Review of Automation Problems in Air Traffic Control

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***Abstract* - Automation of an air traffic control system is expected as a solution for handling high traffic demand in the future. Focus on using automation is mostly on its benefits, but automation could bring problems regarding human performance, which should not be neglected. Air traffic controllers' role and tasks are changing with system automation and their mutual cooperation should be carefully observed. In this paper, performance of air traffic controllers within automated systems is presented. At any time, automation system could fail, and human should be able to take over and perform additional tasks that the system performed before failure. Therefore, it is essential to observe human reaction and recovery response time. The work presents problems that occur during system usage, explains models of automation system and human performance as well as models of individual and team performance. Humans individual differences, such as mental model or trust in automation, are of great importance for predicting human behavior when using automated system. Researchers have tried to solve or prevent problems caused by automation through different projects. This review paper should enable better understanding of automation problems in air traffic control thus encouraging the development of automated systems in a way to solve or prevent automation problems.**

Keywords - automation; air traffic control; human performance; mental models

I. Introduction

Growing air traffic in the ECAC[1] area until 2019 has been challenge for European air traffic management [1]. Although the growth was stopped at the end of 2019 due to COVID-19 outbreak, the air traffic is expected to rebound and even exceed the traffic from 2019 according to one of EUROCONTROL's forecasts scenarios [2]. In order to help the air traffic controllers (ATCOs) to handle expected increase of traffic in the future, automation of air traffic control system is proposed as a solution [3].

Automation has slowly made its entry in air traffic control over the years. Tools such as short-term conflict alert, tactical controller tool or minimum safe altitude warning are some of the many that have made their contribution in helping ATCOs in their work. Today, most tools are used for information exchange. Safety tools help to identify conflicts and mitigate human error while efficiency tools help ATCOs with the planning process [4]. ATCOs are the ones who decide how to solve conflict between aircraft and they do it manually, without the help from the automation systems. However, it is expected that in the future, ATCOs' role will be changed significantly. According to the European Air Traffic Management Master Plan [5] automation will support ATCOs in action selection, action implementation, it will initiate actions for some tasks, and some of actions will be completely performed by automation. For such system to be functional, cooperation between human and machine is necessary.

The reasons for automation usage are the benefits that derive from it. According to Ehrmanntraut [6], as the level of automation rises, the benefits change. In the Figure 1, key performance indicators are set to value of 1 as the baseline and are changed according to level of automation. Indicators that are expected to have the most benefit from automation are safety, capacity, economic growth and ROI [2]. Some of the indicators show degradation such as investment, feasibility and jobs per flight. Nevertheless, these are not only negative effects which come with automation. It is important to look closely at the working position of an ATCO and try to identify the problems in order to solve them.

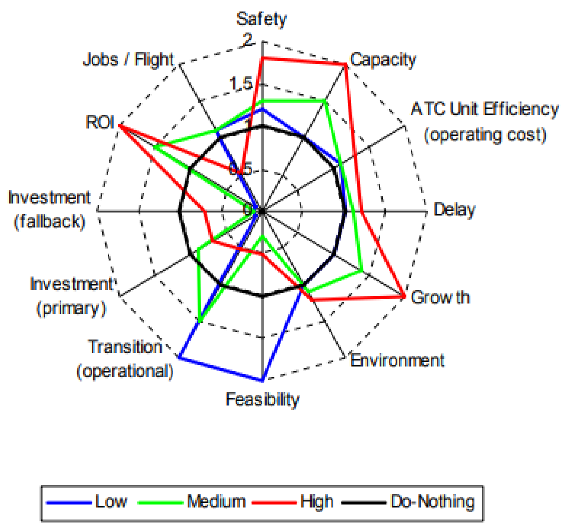

Figure 1. Relative impact of automation levels on key performance indicators [6]

[1] The European Civil Aviation Conference (ECAC) is an intergovernmental organization which was established by International Civil Aviation Organization (ICAO) and the Council of Europe. ECAC now totals 44 members, including all 28 EU, 31 of the 32 European Aviation Safety Agency member states, and all 41 European Organization for the Safety of Air Navigation (EUROCONTROL) member states [1].

