Quantitative prediction of automation effects on ATCo Human Performance

Patricia López de Frutos, Eva Puntero Parla, Elena López Ballestín
CRIDA A.I.E ATM R&D + Innovation Reference Centre
Madrid, Spain

José Juan Cañas, Pedro Ferreira
Mind, Brain and Behaviour Research Centre
University of Granada
Granada, Spain

Fernando Gómez Comendador
Aerospace Systems, Air Transport and Airports Department,
Polytechnic University of Madrid
Madrid, Spain

Francesca Lucchi
Industrial Engineering Department
University of Bologna
Forlì, Italy

***Abstract*— Human operation in highly automated environments has been extensively researched finding out that the human-automation interaction presents serious performance drawbacks due to the risk of the "out of the loop" effect especially in case of automation fail. This paper presents research on a psychological model for Air Traffic Controllers (ATCo) to be computerised to quantitatively predict the automation effects on ATCo performance. The research has been conducted within AUTOPACE project (Grant 699238) funded by the SESAR Joint Undertaking as part of SESAR 2020 Exploratory Research Programme.**

The psychological model is based on the cognitive system function of an ATCo and the required attentional resources for its functioning. The research includes a preliminary quantitative assessment of the cognitive demand expected for the ATCo in highly automated scenarios (2050 time frame horizon) in nominal and no nominal situations. This assessment has been achieved through (a) fast time simulations of future automation scenarios modelling 2050 concept of operation and; (b) psychological cognitive assessment of the ATCo tasks in such scenarios using an existing computational model, COMETA (COgnitive ModEl for aTco workload Assessment). COMETA results reveal how the functional structure and the functioning of the future ATCo cognitive system drastically change with automation.

This paper provides strong justification to invest on further research to improve existing computerised models to predict ATCo performance that will support the design of mitigations.

Keywords-component; Automation, Human Performance, ATCo Psychological Model, Mental Workload, Computerised Models

I. INTRODUCTION

The Air Traffic Management (ATM) system moves towards an increasingly high level of automation [7] which unavoidably will change the Air Traffic Controller (ATCo) work environment. The role of the ATCo will move towards tasks focused on monitoring and supervision of the system 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.

Several research paths are open to solve this issue [8] proposing to (a) perform demonstrations of model-based adaptive automation and benefits for human performance, workload, situational awareness and work motivation, (b) establish the relationships of cognition and automation to approach training and interface design, (c) apply established theories to quantitatively predict optimal states of human-machine symbiosis and provide basis for ensuring system stability and (d) develop training programs for addressing unknown operating circumstances.

AUTOPACE provides a better understanding on how cognition and automation live together to support new training strategies and interface design. 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 [1]. This model would allow prediction of optimal states of human-automation interaction to ensure a safe operation.

The results of psychological model research are potentially expected to be integrated into an existing computational prototype called COMETA (COgnitive ModEl for aTco workload Assessment) developed by CRIDA [16]. Currently COMETA predicts cognitive demand associated to the ATCo tasks and has supported the preliminary analysis in AUTOPACE future automation scenarios.

II. A PSYCHOLOGICAL MODEL TO PREDICT AUTOMATION EFFECTS. COMETA COMPUTATIONAL MODEL

A. *The ATCo Psychological Model*

In AUTOPACE, the ATCo psychological model considers the description of two main components: the *functional* *structure of the ATCo cognitive system* and the attentional resources needed for its *functioning* to carry out the ATCo tasks.

1) *Functional structure of the ATCo cognitive system:* The cognitive system has 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. The reference taken for the ATCo psychological model is proposed by Histon and Hansman [9] (Fig 1) which incorporates aspects to better represent the ATCo activity. This model includes the levels of processing that constitute the Situation Awareness (SA) [4]: perception, comprehension, projection, decision making and execution. The information that the ATCo receives coming from the traffic situation and environment is processed taking into consideration the ATCo long term memory (previous learning and experience). Then, the ATCo will project the current situation into the future to predict how the traffic will evolve and finally, will make decisions to correctly perform the tasks.

