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The realistic consideration of human factors in model based simulation tools for the air traffic control domain

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Abstract. Advanced Air Traffic Management (ATM) concepts related to automation, airspace organization and operational procedures are driven by the overall goal to increase ATM system performance. Independently on the nature and/or impact of envisaged changes (e.g. from a short term procedure adjustment to a very long term operational concept or aid tools completion), the preliminary assessment of possible gains in airspace/airport capacity, safety and cost-effectiveness is done by running Model Based Simulations (MBSs, also known as Fast Time Simulations - FTS). Being a not human-in-the-loop technique, the reliability of a MBS results depend on the accuracy and significance of modeled human factors. Despite that, it can be observed in the practice that modeling tools commonly assume a generalized standardization of human behaviors and tasks and consider a very few range of work environment factors that, in the reality, affect the actual human-system performance. The present paper is aimed at opening a discussion about the possibility to keep task description and related weight at a high/general level, suitable for an efficient use of MBSs and, at the same time, increasing simulations reliability adopting some adjustment coming from the elaboration of further variables related to the human aspects of controllers workload.

Keywords: task, workload, human performance, environmental conditions, context variables.

1. Introduction

Advanced ATM concepts related to automation, airspace organization and operational procedures are driven by the overall goal to increase ATM system performance. Independently on the nature and/or impact of envisaged changes (e.g. from a short term procedure adjustment to a very long term operational concept or aid tools deployment), the preliminary assessment of possible gains in airspace/airport capacity, safety and cost-effectiveness is done by running MBSs.

These simulation techniques are intended for preliminary demonstration of achievable benefits with new operational concepts, and for addressing the complexity of the assessment of alternative airspace organizations, controller working methods, and automation strategies. All modeling approaches currently available require to turn tasks performed by controllers into homogeneous entities (namely times or the so-called weights) allowing the comparison among alternative air traffic scenarios, that is several combinations of number and type of flights, routes, procedures and, sometimes, automation tools.

As the Air Traffic Controllers capacity to handle a given number of aircrafts in a given scenario and time unit is strongly connected with cognitive and physical effort required them, the output of MBS simulation is generally expressed as "controller workload". The problem of modeling how human actors have to deal with the overall ATM system can be investigated under several concepts (e.g. human behavior rather than human workload) and measurement techniques (e.g subjective rather than objective, physiological rather than psychological), but the common goal of this kind of studies is a fair balance between airspace capacity and safety levels, based on an "affordable" human contribution to the ATM system working. From an opposite perspective, it can be said that overall ATM system performances de-

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pend on the appropriateness of human reactions to system stimuli, so that a comprehensive understanding of human response (in terms of quantity and quality of human reactions and human effects on the system) will give awareness of that part of system performances related to human component of the wider ATM system (Figure 1).

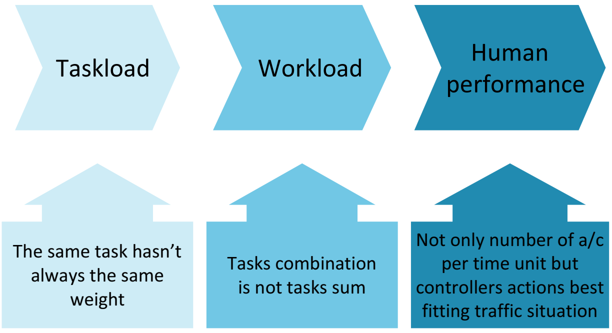

Fig. 1 Critical points in representation of human factors provided by possible approaches to air traffic controllers job modeling.

In this regard, it can be noticed that current simulators and relevant mathematical model consider a very small number of aspects that, in the reality, determine actual workload rates for controllers and that would give a rather reliable account of human performances. In fact, models generally consider tasks performed by controllers as discrete events to be summed up, whilst the expense of human resources is a matter of quality as of quantity, so that the workload picture represented by MBS can result inappropriate for understanding the impact of envisaged transformations on human workload and system performances. The relevance of this issue shouldn't be underestimated, since it is known, for instance, that the major constraint of Europe airspace capacity is determined by the Air Traffic Controllers workload [1].

