and resolution system may have more significant impacts in terms of operational capacity, as this feature is at the core of traffic control processes. However, other not so "central" elements such as the system supported coordination, may generated more widespread impacts. As earlier observed, some functions may not have a central or immediate role in the core of traffic control decision making processes, but may be providing critical inputs, based on which these decision making processes must be grounded. Although that ATCo may be able to cope with such minor or more localised failures, more complex challenges may emerge from the cascading effects resulting from the tight couplings that functions such as the "coordination with other controllers" are likely to generate.

The analysis process documented here was not initially foreseen in the course of AUTOPACE. Despite the additional work that this represented, the input that it provided to other aspects of project work was considered valuable. On the one hand, some of the functions were not fully explored. Relevant function aspects and the resulting coupling may remain unidentified. On the other hand, additional functions may be identified as a result of a more in-depth investigation and a more thorough validation of the FRAM model that supports this work. Nevertheless, the results achieved demonstrate the added value of this FRAM-based approach. The concept of variability and its underlying uncertainty, together with the notion of functional resonance that may be generated by variability, provide the means to investigate the operational impacts of technology from a novel perspective. The dynamics of complex interactions are introduced. Understanding the potential sources of variability and how it may propagate throughout functional interdependencies goes beyond the conventional linear analysis of causality, hence providing valuable support to risk assessment activities.

The ability to reflect on the potential impacts of enhanced automation under the scope of an integrated operational perspective can support the design of, not only future systems, but also the operational processes that must be contemplated, as the aviation industry progresses from its current technology level to the envisaged ones in 2025 and in 2050.

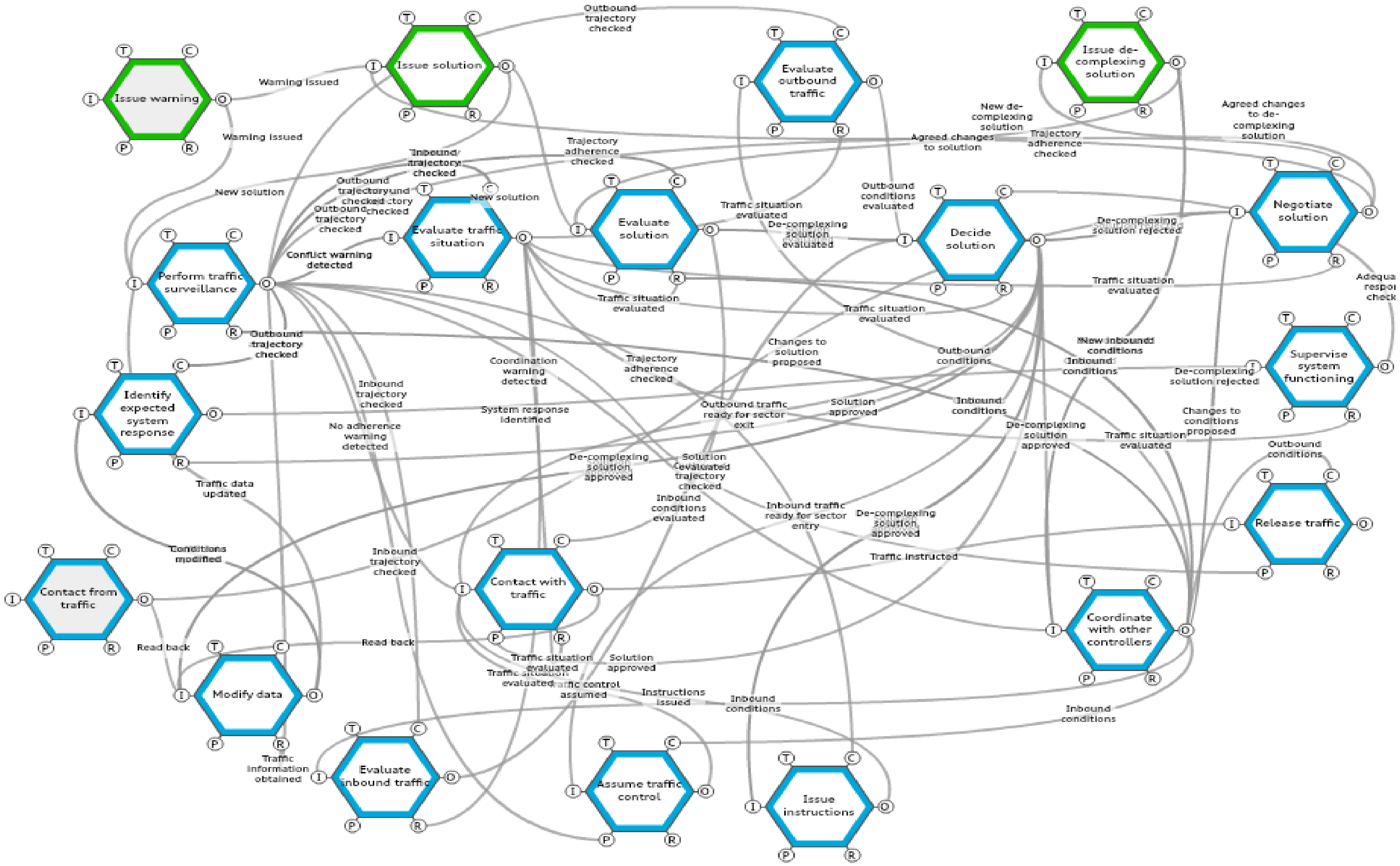

Figure 24 FRAM Model in AUTOPACE