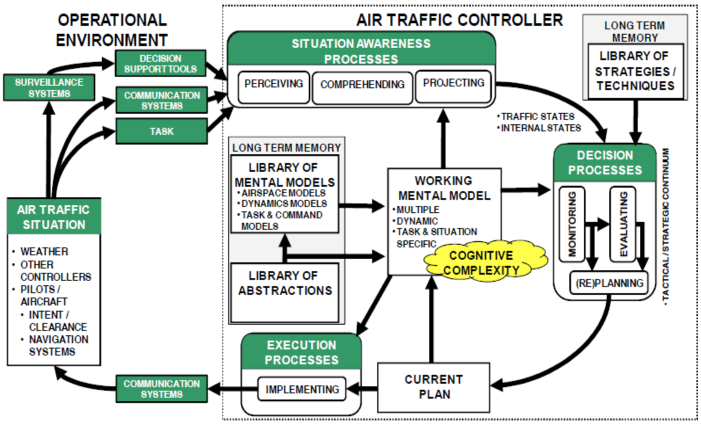

Figure 1. Functional structure of the ATCo cognitive system

2) *Functioning of the ATCo cognitive system- Mental Workload Concept*

The activity of the cognitive processes requires energy [12] and the performance of a task will improve or deteriorate depending, among other things, on the quantity and quality of the energy (attentional resources) supplied [10]. While *demanded resources* are those required by the task and essentially dependent on the task complexity, *available resources* are the resources that the ATCo has that could be used to perform the task and depend on ATCo Level of activation. The cognitive system will work with an efficacy that will depend on the relationship between the demanded and the available resources. This relation is called the *Mental WorkLoad (MWL)* [6]. In current research, it is proposed that the ATCo performance is measured with this definition of MWL.

The quantification of the *demanded resources* is calculated using Wickens's Theory [18] that was refined in [19]. When tasks overlap in time, the demanded resources depend on two main factors:

- The resources demanded for processing each cognitive process: perception, comprehension, projection, decision-making and execution;
- When two tasks are performed in parallel and use the same pool of resources there will be interferences that increase the demanded resources. This increase is the second component of the formula. The interference could be modified by the prioritisation of tasks.

$$Demanded\ resources = \sum_{c=1}^{u} w_c + \sum_{c=1}^{n} \sum_{d=c+1}^{N} i^{(c,d)} \quad (1)$$

w_c= resources demanded by channel: perception (visual, auditory), comprehension, projection, decision-making, respond (manual or verbal) $i^{(c,d)}$= interference between channels c and d

The pool of available resources could be of different dimensions depending on a number of psychological factors such as stress, fatigue, emotions, etc., all being factors that affect the level of activation or arousal. But also engagement with the task, trust on the system and training affects the amount of available resources allocated to perform a task.

3) *Automation impact on the Cognitive Processes and MWL*

Automation understood as a change in the "function allocation" between human and system means that there is a type of processing that the human previously used to do and now the automatic system does, hence a different use of the cognitive processes will occur.

Regarding the effect of automation on attentional resources (demanded and available), according to established attentional theories, the impact of automation will be different. Following the classical theory (Kahneman) [10] automatic systems only reduce the task complexity and hence the demanded resources. But theories such as the Malleable Attentional Resources Theory (MART) [21] assume that automation impacts not only the demanded resources but also the available resources depending on the human trust on the system. When the operator expects that the task will be easy and trusts the system, she/he will reduce the available resources (low level of activation) and there would be more risk of OOTL effect. On the contrary, if the ATCo feels fears of automation failing because the ATCo does not trust the system, the level of activation would increase and then the amount of available resources. In this situation the likelihood of panic and erratic behaviour will be high.

In turn, different levels of automation would mean different responsibilities and therefore different levels of engagement with the task [11]. With high automation levels where ATCo tasks are mainly monitoring less engagement with the task is expected and there will be less available resources dedicated to the task (more risk of OOTL effect). On the contrary, when the ATCo has the responsibility for applying actions, he/she has more engagement with the task (more activation levels) and more probability of being affected by fear of failure.

4) How to analyse automation impact on ATCo MWL?

These different attentional theories set different factors that impact simultaneously on cognitive processes and attentional resources (task complexity, fatigue, stress, emotions, trust, engagement). A scientifically validated method is needed to analyse the different impacts of these factors on total MWL.

An alternative to the methods designed to obtain empirical data to test the hypotheses that are derived from a theoretical model, the "Computational Method" [15] consists of developing a computer model in which the psychological model is implemented. With such a computer model is possible to run computer simulations where the hypothesis derived from the model could be tested. To be able to do that it is necessary that the computer model integrates the cognitive mechanisms responsible for the behaviour of the human actor, the task and the environmental situation in which that task is performed. The hypotheses derived from the model are validated when the computer model responds in the way a human ATCo would respond in that task and traffic and environmental situations.

B. COMETA Computational Model

COMETA is a prototype researched, developed and calibrated within internal CRIDA projects for ENAIRE and for SESAR programme to estimate and predict cognitive demand applied to complexity management concepts[13][14]. COMETA foundations share the *functional structure* and the *functioning of the ATCo cognitive system* models defined in AUTOPACE [2] but for being a prototype not all the sub-models are incorporated.

COMETA algorithm estimates the demanded resources of ATCo tasks following Wickens's and McCarley's Theory [19] taking into account the required cognitive processes to perform the ATCo tasks. What is not incorporated yet is the available resources calculator that is dependent on the ATCo level of activation. Fig 2 shows the COMETA functional architecture highlighting in light blue what is currently developed.