2. Human variables consideration in current use of MBS systems

In the practice of MBS field, experts using simulators have observed cases study where workload levels actually experienced by Air Traffic Controllers are rather different from the simulation outputs. According fast time simulators experts understanding, when these MBSs results are discussed with controllers, they ascribed this gap to some specificity of the investigated sector, which is considered –according their everyday experience– able to affect simulation results. Furthermore, practitioners in MBS field notice that Air Traffic Controllers are able to describe their tasks in general terms but they are not really comfortable if they have to assign a weight to each task when their job is described in a detailed task breakdown structure.

These considerations highlight a two faceted gap between human work, modeled tasks and resulting levels of human workload: one aspect of this gap concerns MBS outputs, and then their reliability, due to the difference between actual and modeled workload in some sectors; another aspect of this gap draws attention to the difficulty to appropriately handle human related data within a simulation model.

A key consideration is that air traffic controllers perform their tasks in a multitasking way rather than in a sequential manner, but this aspect is not always considered enough in the majority of fast time simulators actually used in ATM research field. Furthermore, the current approach to MBS assumes that, for instance, Air Traffic Controllers responsiveness and control "styles" are independent on a number of personal and context variables such experience and age, circadian rhythms, shift lengths, worked hours and overtimes, weather conditions, software interface and technical features, etc. On the contrary, modeling practices in ATM domain should not neglect that workload is a multidimensional concept, characterized by a qualitative dimension rather than a quantitative one, and it cannot be reliably measured overlooking intensity, duration and distribution of tasks in the time or without considering the quality of the mental and physical workload (e.g. perception rather than mnemonic or reasoning tasks) or work environment influence [2].

A joined study of FAA and Eurocontrol [3] about human performances modeling in existing tools states that "determining perceptual, cognitive, and motor requirements and exploring augmentation of performance were perceived as too detailed for system wide investigations", whilst "certain mechanisms of human performance could be scaled to demonstrate an effect on system wide operations. These include closed-loop operator loading (e.g., feasibility and recoverability measures) and the requirements for, and effect of, aiding systems (e.g., reduction in demand on an operator and/or the likelihood of, or impact of, an error"). Despite that, the mentioned study concludes that none of the corresponding capabilities in the MBS were identified in the surveyed tools. Only in some cases, the modeled workload level is adjusted considering some traffic complexity parameters like number of aircrafts or duration of control for each of them; moreover, not always a distinction is made for what concerns workload sharing among the Air Traffic Controllers roles. Anyway, finest modeling systems still require great efforts in terms of skills and time for tasks observations and model configuration [1], but it is also easy to understand that from the controller's point of view, "it is obvious that each aircraft does not amount to the same weight in terms of workload" [4].

The effect of these factors on airspace capacity need to be understood at earliest stages of innovation development if realistic strategies for increasing capacity are to be implemented, and greater effort should be aimed at determining all the factors associated with the features of air traffic and sector (i.e. ATC complexity factors), and quantifying the link between controller workload and a number of complexity factors.

3. The challenge to better integrate Human Factors in MBS tools

3.1. The role of MBS in future ATM system for human factors assessment

In the SESAR Definition Phase, the ATM stakeholders have agreed that human factors expertise must be considered and involved as early as possible in the various phases of every ATM project [5]. There, it is also expressed a clearly identified need for continuous integration of Human Factors into safety management, into the design and deployment of new systems, and into operational training.

This prompt from SESAR is one of most critical aspects in human centered innovations, since usually Human Factors investigations start when conceptual and technical improvements have already been settled and there is the possibility to use prototypes for testing human-system interactions.

The current practice of Human Factors measurement is mainly based on real time simulations. Actually, for those human-in-the-loop experiments, it is relatively possible to grasp a measure of physical and mental resources consummated by controllers. But it has to be observed that Real Time Simulations "are only suitable for evaluating systems that are at a very late design stage. Designers need workload measures early in the development cycle, for prediction of new concepts of operation, interfaces and tools, to enable early concentration on the most promising potential systems" [6]. On the other hand, "success of these evaluation efforts is subject to the availability of valid and reliable measures" [7], since "understanding the impacts on the controller earlier and in a more extensive way also enables cost benefit trade-offs and different system options to be considered before too much development is done ensuring that the right system choices get made most effectively" [8].

