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DEVELOPMENT OF AN ADVANCED ATCO WORKSTATION

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Abstract

Several important mega projects as the European SESAR, the US NextGen, or the Japanese CARATS are addressing the future air transportation system, future traffic management. In these systems, the role of the air traffic controllers (ATCOs) is changed by introducing intensive automation. Generally, the future systems intend to decrease the ATCOs workload, however, with increasing traffic complexity and human-machine collaboration, the role of air traffic controllers and their effect on flight safety might increase.

This paper analyses the possible models of ATCOs in future ATM and describes the development of an advanced ATCOs workstation, working environment. The developed model covers the situation awareness and decision making processes, including the subjective aspects of the ATCOs decision making based on their workload, mental condition, knowledge or practice. The developed advanced working environment supports the future ATCOs' work by including (i) special information displays with augmented reality, (ii) ATCOs' workload and mental condition measurement / monitoring system, and (iii) a decision support system.

1 Introduction

Air transport plays a deterministic role in the global economy and society [1], which faces numerous problems [2, 3] that require new ideas and future targets. Several mega projects as the European SESAR (Single European Sky ATM Research [4]), the US NextGen (Next Generation Air Transportation System [5]), the Japanese CARATS (Collaborative Actions for Renovation of Air Traffic System [6]) or the Brasilian SIRIUS (Impulsionando o Desenvolvimento do ATM Nacional [7]) intend to address the future air transportation systems, including e.g. aircraft or ATM development.

These investigations have a direct influence on the air traffic controllers' (ATCOs) work [8, 9, 10] and consequently on their optimal working environment, workstations. While some roles and responsibilities from ground (from ATCOs) will be delegated to on-board (to pilots and automated systems), the intensive automation will lead to a transition from active control to passive monitoring, with minor active control in case of emergency cases or abnormal flights.

Recognising the facts above, the Budapest University of Technology and Economics (BME) in collaboration with HungaroControl, started to investigate the potential development of an advanced ATCO workstation. The university and its Department of Aeronautics, Naval Architecture and Railway Vehicles has an outstanding experience in the development of advanced simulation environment [11, 12], electric systems / sensors [13, 14] and mental models [15, 16].

The cooperating partners, initiated a research project to develop an advanced working environment with a special decision support system [17, 18], which permits to continuously measure the workload levels and being coupled with an improved information display. This paper describes the major results of the project.

2. ATCOs in future ATM

2.1. Role of ATCO in future ATM

ATCOs are responsible for the safe and efficient movement of air traffic, including the ground, terminal and en-route operations.
The general duties of the ATCOs could be divided into the three following tasks [19]:

- direct support tasks: check technical equipment at the working position, make a “mental picture” of the air traffic, handle and process the flight plan information, ensure the correct co-ordination, manage the air traffic within the area of responsibility, develop and update the working knowledge, conform with medical requirements;
- core tasks: maintain “situational awareness”, make decisions for control actions, conduct R/T-communication, provide pilots with relevant information, provide separation, provide assistance to A/C in abnormal situations, provide tactical air traffic management;
- indirect tasks: prepare operational documentation, supervise control room, report on activities, co-operate in incident and accident investigations, participate in ATC development and implementation programs, participate in ATC evaluations, provide unit-training, determine the operational competence of controllers.

To manage these tasks, ATCOs must implement their knowledge and skill in situation awareness and decision making. In other words, they must perform cognitive and performance tasks.

The future systems (e.g. SESAR, NextGen) change the role of ATCOs by redefining and introducing new principles (as free flight, performance and trajectory based airspace, airborne, net-centric service, single supporting info-communication system, automation, collaboration, 4D contract based management, dynamic resource management, improved surface operations, integrated flight planning, system wide information management) and a high level of automation (Fig. 1.).

