HERMES
AIR TRANSPORT ORGANISATION

POSITION PAPER

R19-PP/05
04/04/2019

Education and Performance in Aviation: Realising and Sustaining Benefits

Presented by EUROCONTROL

How to make automation a good solution to the current problems in ATM?

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Abstract. The present paper is concerned with training and competencies. These elements are the enablers of human performance in automated systems. Among the many methods and processes that are currently in use, the first one to be widely exploited was Instructional Systems Development (ISD), and its variants, which are part of the Systematic Approach to Training (SAT) instructional design family. One of the key features of these processes is Instructional Task Analysis, particularly the decomposition of a job into its tasks and sub-tasks to determine what knowledge, skills and attitudes the trainee must acquire. In the context of automation, this paper advocates the need to accurately establish the human-machine collaboration and to carefully define the allocation of functions, the allocation of responsibility and the allocation of authority. It is important to note that these allocations are required to be dynamic in order to cope with the evolution of the context and the environment, such as human or system failures. Efficient and thorough training is one of the key element to ensure system and operators' tasks congruence even under adverse circumstances especially when interacting with dynamic and partly autonomous systems. This said, the first step is to have well designed automations and a fit for purpose advanced tools. This includes designing how operators will work with automation (e.g. trigger, supervise or stop) as well as how takeover and handover will be performed. We cannot expect training to compensate for design deficiencies or wrong automation goals. It is therefore important to remind the main goal of automation, the different possible levels of automation and the impact of such automation solutions.

1. Introduction

Increasing automation as a mean of improving productivity and quality is what remains in the collective memory from the industrial revolution. However, this automation from the early days, came with a set of drawbacks ranging from fragility (if one of the supply chain component fails, the entire production system collapses), the need to educate the population to higher levels of knowledge and qualifications (thus making them unproductive for extended training period) and the consumption of non-renewable natural resources to produce both products and factories [2].

In the ATM domain we have reached the limits of conventional solutions (re-sectorisation, reduced separation, increased precision ...) to absorb an ever increasing demand and therefore we expect a lot from new technologies and automations. Often we even expect perhaps too much, having our needs and desires blinding us from the true possibilities of automation design and technology. We tend to forget the lessons from past and expect that limitations or difficulties of automation deployment will not hit you as they did in other domains.

Early approaches dealing with automation and Human–Computer Interaction were focusing on the human factors aspects of users interacting with automation. Generic functions to be performed were listed and allocated to the best player between the machines and users (e.g. Fitts' approach called Machines Are Better At - Men Are Better At [13]) and refined for computers by Carver and Turoff [19]. These lists were supposed to support the design of function allocation and produce better systems, by applying best player allocation per function. Another view was to design automation at different levels of human or machine authority and for different processing stages, such as information acquisition, information analysis, decision making, and action implementation [14]. Other approaches proposed high-level metaphors to design automation [16] at a high-level of abstraction and ended up never being implemented in systems.

The current drive in automation is towards fully autonomous systems (e.g. Tesla [17] or Waymo self-driving technology[1]) which raises critical design, implementation and training issues such as:

[1] https://waymo.com/mission/

- How to ensure dependability of fully autonomous systems and how to test them?
- How to make it possible for users to foresee future states of the automation?
- How to disengage automation?
- How to re-plan automation after disengagement?
- How to carry on activity and overall service provision under automation degradation?
- How to ensure usability and understandability of the information flow from automation?
- How to learn how to use automation?
- How to not de-skill operators that are using automation?
- How to ensure that the system is serving the user and not the opposite?
- How to address legal issues (e.g. responsibility) raised by safety concerns (both for users and the environment)?

This list of questions is far from being exhaustive but provides an idea of some critical aspects of automation design, implementation and use, beyond the feasibility aspect that are trying to address. Some of these questions address the predictability of automation, others question transparency and controllability [15] (which are typical HCI problems) while others relate to dependability and software engineering aspects similar to the ones for interactive systems [26]. These questions demonstrate that automation brings additional complexity at the design, specification, development, validation and deployment phases.

2. Goals of automation

The fantasy goal of automation is to replace humans, and in so doing eradicate human error and ultimately improve safety. There are a few such successful examples as autonomous train but we must keep in mind the fact that they operate in one dimension and that the environment is fully controlled. We usually forget that those processes are still controlled by humans supervising the entire system and if the supervision fails, we suspend the service (example of the ORLYVAL). The hope is that such examples can be translated in other context, more dimensions, with increased complexity, because this is were the benefits of "good" automation are higher. The latest example of this approach is the concept of autonomous cars. Designers have taken the human out of the loop (and out of the driver's seat). A car driving by itself amazes everyone but nothing is mentioned about overall performance of the transportation system involving those cars. Clearly, transportation performance would decrease with autonomous cars, as the main goal is to be safe by reducing accidents from human drivers. However, autonomous cars get lost, get deadlocked, get involved in (sometimes fatal) accidents demonstrating they are not yet ready for deployment. The autonomous taxi in Paris were planned for next summer but deployment was recently delayed for at least four years (whin an initial test period of two years). Even lower level of automation has required a very long lasting testing and development phase. A good example in aviation is the development of the Autoland functions in civil aircraft. The first prototypes of the Autoland system were designed in the early1940s, but the first certification was only performed on the 28th December 1968 for the Caravelle (Airbus) aircraft. To get to certification was a succession of improvements such as AutoPitch, AutoThrust and AutoRoll, that all needed to perform a "full" Autoland. In this case, the automation was developed to enable a task to be performed (landing) that was otherwise not possible (due to low visibility conditions for instance). With the introduction of the Autoland system, additional tasks for pilots to supervise the system, understand the system and operate it correctly were introduced. Autoland also came with operational limitations such as no landing with a tailwind above 10 knots. Training needed to be modified to ensure that pilots understood and respected these limitations. Incremental design, development, certification and deployment was need to automate a single function.