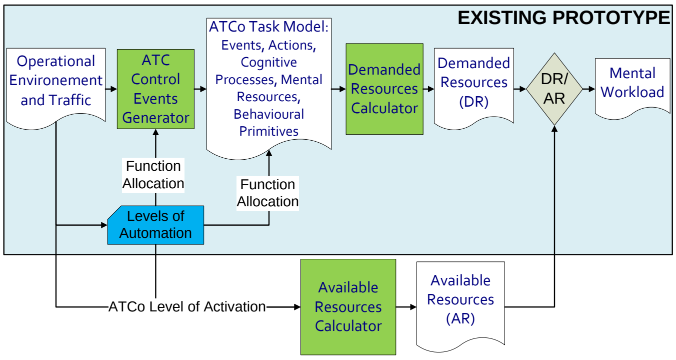

Figure 2. COMETA Functional Architecture

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 would be 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.

1) COMETA Model inputs: ATCo task Model

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

- **ATC Control Events** are 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 that might be acquired in real-time or post- processing or generated through simulation.
- **Actions:** They are observable behaviours that can be defined as the "behaviour of an actor directed to an objective" [17]. The actions are carried out with the implication of cognitive processes that consume attentional 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. For example, TABLE I identifies the behavioural primitives linked to the execution process (manual and verbal) of an ATCo interacting with the system interface.

Usually the ATCo Task Model is a representation of a typical ATCo who is fully trained. The actions and behavioural primitives are based on historical observations of ATCo activity and operational support. The estimation of associated cognitive processes and the required attentional resources are obtained from expert cognitive psychologists. The ATCo Task Model can be tailored according to ATCo experience, task complexity and the level of automation (function allocation).

TABLE I. BEHAVIOURAL PRIMITIVES' EXAMPLE

Cognitive Process	Cognitive Channels	Behavioural Primitives
Execution	Manual	Reach Object
		Press with foot
		Move with pattern
		Continuous adjustment
		Grasp
		Mark/Point to an Object
		Touch (screen)
		Press and release (mouse)
		Adjust by rotation
		Write
		Type
	Verbal	Say a message

2) COMETA Model outputs: MWL & Functional Structure of the ATCo cognitive system

COMETA provides not only an estimation of the ATCo MWL (demanded resources) but also other additional indicators of air traffic complexity. These additional indicators are described in the following bullets.

- **Occupancy:** number of aircraft under the ATCo responsibility in periods of five minutes;
- **Control Events and Actions List:** flight indicators managed in the period of study along with the control events and actions;
- **MWL:** estimation of Demanded Resources (cognitive demand) assuming Available Resources as fixed;
- **Cognitive Processes Distribution:** cognitive demand percentage used by each cognitive process out of the total amount of demanded resources.

III. QUANTITATIVE ASSESSMENT OF ATCO COGNTIVE DEMAND IN AUTOPACE FUTURE AUTOMATION SCENARIOS

A. Assessment Methodology

The methodology followed to perform the assessment of the ATCo Cognitive demand of AUTOPACE scenarios is detailed in Fig 3.

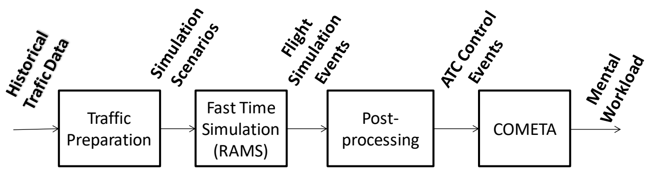

Figure 3. Methodology for laboratory studies

Firstly, a representative day of the year 2015 is selected and three peak hours are identified. Future traffic is cloned to emulate the increase expected by 2050 [5]. Secondly, several simulation scenarios (as described in section C) are modelled in a FTS tool (RAMS[1]) to reproduce the concept of operations of AUTOPACE. Then, the scenarios are executed to identify the Flight Simulation Events occurred in RAMS. The Flight Simulation Events are post-processed into ATC Control Events by means of logic (rules). For example, the identification of the ATC 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, behavioral primitives, the associated cognitive processes and attentional resources) is detailed reflecting current and future AUTOPACE scenarios. COMETA calculator is then executed. As a result, the MWL (demanded resources) are obtained for each simulated scenario.