[2] ROI-Return on Investment [6]

Over the years, new tools have often caused false alarm that would require additional attention from an ATCO and would end up being unused. Automation requires increased human-computer interaction, high reliability levels and user-friendly software which is not always the case [4].

Following important questions can be identified in development of implementation of automation systems in air traffic control: how does a human react in automated environment; what happens when system performance degrades; how and why does a human react in a certain way; which individual differences influence acceptance of automation; what does ensure cooperation between system and a human. To answer them, it is important to look closely into the mental model of ATCOs and on individual and team performance. Automation is an inevitable change in air traffic control thus, it is important to find the appropriate development path for it.

The aim of this paper is to give brief overview of problems using automation in air traffic control focusing on human performance. The topic has risen from literature review of automation used by air traffic controllers. The need for presenting significant automation problems side by side was recognized in order to answer fundamental questions. With all the relevant research summarized, this paper enables development path for automation in air traffic control for future researchers. The paper identifies three major research topics covering problems in air traffic control automation: human performance in automation, air traffic controllers' interaction with dynamic systems and automation failure.

II. HUMAN PERFORMANCE IN AUTOMATION

A. Mental workload

Mental workload and situational awareness are terms often used to explain human performance in automation. Therefore, comprehension of their meaning is important. Mental workload depends on psychological model which explains the functioning of the human cognitive system by using mental resources [7]. Demanded and available resources differ. On one hand, demanded resources are the ones required by the task and dependent on task complexity. On the other hand, available resources represent the pool of resources that the ATCO has and can use upon task execution. Different factors such as stress, fatigue, and emotions affect the level of activation of the pool resources. A human can also decide on quantity of resources to be used for completing the required task. Mental workload represents the relationship between demanded and available resources. Three situations are possible when it comes to mental workload:

- The amount of available resources is equal to the amount of demanded resources. The task is performed optimally.
- Demanded resources are higher than the available resources. The human is in a mental overload situation. An effort to perform the task affects physical and mental health of the operator.
- Available resources are greater than the demanded resources. The human is in a situation of mental underload. Spare available resources can be directed to some other simultaneous task and if there is significantly large amount of resources left, it produces boredom, distraction and drowsiness [7].

B. Situation awareness of an individual and a team member

Endsley [8] defined situation awareness (SA) as the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future. Each of the three segments represent one level or SA. Different types of errors such as *data not available* or *memory failure* can lead to incomplete or inaccurate SA [9,10]. Introducing automation in ATCO working position is likely to affect the SA of ATCOs. There are three types to measure SA: query techniques, rating techniques and performance-based techniques. In project named SHAPE[3], a tool for measuring SA of the operators using computer-assistance tools or other forms of automation support is developed. Two measures for SA are introduced: SA for SHAPE on-line (SASHA_L) and SA for SHAPE questionnaire (SASHA_Q) [11].

SASHA_L is based on previously known technique SPAM[4] developed on the premise that SA includes simply knowing where to find a particular piece of information in the environment rather than remembering it. During the simulation, an ATCO answers the questions via phone call without simulation being stopped and with no blockage of the screen. The questions asked are always based on the relationship between two or more items (e.g. between two aircraft, between one aircraft and the sector or a specific area). Maximum one query is asked in 5 minutes. Response time of answering the phone call and time to correct answer are taken into account [11].

SASHA_Q is a self-rating questionnaire. It is given to ATCOs after simulation run. The questionnaire is combined of six generic questions which are not related to the specific aspects of the simulation, three questions aimed at a particular tool and one question for SA. The questions relating to specific system are composed by subject matter expert or human factors specialist [11].