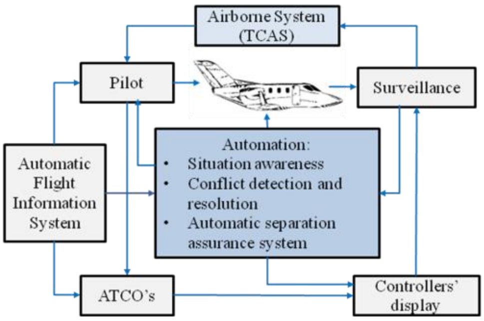

Fig. 1. The wide automation introducing major changes in ATCOs' role

These two aspects introduce a paradigm shift in the ATCOs' roles. NextGen envisions [20] five types of navigation service provider personal roles :

- capacity managers in collaboration with airspace users and flight operators,
- flow contingency providers in collaboration with flight operators,
- trajectory managers in collaboration with flight operators,
- separation managers (might be flight crew depending on the airspace and the operation),
- automated dissemination to operators and flight crews, flight operation centers, third-party service providers.

The process model of ATCOs' core tasks is also changing (Fig. 2.).

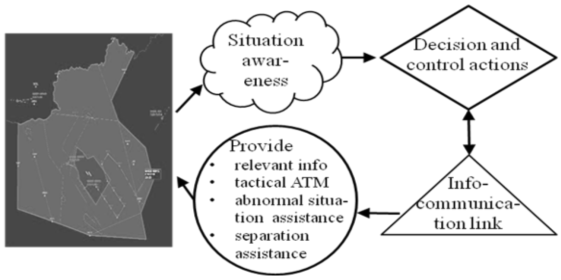

Fig. 2. Process model of ATCOs' core tasks

It is clear that ATCOs use the relevant information in situation awareness - decision and control action processes. They provide relevant information to pilots, make tactical ATM and especially they must assist the abnormal situations. By doing so, ATCOs might be seen as passive monitoring bodies, which however must provide assistance in abnormal circumstances. This will define new requirements regarding the controllers' individual skills, knowledge and competence.

2.2. ATCO situation model

The first investigations and modeling of the ATCOs' roles, tasks and working quality goes back to the 1970s. At the end of the last century, numerous models were developed on (i) the situation awareness [21], (ii) the information processing at human behaviour levels [22], (iii) the cognitive decision making [23], (iv) the taskload and workload relations [24] or (v) the psychological aspects [25]. These models were updated and adapted [18] to the new requirements (for example on safety, cost-efficiency) and the system framework as defined by SESAR and other strategic research agendas.

The model of situation awareness and dynamic decision making developed by Endsley [21] was adapted for defining the ATCOs model being relevant in the context of the future air transportation systems (Fig. 3.). The model contains three levels:

- system factors: such as system design aspects, performance, capability, operability, controllability, automation, environment, system operational factors, intensity and complexity, or observability, which define the operator (ATCO) working environment, task, information and workload;
- tasks: as process model of ATCOs (Fig. 2.) has three hierarchy sub-levels:
  – sub-level 1. - encompass and awareness of specific key elements of situation,
  – sub-level 2. - comprehension of current situation, integration of that information in the light of operational goals,
  – sub-level 3. - ability to project future states of the systems;
- individual factors: including
  – skills and competences (ability, knowledge, tacit knowledge, training, intuition, mental condition) of the ATCOs,
  – information processing and mechanism (depending on long term memory)
  – system management (e.g. goals, objectives, preconceptions).