Even in the case of successful automation we have to recall that it didn't went all smooth and not without delays... the example of autoland in aircraft is a nice illustration of that. We now can judge it as a success and may praise its success story... but it took almost three decades to design and implement and there are still many limitations for its use thus requiring the presence and the constant involvement of operators. In terms of drawbacks, Autoland introduces complacency and deskilling thus reducing its use in normal conditions.

Instead of attempting to replace the operator, the goal of automation should be directed towards better overall socio-technical system performance [18] by:

- Supporting humans who are performing demanding tasks or activities that humans are not able to perform e.g. flying, mentally computing Pi number precisely, detecting infrared signals, etc., and thereby supporting the perceptive, cognitive and motoric capabilities of humans.
- Executing low level, well-defined tasks that likely to be error prone for humans (counting the number of zeros on a directory page), monitoring and surveillance tasks that humans fail to perform reliably [6].
- Performing tasks that humans are reluctant to do because they are repetitive, not attractive or degrading (e.g. washing clothes). However, for these tasks, it is quite possible that the automated performance may be lower than when undertaken by human operators.

There is significant pressure to deploy automation to improve the performance of global systems. In the case of ATM, this is to increase the capacity in sectors, make the aircraft routing more efficient and improve KPIs. In this context it is easy to forget the purpose of automation and the drawbacks that come with the benefits.

3. Reality of automation

As argued above, automation will require additional tasks to be performed by the operator, for instance to establish the parameters of the automation (e.g. setup your alarm clock, setup a TV recorder, …), to supervise the execution of the automation (checking that there is still electricity for the alarm clock) and understand automation (check that the time, the day and the sound have been properly setup). These additional tasks may impose strong constraints on the automation design that go beyond the functional requirements (e.g. the alarm clock should be able to produce a sound at a given time). These non-functional requirements will require good usability, good user experience and be easy for the operator to learn and to remember (just to name a few).

Without taking into account these non-functional constraints, operators will not have the possibility to known and understand what the automation is doing and why it is doing it, so as to infer how to behave according to what the automation is currently doing and what it will do in the future. These problems are known by researchers and referred to as automation transparency [15] but might not be known by the engineers who design and implement partly autonomous systems. These discrepancies comes from the fact that non-functional requirements are associated with disciplines such as Human Factors, Human-Computer Interaction and Psychology that are not core to engineers training. To close this gap, EUROCONTROL has recently decided to add to their training program a training course (called HUM-DESIGN[2]) that complements other course on Human Factors and addresses issues of competitive goals, issue of technological drive of automation when decoupled from operational goals ……

More importantly, adding automation to a system usually fundamentally changes the nature of the work, transforming the role of the operator from an active actor to a more passive supervisor of the system. These changing roles require different levels of knowledge, different skills and different training. A good supervisor will need in-depth knowledge about the functioning and the environment of the supervised system. This is why pilots learn about aircraft physics, aircraft systems and weather conditions during their training.

On the system side, engineering systems with automation becomes always more complex. Even if we expect a machine to learn using Artificial Intelligence technology (AI) called machine learning, there is a need to observe experts for a huge among of repetitions. Therefore we need users in the loop until skills and practice are fully copied, tested and validated. For dependability, they require mechanisms to ensure that the probability of failure of the automation is acceptable and that the system has been thoroughly tested, covering all the cases that the automation will face. Therefore, during those very long development

[2] Approaches [HUM-DESIGN]" here https://bit.ly/2C7iIzw .

phases of complex systems, users must remain in the loop, increasing the complexity as the automation must explain its behaviour and can be disengaged by the operator/s at any time.

While automated systems perform functions that are impossible or difficult for humans to perform (or augment or assist the human operator), these systems also impose additional workload [21]. Operators of automated systems must be skilled in anticipating system malfunctions, in system level problem solving and in responding to anomalies quickly and effectively.

When we consider the impact of automation on future systems in a specialised domain like ATM, these considerations should start from selection. For years, we have targeted assertive and proactive people who are able to take decisions in dynamic environments where there is a lot of uncertainty. If automation introduces new tasks that require new capabilities (e.g. monitoring vs direct action), then the profile and abilities of future ATCOs should be revised. Sadly, this is not always the case. Even in SESAR, where automation is considered with the human in the loop, the only part that has been stated not to be changed is the selection of controllers.