[1] RAMS: Reorganized ATC Mathematical Simulator. Is a FTS developed by ISA Software (http://ramsplus.com – taken on 29-01-2018)

B. AUTOPACE Automation Scenarios

AUTOPACE scenarios represent the concept of operations expected in 2050 time frame defined in AUTOPACE [3]. As a summary the main features are:

- Annual growth of 2,7% from 2015 to 2050;
- Free route and 4D trajectory concepts;
- Trajectories are de-conflicted thanks to the implementation of the de-complexing processes (only conflicts that the system is not able to solve in the planning phase will remain in execution);
- Sectors bigger than current sectors;
- Flight Centric ATS procedures: Several ATCo will be operating in the same sector depending on their MWL.

Due to the level of uncertainty on how automatic systems will be in 2050, two different levels of automation are described in AUTOPACE: High Automation (HA) and Medium Automation (MA) Scenarios. The definition of AUTOPACE Scenarios is focused on the responsibilities that are expected to be allocated to ATC actors (ATC system and ATCo). The ATCo responsibilities are described by using three actions: Monitor, Apply and Approve.

- **Monitor.** It is used when the ATC system is assuming the major tactical actions and the ATCo has to monitor its behaviour to prevent system deviation;
- **Approve.** Once the ATC system has proposed a solution for an ATC intervention, the ATCo must approve it in order to be implemented. Approving requires monitoring as it is also an evaluation of the correctness of the decision of the system;
- **Apply.** The ATCo analyses the situation, decides and implements the most suitable solution from those proposed by the ATC system according to the information provided by the ATC tools.

For illustration purposes, next TABLE II shows an example of some responsibilities allocation to the ATCo depending on the automation scenario.

TABLE II. ATCO RESPONSIBILITIES FOR THE HIGH AND MEDIUM AUTOMATION SCENARIOS (EXAMPLE)

Responsibilities	**Medium Automation (MA)**	**High Automation (HA)**
Provide early conflict detection and resolution if the early resolution brings operational benefit (either on the ground side or the airborne side)	Approve	Monitor
Assign specified headings, speeds and levels	Approve	Monitor
Provide flight information to all known flights	Monitor	Monitor
Provide separation between controlled flights	Apply	Monitor

In nominal situations, for AUTOPACE HA 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 AUTOPACE MA Scenario the ATCo will be responsible also for applying many of the ATC services after analysing the proposals made by the ATC system (therefore monitoring, approving and sometimes applying). Furthermore, a sample of three representatives no nominal situations are described in AUTOPACE to allow the assessment of ATCo MWL when the system fails:

- **Conflict detection and resolution system fail**: a failure would impede the system to provide proper support to detect and solve conflicts;
- **Complexity management system fail**: At short-term planning phase, implementation of de-complexing measures would have not occurred. Then, it is expected that the ATCo will have to perform more tactical interventions;
- **Communications support system fail**: the ATCo will need to contact the subsequent one via communications channels (not automatic any more) and coordinate the exit-entry conditions of the flight.

The change of responsibilities amongst the ATC actors to ensure ATC service provision during the no nominal situations is also identified.

C. Modelling AUTOPACE Automation Scenarios in RAMS and COMETA

In order to estimate the impact of automation on ATCo MWL and therefore on performance, three scenarios are modelled: Baseline, Reference and Solution (this latter is the AUTOPACE Future automation scenario). The geographic area chosen is Madrid En-Route North ACC (Spanish airspace):

1) Baseline, Reference and Solution Scenarios in RAMS

A *Baseline Scenario* is needed for calibration purposes to determine how the current ATCo operates, how the functional structure of their cognitive system works when performing the ATC activity and how the ATCo uses the cognitive processes. In AUTOPACE, this scenario represents the current mode of operations, considering the executive and planning ATCos, airspace structure (sectors and routes), ATC systems and current volume of traffic (2015[2]). Conflict resolution and procedures are modelled according to ENAIRE procedures. This scenario represents Madrid en-route North airspace implementing current sector configuration (nine sectors), routes structures and traffic selected from PALESTRA in a busy day of 2015. The three peak hours (13:00-16:00) are identified with a traffic data volume of 382 flights.

A *Reference Scenario* determines how the future ATCo would work with the expected traffic demand in 2050 if the current concept of operations and automation features remained. It will help to estimate the benefit of the solution scenario (AUTOPACE scenarios) in comparison with the reference scenario. This scenario represents the "business as usual" scenario with the baseline concept of operations and the foreseen traffic in 2050. Reference scenario considers the annual growth of 2,7% from 2015 to 2050, representing an increase of 94,5% (755 flights during the three hours period of study).

Solution Scenarios (AUTOPACE) are built in RAMS in a step-based wise (summary can be found in TABLE III). The nine sectors of Madrid En-Route North ACC are collapsed into one big sector. The traffic volume for the three peak hours of study is the same as the Reference Scenario (755 flights).