The developed model contains three major new elements:

- the representation of system factors, based on (i) system functions, (ii) operational characteristics and (iii) operator - system interface (working environment), including new elements as system operability (interoperability), controlability, automation; system operational intensity and (traffic) complexity, observability and operational (flight) information system; developed working environment to increase the level of situation awareness,
- the situation evaluates from present situation instead of state of environment, as defined by Endsley,
- individual factors includes new elements, as the actual (present) mental condition of operators, as in systems with high level of automation, the role of psycho-physiological condition of the operators is incresing,

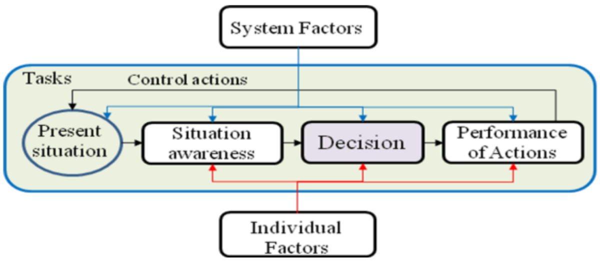

Fig. 3. Simplified model of situation awareness in the future dynamic ATM environment

3. Developing the new models

3.1. ATCO model adaption

According to Rasmussen [22], three levels of decisions can be defined (as summarized in [18]). The first level, the so-called skill-based control is applied by the operators (pilots or ATCOs) when the situation is normal and the operator can easily recognize the situations and can work 'automatically'. At the second level, the operators must recognize and identify the situation and apply the rule based solutions to reach the expected situations. In case of abnormal flight situations or possible flight conflicts, the operators must derive the solution with their knowledge and practice. This is the knowledge-based level.

Dörner [26], already in 1993, defined four basic parameters determining the process of air traffic control: (i) degree of differentiation, (ii) selection threshold, (iii) backup rate, and (iv) speed of information processing. Seeing the features of the coming ATM environment, this should be reconsidered [18]. Firstly, with increasing traffic complexity and stress on conflict detection and resolution, the available time for situation awareness and decision making might play the most important role in the success of the performed actions. Secondly, automation initiates a change in ATCOs' role. ATCOs will monitor the processes instead of direct and active control. This makes their job more monotone, while in case of any errors or problems, ATCOs as operators might solve the problems based on their knowledge-based behaviour. Therefore, human aspects and mental condition will have an even higher role in the future ATM, compared to the present circumstances. Therefore, the ATCOs' model was redefined (Fig. 4.).

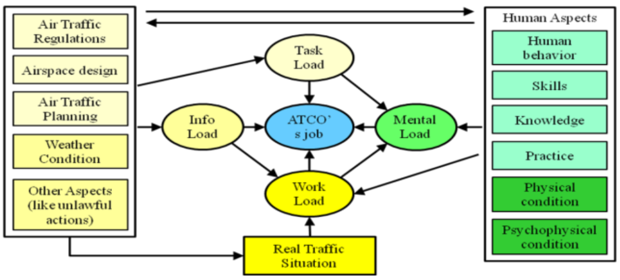

Fig. 4. ATCO model

ATCOs will work under task, info, work, and mental loads. The task load is generated by factors such as airspace demands, interface demands and other tasks [24]. In the future systems, traffic regulation, airspace design and traffic planning might play the major role. However, in highly automated systems, the changes in traffic intensity, abnormal and emergency situation might generate several extra tasks. The task load depends on the weather condition and on the other aspects, like unlawful actions.

The info (or information) load is a relatively new problem generated by information overload, especially if these are generated by different sources. For example, the weather forecast information and information about the real weather condition reported by other aircraft in the same sector.

The task and information loads together with the real traffic circumstances generate the workload of the operators. Hilburn and Jorna [24] analysing the workload explored both the subjective and objective workload of ATCOs. This principle was improved by the introduction of the mental load as the fourth elements of the total workload. The mental load depends on the human behaviours, skills, knowledge and practice, as well as on the ATCOs' physical and psychophysical conditions. In other words, the mental workload is a function of the human quality, acquired characteristics and instantaneous physical and psychophysical condition of the operator - controllers.

ATCOs as an operator - controllers play a deterministic role in the ATM. They make decisions upon their situation awareness. They must define the problem and choose the solution from their resources, which makes human controlled active systems endogenous. Resources are methods or technologies that can be applied to solve the problems [28]. These could be classified into the so-called (i) passive (finance, materials, information, energy - like aircraft control system in its physical form) and (ii) active (physical, intellectual, psycho-physiological behaviours, possibilities of subjects) resources. The passive resources are therefore the resources of the system (e.g. air transportation system, ATM, services provided), while the active resources are related to the controller itself. Based on these, decision making is in fact the process of choosing the right resources that leads to an optimal solution.