[3] SHAPE-Solutions for human-automation partnerships in European ATM [11]
[4] SPAM-Situation present assessment method [11]

Endsley [12] also elaborates SA of a team when several individuals work together to make decisions and execute actions (such as the team of ATCOs). Team SA is shown in Figure 2. Each team member has their own SA, which is determined by the responsibilities within the team. Overlaps in SA represent information important in team coordination. Coordination can be made through verbal exchange, as duplication of displayed information or by other appropriate way. Effectiveness of the team coordination or human machine interface can be observed through quality of team members' SA of shared elements. If the team consists of two members and each of them needs to know the information, it is unacceptable that one team member knows the information, and another one has no knowledge of it. Overall, team SA is a degree to which every team member has the SA required for their own responsibilities.

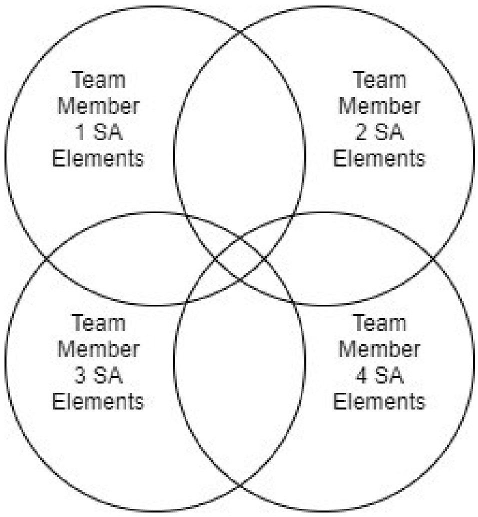

Figure 2. Team SA [12]

Winjgaards, Nieuwenhuis and Burghardt [13] give a new view of teams and their members. They claim that intelligent systems such as robots and agents can be a team member with status equivalent to a human. This gives a new perspective of future ATCO teams in which a team member is an agent. The agent may be able to take initiative and give orders to a human and other agent team members. A team is viewed as actor-agent community. It is a type of complex system in which multiple agents, including humans and artificial systems collaborate to realize the common mission or for the support of a shared process [14]. Perhaps Endsleys' [12] explanation of team SA can contribute in development of such cooperation between human and system.

III. ATCOS' INTERACTION WITH DYNAMIC SYSTEM

A. Mental model and situation awareness

Examination of human performance issues in automation is presented in general framework (Figure 3) [3].

There are three important elements of human interaction with dynamic system: mental model, SA and trust. Mental model reflects the humans' understanding of processes by which automation executes the tasks. The mental model is affected by the system complexity and effectiveness of displaying information such as system functioning, status and performance.

ATCOs' SA depends on the mental model which affects awareness of current and future state of the situation. SA is also affected by effectiveness of information display and monitoring strategy of information [3].

B. Trust

Trust in the automation system answers the question of whether to use the automation or not. It depends on the reliability of the system. Actual reliability of the system can be better than the perceived one, but the controller also includes his mental model and SA when deciding upon trust. If the ATCO decides not to trust the automation, he/she doesn't use it. On the other hand, over-trust leads to complacency. Complacency can cause

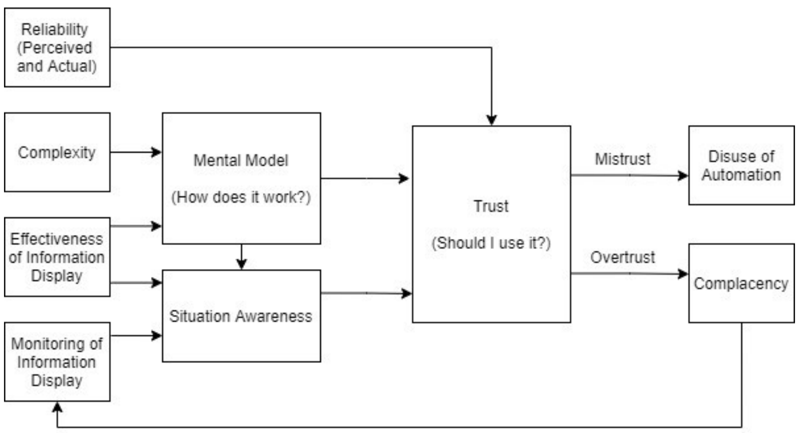

Figure 3. Framework for examining human performance issues [3]

poor monitoring and negative effect on SA [3].