TABLE III. SUMMARY OF SCENARIOS MODELLED IN RAMS

	Automation Level	Traffic Year	FTS Scenario	Sectors/ ATCo
Nominal	Baseline	2015	Baseline	9 sectors/ 9 ATCo
	Reference	2050	Reference	9 sectors/ 9 ATCo
	High Automation (HA)	2050	De-Conflicted	1 sector / 4 ATCo
	Medium Automation (MA)	2050	De-Conflicted	1 sector / 8 ATCo
No Nominal (HA)	Conflict Detection And Resolution System fail	2050	Free-Route	1 sector / 4 ATCo
	Complexity management system fail	2050	Free-Route	1 sector / 4 ATCo
	Communications support system fail	2050	De-Conflicted	1 sector / 4 ATCo
No Nominal (MA)	Conflict Detection And Resolution System fail	2050	Free-Route	1 sector / 8 ATCo
	Complexity management system fail	2050	Free-Route	1 sector / 8 ATCo
	Communications support system fail	2050	De-Conflicted	1 sector / 8 ATCo

- **Free-Route Scenario** modelled in RAMS considering user's trajectories as direct routes from one ACC entry point to one ACC exit point.
- **De-Conflicted Traffic** Scenario built on Free Route Scenario using RAMS rule-base for conflict resolution and post-processing.
- **Flight Centric** procedures modelled by iterative processes: Starting from two ATCo controlling one big sector. Based on Occupancy values and acceptable MWL for every ATCo (values greater than 70% are not acceptable), 4 ATCo are estimated as appropriate for HA Scenario and 8 ATCo for MA Scenario.

2) COMETA ATCo Task modelling

Control Events, Actions, Behavioural Primitives, Cognitive Processes and associated Mental Resources are defined for MA

[2] AUTOPACE started on 1st of March 2016 and finalized on 28th of February 2018

and HA Scenarios based on AUTOPACE operational and psychological expertise.

a) Control Events and Actions: In nominal situations, the Control Events are expected to be the same in MA and HA Scenarios. However, the way in which the ATCo intervenes in each process will be different. As an example, part of Tactical Conflict Resolution Event and its actions are described in Fig 4 for HA and MA. In HA the ATCo only monitors the system conflict resolution meanwhile in MA the ATCo evaluates different solutions proposed by the system and makes a decision on which is the most suitable one.

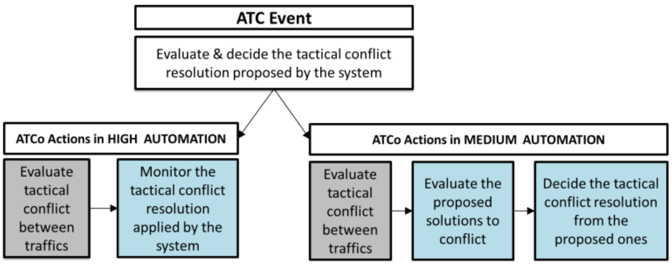

Figure 4. Example of Control Event and Actions in High and Medium Automation

Fifteen control events were used to model all AUTOPACE Concept of Operation: Asume and Transfer a flight, Collaborative Decision Making with Local Traffic Manager, Dynamic Re-sectorisation, Trajectory Management, RBT Modification, Planning and Tactical Inter and Intra Coordination, Provide essential information, Tactical conflict resolution, 4D Trajectory deviation assessment, Restore adherence to planned trajectory and Supervise the system.

b) Behavioural primitives and Attentional Resources: are identified for every action in every Control Event. Both depend on the level of automation in the scenario (for illustration purposes TABLE IV).

TABLE IV. ACTIONS, BAHAVIOURAL PRIMITIVES AND MENTAL RESOURCES (EXAMPLE)

Actions	**Behavioural Primitives**	**Mental Resources**	
		MA	**HA**
Evaluate the solutions to early conflict resolution proposed by the system (planning phase)	Fixate Object	3	3
	Recall	4	4
	Recognise	5	5
	Select	7	4
	Compare	7	4
	Compute	8	5
Decide the early conflict resolution from the proposed ones (by the system) (select a solution)	Decide	8	Not Applicable

No nominal situations imply several changes in the ATCo Task Modeling. When a system fails, the ATCo will have different tasks and times to perform them. Considering events defined for nominal scenarios, some of them are updated to complete the set of tasks necessary to comply with the no nominal situations.

IV. COGNITIVE EVALUATION OF FUTURE AUTOMATION SCENARIOS. RESULTS

A. *Nominal Situations*

Occupancy values for HA and MA Scenarios are shown in Fig 5. Flight Centric concept is in place and the figure represents the occupancy values assumed by one ATCo. As expected, with higher levels of automation, the ATCo can assume more flights (higher levels of Occupancy).