Subjects (like ATCO) could develop their active resources (or competences) with theoretical studies and practical lessons. However, the ability of choosing and using the right resources is highly depending on (i) the information support, (ii) the available time, (iii) the real knowledge, (iv) the way of thinking, and (v) the skills of the subject. Such decisions are the results of the subjective analysis.

The new ATCO model includes the subjective factors, too.

3.2. Redefinition of the requirements related to the ATCO working environment

The air traffic controllers' workstation has changed a lot since 1910s. Today, the modern workstation is quite simple, computerized and it integrates several subsystems into one working environment (Fig. 5.).

Fig. 5. ATCO workstation at a relatively small airport
(Ronaldsway Airport, Island of Man , photo: Jon Wornham - http://www.island-images.co.uk/ATC/zRon2014/1009221616.html)

For the development of an advanced ATCO workstation, the following preliminary the governing rules were defined:

- the system must be developed for the coming systems (as SESAR, NextGen), it is not a simple workstation, it is a working environment,
- ATCOs are the elements in the general ATM systems, man-machine interaction must be designed for system quality (not for human 'pleasure'),
- all the available information must be harmonized and integrated into a single system,
- ATCO models must be based on the developed model shown in the Figure 4.

The last rule introduces the most important improvements, the continuous evaluation of the ATCOs' loads with sensors being integrated in the working environment. The identification and evaluation of the possible methods for monitoring the different loads resulted in the selection of the following definitions:

- taskload is defined by the preliminary records on e.g. flight plans, traffic complexity, weather conditions,
- information load as quality and quantity of information supporting the operators is a relatively new type of problem caused by many available information confusing the operators, and putting them into the difficulty to evaluate the right and required information [29],
- workload depends on real traffic conditions, traffic complexity, and can be determined from the traffic performances (see for example [30]) or evaluated from the operator reactions (for example from the evaluation of the ATCOs voice - see [31]),
- mental load takes into account the human subjective behaviours including e.g. knowledge, practice, physical, psychological conditions) and it is always associated with workload [32]. It can be determined from the human basic medical parameters, like heart rate, blood pressure [33] or electroencephalogram (*EEG*) [34, 35].

During the development of an advanced ATCO working environment, the following actions were made:

- preliminary analysis of the emerging and available new scientific results and technologies (as using the methods of the subjective analysis or investigation of the possible integration of new micro sensors in the working environment),
- analysis of the possible harmonization of the available information,
- concept development (including the operational concept),
- development of the required system elements (as methodologies, sensors, data processing),
- concept testing, and verification in simulation environment (built up at BME),
- validation demonstration tests,
- deployments.

4. Development of the ATCO workstation

4.1. Development of subsystems and elements

Several subsystems and system elements have developed already.

Methods for load evaluation

The different types of the loads are interdependent and they are changing in very complicated forms. Figure 6. shows the task- and workload variations depending on several aspects as defined by [36]. The developed methods for determining the loads are based on simplified adaptive weighted combinations of the factors defined in the previous page. Here, adaptivity means that the methods and weighting coefficient must be adapted to the real environment as real group of controllers.

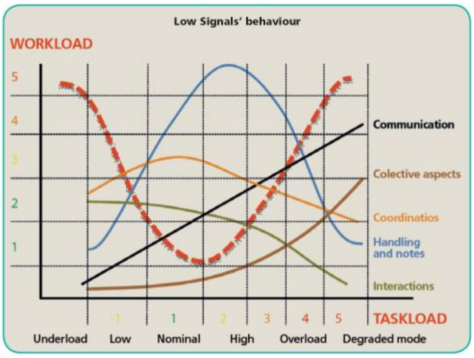

Fig. 6. Workload - taskload interaction [36]

The results are classified in five categories. The different type of loads presented with lines, with their length and colour depending on the measured value of the given load [37]. The lines of task- and workloads are always displayed, while the information and mental loads are only presented once switched on, or in case of overload.