The availability of model based simulators able to reliably describe and represent the impact of changes foreseen for new ATM systems on human actors would also help to overcome the problem of a lack of Human Factors skills in some countries. In fact it has been observed that only some Air National Service Providers have recruited sufficient Human Factors Specialists who can manage and steer the implementation of the available products [5], while existing Human Factors modeling systems need a lot of time from very experienced Human Factors practitioners [1].

In some organizations view, Human Factors is still perceived as something 'nice to have' but not yet as a 'must have' investment for a safe, sustainable and reliable high performance ATM system [5]. Given the European framework, it can be expected that improvements in reliability of Human Factors modeling will help to overcome this perception and will contribute to fully implement/support the role of Human Factors as key enabler and key business success criterion for ATM in Europe [5].

3.2. Making human performances modeling more realistic

Many studies, either theoretical either experimental, state the need for a more accurate description of human related parameters in systems for MBSs; furthermore it can be noticed that this need is expressed with reference to both present and future ATM needs for MBSs.

"To understand how new Air Traffic Control (ATC) systems and procedures may affect individual air traffic controllers and the ATC system as a whole, it is necessary to measure the inter-relationships of mental workload, taskload, sector complexity, and controller performance in ATC" [9]. And, in fact, "although vast amounts of objective data are potentially available from operational ATC system, derivation of valid, reliable, and meaningful measures from them remains a problem. This problem is particularly pronounced when variables of interest are not directly measurable, such as controller workload and performance" [7].

Human Factors consideration in short term scenario for MBS shows that reliability of such simulations could be improved if some traffic parameters that affect Air Traffic Controllers workload are implemented in the simulation model. Despite there is a good consciousness about the relevance of this kind of implementation, only circumscribed experiments have been carried out in his field until today and all demonstrate the promising perspective opened by a human centred approach to MBS. For instance, it is clear that advancements are needed to understand the relationship between these measures (taskload) and the amount of cognitive effort expended (mental workload) or the effectiveness of the results (performance) [10], that are still unclear. Also the dynamic nature of the Air Traffic Controllers work is the cause of the complexity of modelling and requires great efforts to gain an effective consideration of human variables in existing models Human variability has to be taken into account too, since "an individual's performance with the same traffic can also vary considerably: on some days, the controller might just be a better performer; there might be different kinds of background distractions in the control room; slight changes in communications might affect how the traffic pattern develops" [6].

Humans actors of ATM system have to deal with a complex interaction of a number of factors, such as situation in the airspace (i.e. by features of both the air traffic and the sector), the state of the equipment (i.e. by the design, reliability and accuracy of equipment in the control room and in the aircraft), and the state of the controller (including age, experience, and decision making strategies) [11].

Hence, a good basis for workload measurement would require a modulation of some parameters pertaining to the amount and quality of potential interventions required from the controller [4].

Table 1

Summary of main aspects affecting job demand and human performances

AIR TRAFFIC MANAGEMENT SYSTEM COMPONENT	SOME ASPECTS PRODUCING EFFECTS ON HUMAN IN TERMS OF MENTAL & PHYSICAL DEMANDS
Air Traffic Controllers	▪ age ▪ experience ▪ aptitude/mood ▪ …
Traffic	▪ number of a/c ▪ a/c type and consequent performances ▪ a/c equipment ▪ pilots behavior ▪ flows regularity ▪ a/c vertical/horizontal paths ▪ …
Sector	▪ number and position of entry/exit point ▪ geometry ▪ number and layout of routes and waypoints ▪ …
Nature of the task	▪ mental demand (monitoring, remembering, decision making,….) ▪ physical demand (hearing, speaking, …)
Controller Working Posotion	▪ HMI usability ▪ controllers aid tools (and consequent type of job demand) ▪ status of the equipment …
Physical work environment	▪ light/acoustic/thermal comfort ▪ rack/seating comfort (limbs allowances and rest) ▪ Internal Air Quality, fresh air flows ▪ …
Organizational work en-	▪ team

AIR TRAFFIC MANAGEMENT SYSTEM COMPONENT	SOME ASPECTS PRODUCING EFFECTS ON HUMAN IN TERMS OF MENTAL & PHYSICAL DEMANDS
vironment	▪ role ▪ day/night shifts ▪ worked hours and overtimes ▪ …
External constraints	▪ quality of communications ▪ weather conditions ▪ technical malfunctioning ▪ military operations ▪ …

Similar approach has been implemented for safety purposed MBS simulations, where it has been "shown that explicit models of human performance can be integrated into a systemwide air traffic simulation and that their presence makes a difference to the results of the simulation" [12].

