Aircraft in Your Head: How Air Traffic Controllers Mentally Organize Air Traffic

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***Abstract*—The StayCentered Project at Technische Universität Chemnitz aims for assisting air traffic controllers in stressful traffic situations. Therefore we are seeking to comprehend air traffic controllers' principles of operation within the dyadic team structure. First exploratory research revealed insights into air traffic controllers' practices, their information processing (mental models), potential stressors, and related emotional effects. This paper discusses the results and the implications for air traffic controllers' work in general and the StayCentered project in particular.**

***Keywords*–Air traffic control; HCI; Decision Support; Mental Models**

I. INTRODUCTION

In the state of normal operation, a dyad of two air traffic controllers is responsible for any given airspace. Both have access to task relevant information, such as radar data, weather reports, and flight schedules. An impression of a German air traffic controller's workplace is shown in Figure 1. Within the dyad, the air traffic controllers take different roles: one (executive) is responsible for the communication with the pilots using spoken traffic commands over the radio, while the other one (planner) is coordinating the acceptance or handover of flights from or to other sectors. This is necessary, since each sector has its individual operation of flight-levels and is generally only accepting flights within a certain flight-level threshold in order to keep a smooth vertical alignment between adjacent flights. While arranging the handovers, the planner is also responsible to verify the communication between the executive and the pilots and to intervene, if necessary. Therefore, the division of responsibilities is depending on a good internal communication as well as a transparent work situation. Expediting and maintaining orderly traffic flows can be characterized as the main goal of air traffic controllers' work. However, the adherence to strict separation standards for safety reasons sets nonnegotiable rules that act as constraints [1, p 341]. The combination of these two characteristics results in a demanding work, especially because air traffic controllers have to make most of their decisions in a narrow time frame [2][3]. Due to the characteristics of their work and the general limitations of the human ability to process information, air traffic controllers often experience time pressure [1, p 339] that can lead to a stress response. A stress response is the activation of several physiological systems on the affective, cognitive, neural, endocrinal, and muscular level [4] when individuals are facing a stress inducing stimulus (stressor). However, stress is not per se a negative state, since the evaluation of the stressor depends on the interplay of the situational demands

Figure 1. An air traffic controller dyad at the German air traffic control center in Munich (Source: DFS Deutsche Flugsicherung GmbH).

and the abilities of the individual to cope with the situation [5]. Since time pressure is a situational characteristic in the daily work of air traffic controllers, the occurrence of negative stress and its emotional and psychological consequences (short term: anxiety, despondence, anger, cognitive impairments; long term: fatigue, health issues, depression) is likely (see for instance [6][7]). Therefore, the reduction or rather avoidance of stress inducing situations is an important goal in the daily work of air traffic controllers.

Within this paper we will introduce the StayCentered project context that motivates our research. Section III outlines the methods used to gain the findings that will be discussed in Section IV. The following sections relate findings to the project context in terms of the future mental and emotional model as well as future interfaces. Section VII summarizes and concludes the paper.

II. THE STAYCENTERED PROJECT

Typically, the work of an air traffic controller involves managing various flight routes, aircraft, and altitude as well as air speed differences. Additionally, meteorological circumstances, technical maintenance activities or, in rare circumstances, emergencies can occur at any given moment and require swift and correct reactions by the controller. As air traffic controllers often work in dyads, in order to have an inherent corrective at all time and to provide redundancies, the StayCentered project at Technische Universität Chemnitz aims for enhancing the already high security standards of air traffic controllers, and for identifying as well as for offering assistance within cognitive stressful flight situations. Therefore, the dyadic team structure has to be analyzed comprehensively: both their voiced interactions between themselves and with the pilots within their controlled airspace. The goal is to be able to identify human error potential in voicing commands, interpreting visual data representations and to identify limits in cognitive processing capabilities. The resulting model of a working controller dyad is then used to simulate the emotional and cognitive state of the dyad in regards to upcoming air traffic some hours in advance. For example, planned but delayed flights (e.g., a sandstorm in Dubai and a thunderstorm in Moscow) will lead to an increased number of aircraft in their destination sector. Flight control management would then be able to split sectors and to call in additional controllers in order to keep the workload at a comfortable level. In addition, the controller stations themselves already offer the possibility for the controllers to signal an increased workload. However, the implementation of the projects biophysiological measurements would allow for an objective and immediate feedback to the controllers about their current cognitive state and troubleshooting capabilities [8], as well as for a workload regulation [9]. Therefore, the galvanic skin response, facial action coding, body posture, vocal properties, eye movements and pupil dilation are recorded and used to infer an emotion valence, arousal level, and cognitive load [10].