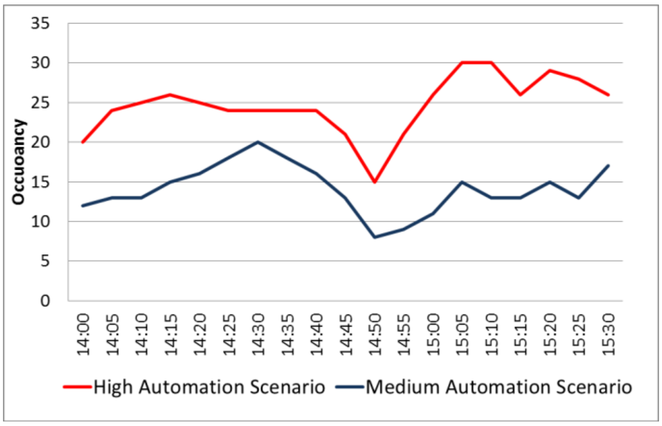

Figure 5. Occupancy in High and Medium Automation Scenarios

The associated MWL is represented in Fig 6. Since the number of ATCo to control one sector in both scenarios was estimated to ensure that MWL values (in average) were acceptable, the MWL in average (arithmetic mean) is similar (dotted lines). For HA 4 ATCo were needed and in MA 8 ATCo.

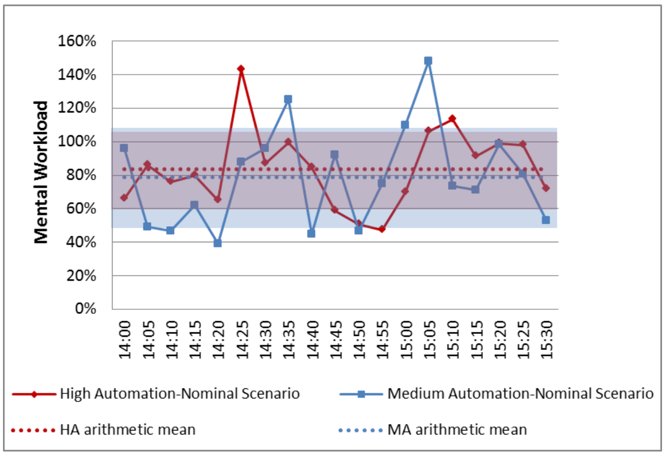

Figure 6. MWL for High and Medium Automation Scenarios

Nevertheless, the standard deviation (coloured bands) is smaller in HA than in MA Scenario showing a more stable behaviour (more robustness to variations of occupancy). In HA the ATCo is mostly supervising and monitoring the system. In MA, "approving" and "applying" actions are also in place and hence, the ATCo is performing more diversity of tasks that imply more variability in terms of MWL.

Fig 7 represents the distribution of the use of cognitive processes in the Baseline, MA and HA Scenarios. While current ATCo is demanded to use perception (visual, auditory) comprehension, projection, decision making and execution (verbal and manual) processes in a balanced way, the future ATCo should focus his/her cognitive effort on mainly comprehension and projection. The ATCo needs to understand the situation, to build a consistent mental picture and to project what is going to happen to be able of monitoring system performance without missing Situational Awareness.

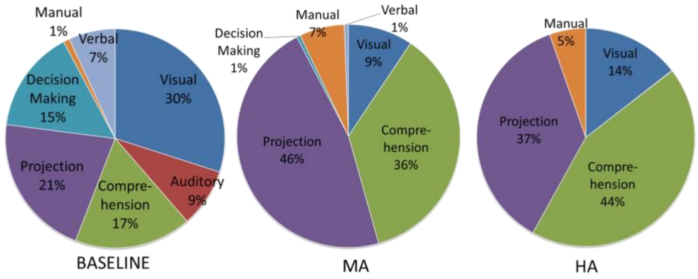

Figure 7. Functional structure of the ATCo Cogntive processes in future and current scenarios. Baseline, MA and HA Scenarios

Visual cognitive process: Compared to the other cognitive resources, visual resources are less used in the MA Scenario than in HA Scenario. The ATCo responsibility in HA is more focused on monitoring, therefore the perception have to be solid to ensure a good mental picture (comprehension) to understand what the system is doing. Most ATCo actions in HA Scenario are related to supervising and monitoring tasks while in the MA Scenario the ATCo actions are more diverse.

Auditory cognitive process: Auditory cognitive process is important in the baseline scenario as the communications are not data linked. On the contrary in the future scenarios (MA and HA), the use of this cognitive process is not demanded as communications are through data link and coordination is automatic.