"However, the temporal aspect of air traffic is never used explicitly. Modeling the traffic as a dynamical system would allow encompassing geometric and temporal aspects in a single model, thus yielding a much more accurate description of the complexity" [4].

3.3. The relevance of realistic modeling for ATM innovation challenges

It can be said that "workload models for future systems have to be developed from taskload models plus some new ideas about how task timings will change with different data flows, computer assistance/automation. It is essential that taskload be modelled in such a way that it correlates well with acceptable workload over the whole region of interest" [6]. But it is not enough: an appropriate model for human performance assessment in possible future ATM systems should take into account that the amount of workload experienced by the controller can be modulated by the control strategies adopted to accomplish the required tasks, possibly based on " an evaluation of the amount of controller's resources demanded by each aircraft and on the management of the available resources by the controller" [4]. This is very relevant if tasks are shifted from the controller to pilots or automation, that require a deeper consideration of information processing, multiple specific resources and time pressures [6], whose effect on controllers should be preliminarily assessed by mean of MBSs.

The proposed approach is driven by a whole Human Factors perspective, trying to embrace the range wide as much as possible of all human related aspects that can determine human workload, and, consequently, human and system performances. The table below shows some aspects of the ATM system component influencing controllers workload whose consideration may make a difference in workload rates calculation.

4. Conclusions

The framework of current practices and tools for ATM capacity measurement arises two initial questions: first one relates to the fact that some specific, but not to be neglected, combination of the above mentioned factors may shape a traffic scenario to far from human-related conditions assumed as framework in implemented measurement models, with the possible consequence that results of a simulation could be insufficiently reliable. The second issue concerns the extent on which workload rates obtained running MBS are correlate to the actual, whole, response of controllers to the specific traffic situation. That is asking the question: are present workload measurements representative of human performance? If workload estimation could be refined paying greater attention to the human factor in ATM system, type and quantity of "spent" human resources (e.g. memory, reasoning, speaking, …) could be better elicited than now, and even air traffic could be designed in order to optimize human performances.

This matter becomes particularly relevant if MBSs are intended to be used for new operational concepts and technological enablers evaluation, for which changes in air traffic controller working methods and operational procedures are assumed. In this case, time or weight representing control tasks cannot be quantified interviewing controllers or observing their actual behavior, so that human resources involvement could be estimated mainly on the basis of a human centered analysis. Furthermore, it has to be considered that the shift in task allocation from humans to machine or pilots cannot be treated simply subtracting a given task from an existing list of items to be summed up, since, for instance, a single clearance involving multiple aircrafts requires greater decision making efforts, while an automated task will require wider efforts in surveillance duties.

It can also be considered that the proposed approach opens some more general questions about the practice of integrating Human factors in ATM system development. The involved ergonomists/HF researcher community should wonder about:

1. How to bridge the gap between technology development (always faster) and the development of HF methods & techniques for technology assessment (probably not fast enough)?
2. Human Factors as something 'nice to have': is it a problem of reliability or quantitative evidence of HF benefits?
3. Which could be the driver for suporting HF investments? Are more studies about HF return on investments in ATM needed?

Claiming a greater attention towards human variables could seem to bring to a complexity level too difficult to be dealt with, but a deeper consideration of human factors in model based ATM studies is a challenge worthy to be engaged, given the risk to implement innovations that will be inefficiently used by controllers and that, finally, will not match the expected level of ATM system efficiency. Results of this challenge are totally open.♦

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♦ Editorial note for Italian readership: paragraphs from 1 to 3.2 can be attributed to G.D, whilst paragraphs from 3.3 to 4 can be attributed to E.A.