III. Methodology

To assess whether or not an air traffic controller experiences stress and the associated negative emotions, it is necessary to fully understand how the controller is receiving and processing the crucial information and how this is converted into practical actions. Since it is not possible to gain insight into the information processing objectively from the outside, it is necessary that the air traffic controllers verbalize their cognitive processes. For this purpose, we used semi-structured interviews outside the work situation to gather general information about how air traffic controllers experience work-related stress and how they cope with it. Among others, we let them describe exceptional situations which were especially demanding, how they solved them, and how they felt afterwards. Furthermore, we used the thinking-aloud approach in interviews to get a basic understanding on how air traffic controllers process information. We confronted them with a typical radar screen printout. The sector and scenario were unknown to the participants. It described a situation containing 8 aircraft, a mid term conflict of two aircraft with same heading and differing speed and a lateral conflict of two aircraft with opposite heading, but vertically divided. We asked them to evaluate the given flight situation regarding the salience of important information as well as the order in which critical data are perceived and processed. Additionally, we observed the air traffic controllers during their work at the level of moderate participation, allowing us to ask specific questions. Here, we also used the thinking-aloud approach to get information and explanations about certain actions and events. The observation under real working conditions is especially important since cognitive and emotional reactions are known to be a combination of person and situation, and thus only the inclusion of the given situational characteristics allows for a meaningful interpretation of the data gathered in the interviews. We decided to use this combination of methods in an exploratory approach in order to get the information of the air traffic controllers as authentic and natural as possible. Expressing thoughts, ideas and considerations in their own words in an actual work situation as well as in the reflecting, meta-cognitive form of an interview appears to be the adequate methodical approach for this kind of research problem. The data was collected between February and April 2015 at the facilities of the Deutsche Flugsicherung (DFS) in Langen and Munich. To assure a sufficient variability in the data, we interviewed and observed experienced and novice air traffic controllers likewise. Altogether, we collected data of N=21 air traffic controllers (age: 18 to 57). Since the evaluation of the air traffic controllers' work requires a basic level of expertise regarding the work station, work processes and air traffic, all researchers received an introduction to the air traffic controller's work by an expert of the DFS before data collection. Since recording audiovisual material is problematic due to security reasons, all interviews and observations were recorded by pen and paper. For the purpose of the analysis, all data was coded and categorized. Due to the exploratory nature of the research, we did not follow a standardized coding scheme. Instead, we tried to identify all relevant factors regarding the cognitive and emotional constitution and experiences of the air traffic controllers in relation so the given work situation.

IV. Findings and Discussion

By fulfilling their daily tasks, air traffic controllers face highly demanding situations. They need to process plenty pieces of information simultaneously that are arriving on multimodal channels (primarily auditive and visual). Based on this information, controllers have to make quick and reliable decisions to ensure safety of the aircraft, and thus people, under their control. When thinking of the air traffic controllers task, we first thought about the controller sitting in front of the radar screen and scanning the actual flight situation for potential conflicts all along. But according to our data, the radar screen is most of the time rather a secondary tool that is used to check whether every aircraft behaves the way it should. Usually, the air traffic controller is creating an internal representation of the current flight situation reaching about three minutes into the future. This picture is mainly build upon flight plan data that can be accessed via the (digital) flight strips, the controller's experience, and internalized knowledge about standard routes and so forth. A schematic diagram of the air traffic controllers' mental situation is depicted in Figure 2. According to Mogford [11], such a picture consists of situation awareness that is based upon the controller's mental models. While in literature mental models of air traffic controllers are often described as somewhat three dimensional models [11][12], our controllers explicitly stated that they do not build up a three dimensional model of the situation. They described it as a two dimensional model, similar to the radar display that is expanded by a variable indicating vertical layers. Other studies revealed that air traffic controllers [13] and already controller students [14] do not necessarily build up a three dimensional mental model. They develop an individual mental structure to represent the three dimensional data over time. In standard situations, when a flight strip is appearing on the controller's screen representing an airplane that is about to enter the sector soon, he is first looking for the route it is tending to take and at which flight level. For first conflict detection, the controller is checking overflight times at the fixes. If overflight times are overlapping ten minutes to the ones of another flight he marks a potential conflict. When the involved aircraft appears on the radar screen, the controller is checking a second time for the conflict and then improving gradually the quality of his prediction

 ISBN: 978-1-61208-447-3

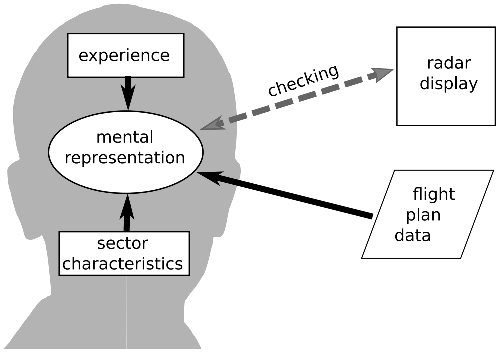

Figure 2. Schematic diagram of the air traffic controllers mental situation representation and its sources.

about a possible problem. First, he is estimating vertical and horizontal separations according to his experience (rule of thumb). He can use distance measuring tools provided by the system on the radar screen, but he is also able to do exact calculations using mental arithmetics, if necessary.