Large number of empirical research have been done to describe the trust in automation. Hoff and Bashir [15] have created a three-layer trust model based on the conclusion of all previous research. The model divides trust on dispositional, situation and learned trust. Dispositional trust represents the tendency of an individual to trust automation. It is a stable tendency that arises from biological and environmental influences (age, gender, culture and personality). Situation trust depends on the situation, internal (self-confidence, expertise, mood and attentional capacity) and external (type and complexity of system, difficulty of the task for which is used) variabilities [16]. Learned trust is the human's evaluation of a system based on past experiences and current interaction.

Trust also affects mental workload. According to the MART [5], available resources are influenced by task complexity and the operator's expectations [17]. If ATCO trusts the automation and does not expect an increase of task difficulty soon, the available resources are reduced. At the same time, automation decreases demand resources, and the mental workload is constant. Overconfidence in the system can lead to lack of SA and out of the loop phenomena (OOTL). The operator is at the risk of overload in case an unexpected situation happens. On the other hand, if ATCO has a fear of automation failure, the stress increases and so do available resources. The operator is in situation of mental underload. Extra resources can cause disorientation, overacting or erratic behavior [18, 19]. Trust is an important factor when it comes to automation acceptance in air traffic control. The presented model explains how individual differences can affect trust. Perhaps human operators should be chosen depending on their personal tendency towards trust in automation or it is possible to influence on some of the humans' factors included in the Hoffs' and Bashirs' three-layer trust model through training.

C. OOTL phenomena

OOTL phenomenon is observed in ATCOs' behavior in three ways: higher difficulty in detecting system failure (1), higher difficulty in properly assessing situation and operational status (2) and higher difficulty in producing adequate or correct and timely response (3) [19].

Few projects have dealt with OOTL phenomena lately. Project AUTOPACE proposed human training as a solution to mitigate OOTL. The idea is to train ATCO to recognize behavior that leads to OOTL and thus prevent OOTL development [7]. Another project titled MINIMA[6] focused on OOTL in highly automated systems [20]. According to Kaber and Endsley [21], adaptive automation would be able to keep the operator in the loop by dynamically assigning manual actions. In the project, Vigilance and Attention Controller (VAC) was developed to adapt the automation level depending on the real-time ATCO vigilance. VAC is a system based on electroencephalography and eye-tracking techniques. Results show that system based on adaptive automation counteracts vigilance decrease which is caused by highly automated systems. In such a system ATCOs were more engaged in the task, had less task-unrelated thoughts, showed higher reacting gaze behavior and were best performing [20].

IV. AUTOMATION FAILURE

When automation failure occurs, recovery is important for maintaining safe air traffic. Automation can be introduced for many functionalities. Consequences of automation failure vary depending on the automated function. Failure recovery model of ATCOs is described as the capability of ATCOs to recover and restore safety in which automation has failed. Model framework of failure recovery is presented in Figure 5. Automation affects the following variables: capacity, density, vulnerability, complexity, workload, situation awareness, manual skill and recovery response time. The signs minus, plus and zero represent influence of automation on each variable (decreasing, increasing or no influence) [3].

Automation will likely increase airspace capacity [3]. Depending on traffic distribution, automation can increase or have no effect on traffic density. Complexity of the airspace will be changed with automation due to changes in traffic flow and flight trajectories adjusted for capabilities of individual aircraft. Situation awareness can be increased or decreased depending on the automated function. In the same time SA is affected by complexity and workload. Workload is affected by density and complexity. When workload rises, SA of ATCO decreases. With automated functions in use, manual skills are compromised due to human nature of forgetting and skill decay over time [3]. Careful consideration is needed to select functions to automate in order to prevent skill decay.