Comprehension and Projection cognitive processes: MA and HA scenarios present a relevant demand on comprehension and projection cognitive processes compared to Baseline Scenario. In the Baseline Scenario as the ATCo performs a more active role, the tasks are more diverse and he/she needs to invest the resources in a balanced way among all processes. In MA Scenario, Projection is more relevant than Comprehension as ATCo needs to invest more resources on projecting future pictures to correctly understand the solutions proposed by the system and to decide appropriately. On the contrary, in the HA Scenario, what is important is to have a more robust mental picture of what is occurring to monitor system performance, meaning that a better comprehension than projection is needed.

Decision making cognitive process: This cognitive resource is important in the current scenario (baseline) as the ATCo actively performs tactical resolution decisions. However, it is remarkable that this process almost disappears in the future situations. In HA Scenarios the decisions will be taken by the System and the ATCo is just monitoring the system behaviour. In MA, the demand on this process is low in comparison to the Projection and Comprehension demands.

Manual cognitive process: this cognitive process is the less demanded in the baseline scenario, as the actions associated to this process are high automatized (interaction with the system) and the others cognitive resources acquire more importance in the tasks developed by the ATCo. However in the future scenarios is the fourth more used cognitive process as the actions that the system performs must be checked by the ATCo through a constant interaction with the system.

B. No Nominal Situations[3]

Occupancy for no nominal scenarios is the same as in nominal scenarios. In HA Scenarios (Fig 8) Conflict resolution failure could be declared as unsafe, not being possible to be assumed by the ATCo. The other no nominal situations present a higher workload than in nominal scenario but they might be assumed if mitigation actions were in place.

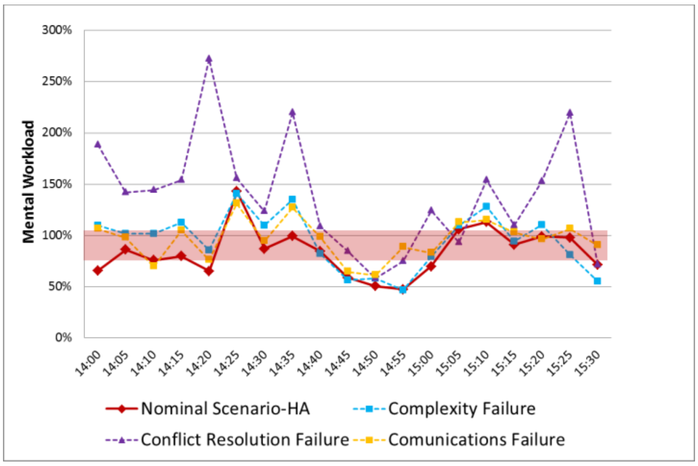

Figure 8. MWL for High Automation Scenario. Nominal and No Nominal

In MA Scenarios (Fig 9), the MWL distributions are not so far from nominal situations as in HA Scenarios since the ATCo activities do not change so drastically. Mitigation actions should be put in place to make situations affordable and safe.

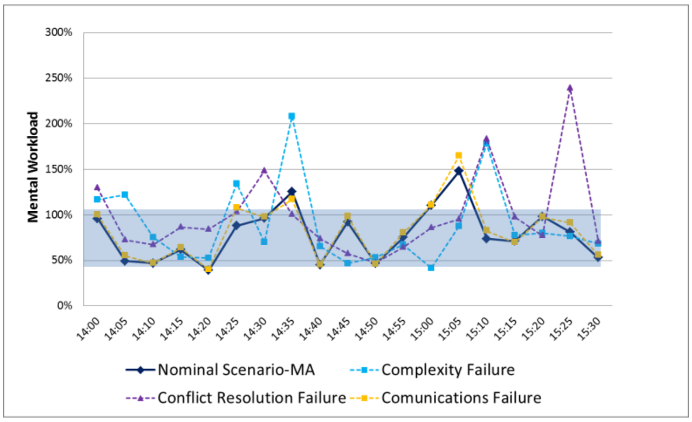

Figure 9. MWL for Medium Automation Scenario. Nominal and No Nominal

3 Transition from Nominal to No Nominal Situations is not analysed

V. CONCLUSSIONS AND FUTURE RESEARCH

AUTOPACE project has offered the possibility to research on a psychological model to better understand how automation will impact on ATCo performance through the MWL estimation and the cognitive processes analysis. The computerization of the psychological model which integrates the cognitive mechanisms responsible for the behaviour of the human actor, the task and the environmental situation would provide a powerful tool to quantify the benefits and weaknesses of different levels of automation (different hypothesis and assumptions) as an efficient alternative to the methods designed to obtain empirical data (high cost and effort consuming).

Today a prototype exists (COMETA) that has been used in AUTOPACE along with a Fast Time Simulator to estimate the future ATCo cognitive demand (demanded resources) in future automation scenarios. The research has shown that the cognitive processes implied for information processing by ATCo changes drastically from current and future automated environments. 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. These cognitive processes are the key to build the correct mental picture of the situation allowing the ATCo monitoring the system behaviour and preventing its deviation. The analysis of the change in the distribution of cognitive processes would provide guidance for system design to boost the use of the required cognitive processes in highly automated environments.