Automation of industrial processes tends to expand rather than eliminate problems for the human operator. Human factors is now, more than ever, important in the ATM domain as developments in automation are increasingly showing the 'classic' approach of leaving the operator with the responsibility for managing abnormal conditions (such as automation failures [25]). These failures are likely to occur due to the complexity of engineering automation [26], which requires the integration of knowledge and practices from human factors, human-computer Interaction, design and software engineering disciplines. This approach is not new and was already highlighted in 1983 by Bainbridge as ironies of automation [22]. Bainbridge described how automation fundamentally altered the role of the human operator in system performance. Requiring the operator to oversee an automated system that could function more accurately and more reliably than he/she could, can affect system performance in the event that operator intervention is needed. Furthermore, taking over when automation fails, is beyond what can be expected from operators. As seen in the aviation domain, as the degree of automation increases, there is an increased risk that performance following return to manual control will be degraded [23].

We can also observe that research projects are not consistently considering integration of future technology (an in particular automation) for ATM.

The AUTOPACE[3] (Facilitating the AUTOmation PACE) project suggests that air traffic controllers can learn new competences through psychological training, biofeedback training and non-nominal training on simulators that can prepare them to face the challenges of automation scenarios as defined by SESAR for 2050. The problem is that one of ATCO competencies required for future work with automation is concerned with the ability to identify a system malfunction, and recover any non-nominal situations. This means that there will be a requirement to maintain the current competencies but without the same level of proficiency, because in nominal cases the automation is doing most of the task and acquiring new ones. Even in those research projects that are not constrained by technological limitations, the improvement in the performance of the human machine couple, is predicated on the human operator being able to assume more task responsibilities and adaptations to current responsibilities.

Conversely, STRESS[4](Human Performance neurometrics toolbox for highly automated systems design) a recent SESAR project involving EUROCONTROL, ENAC, DEEP BLUE, Sapiensa University and Anadolu University, concluded in 2018 that we can rely on technology to better support human capabilities and limitations. The project had a number of outcomes, including ‘guidelines for the design of innovative technologies that are compatible with human capabilities and limitations.’ However, arguably the most important development of the project is a neurophysiological measurement toolbox, which can assess the impact of future ATC scenarios on controllers. The STRESS technology could be used by ANSPs during the testing and validation of new automation. Controllers would be able to objectively show whether new tools/ automated systems were, in fact, increasing their workload beyond a reasonable limit.

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[3] http://autopace.eu/

[4] http://www.stressproject.eu/

The SPAD[5] (System Performance under Automation Degradation) SESAR research project studied how performance of the overall ATM system might be influenced by automation degradation. More precisely the project studied the propagation of automation degradation and aimed at

- understanding, modelling and estimating the propagation of automation degradation in ATM;
- evaluating and estimating the consequences of degradation propagation on ATM performances;
- supporting an effective intervention for the containment of automation degradation.

This is one of the very few projects that considered automation degradation at a critical element to be studied. Unfortunately, detecting faults, tolerating or removing faults was not part of the project objectives.

These three projects illustrate some of the challenges of automation research that brings highlighting the need to address jointly human factors and engineering and the dilemma of whether to adapt the technology to the human, or whether we expect the human to adapt to the technology development.

4. Position and Conclusions

The concerns regarding controller capacity and performance in a highly automated future environment suggest that new training approaches may be required. In the same way that pilots had to learn and develop new skills for dealing with cockpit automation, so now must controllers also expand their repertoire to include new skills, perform new tasks, and acquire new knowledge to operate, understand and monitor the automations that are polymorphic per nature. According to Hopkins [24], humans will have a central role in future ATC systems because their problem solving skills will be needed and it is also clear that they will be the ones in charge of handling unforeseen circumstances. Training techniques must be designed and implemented to ensure that controllers work effectively as managers of automated systems but also remain capable of handling traffic in case of automation degradation or failure.

In terms of automation acceptance [28], the challenges introduced by automation are caused by the lack of knowledge of what automation is in reality (see section 3) and should not be there only to replace the human. Automation alters the performance of some tasks with new tasks and procedures, which in turn changes the training needs. The co-evolution of operators, systems and training is thus required as identified in other domains such as ground segments of satellites [27].

Most of the current challenges of automation are not new and can potentially be managed by better understanding of the relationship between operators and the system they are managing. The design, implementation and validation of systems featuring automation raises a lot of challenges that must be addressed at research and operational levels prior to deployment. More globally, better consideration of human needs and capabilities is required in order to make those systems trustable and reliable. Training operators to understand the behaviour of those systems, to get the best of them and to ensure safe and efficient operations remains one of the most critical challenges that must be addressed in the near future.

A big question remains: what kind of research should be carried out to solve problems that have not been solved in the last two decades? The purpose of this paper was to highlight some directions but also some dead ends based on experience in ATM but also learning from other domains like aviation.

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