Micro sensors integrated in the workstation elements

Several devices were developed with integrated micro sensors. For example, for the monitoring of the mental loads, mental condition of the ATCOs, a special mouse was prepared with micro sensors measuring the acceleration, skin resistance, temperature and hearth rate (Fig. 7.). Other sensors, as eye and head tracking systems, or infrared cameras were also introduced.

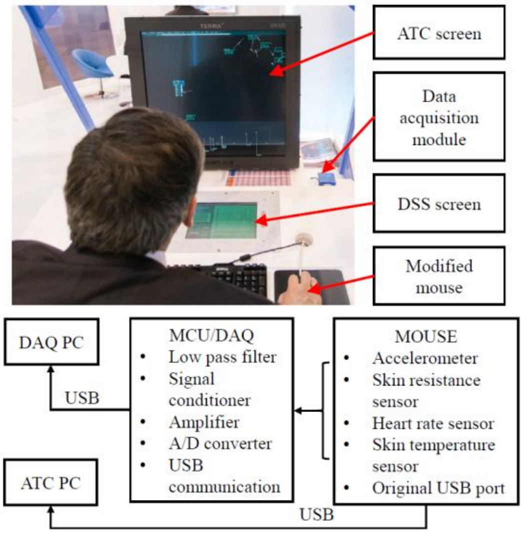

Fig. 7. Use of the developed mouse with micro sensors
(DAQ- data acquisition board, MCU – Micro controller unit, USB – universal serial bus, DSS – decision support system)

Eye tracking control

In 1989, the FAA published a literature review on "Air traffic controller scanning and eye movements in search of information" [38]. Nowadays, due to the rapid development of image processing and sensing technologies, the eye and head tracking technologies are ready for being integrated in the ATCOs' working environment.

At first, a special system was developed with a binocular box. 4 special motion sensor cameras were installed in the laboratory test environment (simulating the remote / virtual control tower) to detect the position of the binocular box (Fig. 8). Finally, near the target an information label was presented on the screen, and the actual available information about the target.

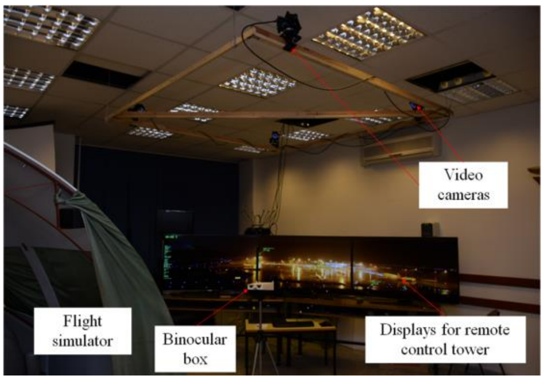

Fig. 8. The investigated eye tracking system control system

Later professional tracking systems (OptiTrack, myGaze, Xsens, Vicon) were also investigated. The results demonstrated that the created software works as planned and supports the targeted investigation. The information required by the controllers is visualized at the right target, the right time and in readable form. The system was able to track multiple boxes simultaneously, which proves that the system can support more than one ATCO's work in the same time.

4.2. Novelties of the developed system

The developed advanced ATCO working environment has three major novelties [18].

Three layer information displays

All the available information were presented in high resolution interactive displays. The first layer of visualization shows the live (real active) situation based on the radar, flight information and ground service data. The secondary level of information could be automatically displayed if the system detects that further information is required for the controller where he/she is looking at. This function is initiated by the eye tracking control and it shows the available information on at the target (for example from secondary surveillance system, ADS-B, weather forecast information). The third layer is dedicated to the analysis of the situations (as changing the lighting or air conditions, or displaying the regulatory aspects in abnormal situations).