Response time is the time required to respond to unexpected failure situations and to possibly intervene with manual control skills. That time can be predicted by SA level, manual skill, individual skill differences, redundant characteristics of the team environment, complexity of the problem and by a degree to which the failure is expected. If the ATCO is less skilled and has lower SA, the appropriate reaction to the situation is slower. Dashed line in graph of Figure 5 shows hypothetical function that relates recovery response time and level of automation [3].

[5] MART-Malleable attentional resources theory [17]

[6] MINIMA-Mitigating negative impact of monitoring on high levels of automation [20]

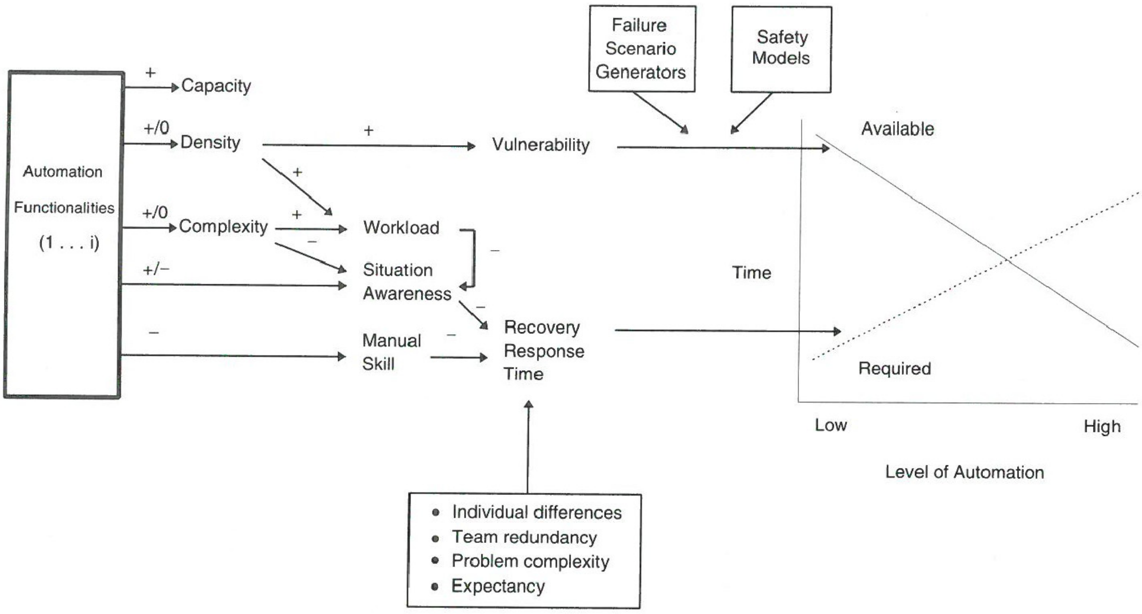

Figure 5. Model of failure recovery in air traffic control [3]

Traffic density increases the vulnerability of the system. When a failure occurs, it affects system's safety depending on the vulnerability. If aircraft are close to each other, there is less time to react safely. The solid line in the graph shows the time available to respond to a failure. Therefore, graph shows the time required to ensure safe separation and time available for ATCO team to react safely [3].

Figure 5 shows the importance of recovery response time which should be carefully considered for each automation level. System developers should ensure ATCOs enough time to react and think of ways to decrease recovery response time. Once again individual differences are stressed. Importance of teamwork should not be neglected, and each team member should know their role when failure occurs. Training of manual skills should be properly included in ATCOs work hours to prevent skill decay.

CONCLUSION

Different models have been used to explain human behavior in an automated system. Problems such as loss of situation awareness, trust in automation and recovery response time are presented in this literature review. Automation developers should take into account all the aspects presented in order to maintain or increase safety levels. However, not every problem can be prevented through the development of a system. As mentioned above, some of the problems could be solved through training or by choosing an ATCO trainee with the required individual characteristics. A combination of all three could be the most appropriate approach. Teamwork also affects situational awareness and recovery response time. Roles in the team are expected to be changed in the future. In future research in cases where an agent makes a team member, it should be thoroughly considered how to change roles and which tasks should be left to a human operator.

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