COMETA is still a prototype and further research is needed to incorporate the ATCo level of activation model and therefore the quantification of available resources. This will allow calculating the MWL understood as the relationship between the demanded resources for the ATCo activity and the available resources that the ATCo allocates to perform those ATC tasks.

In turn, the MWL quantification would also support quantification in terms of Airspace Capacity and Cost-Efficiency (ATCo productivity). 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 research on the psychological model also has allowed in AUTOPACE to identify preliminary training strategies to mitigate the performance drawbacks due to automation. Not only training on technical aspects but psychological ones are needed to mitigate the OOTL effect or the fears of automation failures. The benefits of the training and its effect on ATCo MWL could be tested with the abovementioned computational model to see the most promising training plan. Even though, once the training plan was tailored to ensure the ATCo acquires the appropriate competences, the psychological model might become as the reference for the ATCo trainee. The final goal for the ATCo trainee would be to manage the traffic within acceptable MWL levels as the computational model does.

ACKNOWLEDGMENT

This paper is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 699238 (AUTOPACE - Facilitating the Automation Pace, http://autopace.eu/) under European Union’s Horizon 2020 research and innovation programme. The opinions expressed herein reflect the authors’ view only. Under no circumstances shall the SESAR Joint Undertaking be responsible for any use that may be made of the information contained herein.

REFERENCES

[1] Cañas, J.J., Ferreira, P., Puntero, E., Rodriguez, S., Gómez, F. López E. Dominguez, D., & López, P.AUTOPACE, D3.1 ATCo psychological model with automation, 2017.

[2] Cañas J.J., Ferreira P., Puntero E., López P., López E., Gómez F. An air traffic controller psychological model with automation. 7th EASN International Conference 2017, Warsaw, Poland.

[3] De Crescenzio, F., and, & Lucchi, F..AUTOPACE, D2.1 Future automation scenarios, 2016

[4] Endsley M. R.: Toward a theory of situation awareness in dynamic systems. 37, 32-64, 1995.

[5] EUROCONTROL. Challenges of growth 2013, task 7: European air traffic in 2050

[6] Gopher, D. and Donchin, E. Workload – An examination of the concept. Handbook of Perception and Human Performance. Volume 2. Cognitive Processes and Performance. K.R. Boff, L. Kaufman and J.P. Thomas, John Wiley and Sons, Inc: 41-1:41-49, 1986

[7] HALA! SESAR Research Network, HALA! Position Paper, Version December 2014

[8] Hancock, P. A., Jagacinski, R. J., Parasuraman, R., Wickens, C. D., Wilson, G.F. & Kaber, D.B. Human-Automation Interaction Research: Past, Present, and Future. Ergonomics in Design: The Quarterly of Human Factors Applications vol. 21 no. 2 9-14, 2013

[9] Histon, J. M., & Hansman, R. J. Mitigating complexity in air traffic control: The role of structure-based abstractions. report no. ICAT-2008-05. Cambridge, MA: Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, 2008.

[10] Kahneman, D. Attention and effort. .Englewood Cliffs, N~ Prentice-Hall, 1973

[11] Metzger, U., & Parasuraman, R. The role of the air traffic controller in future air traffic management: An empirical study of active control versus passive monitoring. Human Factors, 43(4), 519-528, 2001.

[12] Rabinbach A.: The human motor: Energy, fatigue, and the origins of modernity. Univ of California Press, 1990.

[13] SESAR JU, P04.07.01-D72 Step1 Final Validation Report, 2016.

[14] SESAR JU, P05.03-D99-Validation Report EXE-05.03-VP-804, 2016

[15] Sozou P.D., Lane P.C., Addis M., Gobet F.: Computational scientific discovery. In: Springer handbook of model-based science, pp. 719-734. Springer, 2017.

[16] Suárez, N., López, P., Puntero, E., & Rodriguez, S. Quantifying air traffic controller mental workload. Fourth SESAR Innovation Days, 2014.

[17] Vicente, K. J. Cognitive work analysis: Toward safe, productive, and healthy computer-based work. Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers, Mahwah, NJ, 1999.

[18] Wickens, C. D. Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science, 3*(2), 159-177, 2002.

[19] Wickens, C. D., & McCarley, J. S. *Applied attention theory*CRC press, 2007.

[20] Wickens C. D.: Effort in human factors performance and decision making. , 0018720814558419, 2014.

[21] Young, M. S., & Stanton, N. A. Malleable attentional resources theory: A new explanation for the effects of mental underload on performance.Human Factors, 44(3), 365, 2002.