Load monitoring system

The load monitoring system is continuously measuring and displaying the individual task-, information, work- and mental loads of the individual ATCOs. Generally, this information is available for the given ATCOs, however, in case of overloads, the system is reporting to the control managers.

Decision support system

The decision support system assists the ATCOs to perform their job as requested. The system has three subsystems. The first is the load monitoring system, which measures and monitors the ATCOs' load conditions, and might advise the required actions in case of overload.

The second subsystem is the situation awareness - situation analysis - and decision support process with a developed subjective decision model. This means that the decision support system will self-adapt to the mental condition of the individual ATCO.

Finally, the third subsystem works as an emergency alert. It estimates the possible abnormal or emergency situations, conflicts and/or identifies the appearance of emergency situation in their early stage to alert the user and provide recommendations to solve the situation.

Overall system set-up

With the developed subsystems, system elements and based on the three potential novelties discussed above, a special system, an advanced ATCO working environment, workstation was developed (Fig. 9.) with the following features:

- tower-less, augmented reality or/and large display systems (for individual solutions),
- three layer information including,
- live (active) radar and ground service information,
- information from automatic flight information system,
- other information packages (weather forecast, regulatory requirements),
- monitoring system and sensors to measure the ATCOs' condition

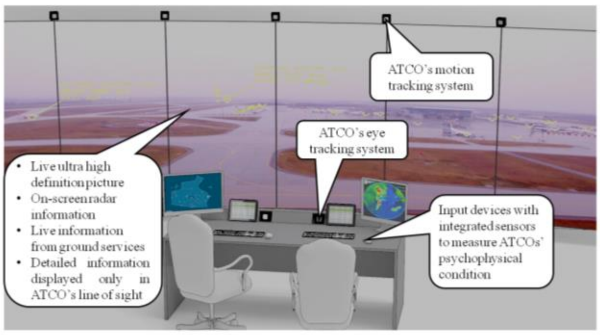

Figure 9. The basic set-up of the overall system.

The advanced ATCO workstation was also tested. The first part of the tests shown promising results [18]. 78 % of the researchers and invited ATCOs believed that the developed system improved safety and airport capacity. About 16 % of the researchers underlined that the task and moral information might confuse the ATCOs. The rest (around 6 %) thought that the measured information load has no serious effect on the ATCOs' work as they already filtered and optimized the information, and the subjective factors are not that important due to the well-developed training methods.

5. Conclusions

In the coming future air traffic systems, the ATCOs' workload is expected to be decreased with various tools and higher levels of automation. The new sub-systems will provide expanded information and improved decision-making capabilities. However, with increasing traffic complexity and human-machine collaboration, the role of air traffic controllers and their effect on flight safety might increase.

The joint research initiative between HungaroControl and the Budapest University of Technology and Economics created and introduced a new approach to model the ATCOs' working processes and developed an advanced workstation, working environment. The investigations also redefined the ATCOs' core tasks based on situation awareness - situation evaluation and decision making. The created ATCO model included the task, information, work- and mental loads. Another novelty of the created model is the introduction of the influence of subjective factors on the working quality.

The developed working environment has three major novelties: (i) special information displays, (ii) ATCOs workload and mental condition measurement / monitoring system, and (iii) a redefined decision support system.

The major system components were designed, manufactured and preliminary tested in laboratory environment. It was found that the basic concept is feasible, works as expected and seems to bring the envisioned benefits.

In the future, the concept would be tested through various simulators to demonstrate its cost-effectiveness and operational safety.

This research was made in a collaboration between the Budapest University of Technology and Economics and HungaroControl. This permitted the scientific bases to be combined with the ANSPs' requirements and expectations, leading to innovative solutions. Some of the system core elements were also exhibited in the World ATM Congress in 2014 and 2015.

Acknowledgement.

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