However, there are still situations requiring the air traffic controller to construct the current situation from flight strips and radar screen (e.g., during a hand over, the controller gets a description on the situation while scanning the radar and the strips). The first variable controllers focus on, while scanning the radar display, is altitude information and whether an aircraft is climbing or descending. After this, aicraft's heading and position are considered and lastly, ground speed gives a hint on the existence of a potential conflict. Rantanen et al. identified in their experiments [1] altitude as the information that is processed first for conflict detection. Furthermore, Mogford et al. emphasized altitude and heading as the most important information for air traffic controllers' situation awareness [11]

During interviews the air traffic controllers mentioned three main stressors:

High Traffic Load
The crucial factor for traffic load is the number of aircraft under control. However, the resulting workload goes beyond the sheer number. The structure of the airspace and standard routes as well as directions of the aircraft have an impact on perceived complexity. Plenty of vertical movements, as in approach sectors and sectors in the lower airspace, and lots of crossing trajectories increase the probability for potential conflicts.

Unexpected Events in the Airspace
Since air traffic controllers tend to have a detailed picture of upcoming events, unconsidered events may cause additional load, since they often require a swift reaction while simultaneously adding a unknown variable to their calculations. Usually, these are events that are neither listed in nor logical consequences of flight plan data. Initially, we considered emergency flights as unexpected things causing stress because air traffic controllers have to clear the way for them. However, most of the emergencies will already be marked in the actualized flight plan by the pilots. Thus, they can be regarded as expected traffic, just with a higher priority, making them just another variable in the air traffic controller's mental model. Even closures of single airports aren't surprising, because every flight has an alternative destination stated in its flight plan. However, an unplanned aircraft calling in or flights within their sector boundaries, which are not under their control, are stress inducing factors. Hence, a pilot who forgot next sectors frequency, just asking for it once again, may cause more confusion than emergencies, because the controller already deleted the associated flight strip and thus also removed the flight and callsign already from his mental model.

Malfunction of Equipment
Generally, the air traffic controller is dependent on his equipment. Without radar display the controller has to rely on the pilots following his instructions without any misapprehensions. Without flight plan data, the controller would loose the ability to proactively regulate air traffic. Still, air traffic controllers emphasized especially malfunction of the radio as problematic. Without the ability to communicate with the pilots the air traffic controllers are completely incapable of action. They don't know about pilots' plans and aren't able to forewarn them of an upcoming danger.

Other Things Indirectly Being Relevant
For efficiently building their picture, air traffic controllers rely mostly on their experiences and internalized information, such as standard routes and sector borders. If controllers are returning after a period of absence (e.g., illness or holidays), they perceive their work as more demanding, due to changes in standard routes, sector boundaries, or agreements. Also, other impact factors like general well-being, mood, private problems etc. were mentioned by air traffic controllers to influence the work performance. Therefore, personal factors often change the perceived demands. According to the air traffic controllers' experience, the same workload can be experienced differently.

These results on potential stressors align with the five most stressful items found by Brink [15]. South African air traffic controllers rated the number of aircraft, extraneous traffic, unforeseeable events, peek hour traffic and limitations, and reliability of the equipment to be most stressful factors out of a questionnaire with 20 items.

Let's have a closer look at the term 'team'. When we initially used the word 'team' within the context of air traffic controllers, we had the air traffic controller dyad in mind. However, the air traffic controller's understanding of 'team' covers more than initially assumed. On the one hand, they used the term when speaking about all the air traffic controllers responsible for German airspace and adjacent sectors. When recognizing a potential conflict situation that would happen in the neighboring sector, but could be prevented or already solved within their own sector, they would do so. When recognizing a conflict situation within an other sector, they would warn the responsible controller. When recognizing that controllers responsible for an adjacent sector have high traffic load and they are stressed, they try to keep further traffic away from that sector or try to avoid more stress for their

 ISBN: 978-1-61208-447-3

colleagues by organizing the flights in their own sector in a way that makes them easy to handle in the next one. This understanding of a team is also supported by the fact that air traffic controllers are on a first-name basis with each other. On the other hand, the term 'team' was used while talking about the air traffic controller's organizational entity. In German air traffic control centers, there are groups of air traffic controllers that are responsible for several neighboring sectors. These sectors share borders and in times of low traffic load they can be combined. Each controller out of this group has the admission to work on every position within these sectors. Thus, each of the controllers will somewhen constitute a dyad with every other controller out of this group.

However, good communications and collaboration with the air traffic controller's colleagues, his supervisor, and the pilots is critical to safety and efficiency in air traffic. We determined the following typical forms of communication. Short-term collaboration with pilots consists of speech over radio using predefined terms and routines in order to minimize the number of misunderstandings. The supervisor communicates to the controllers through the display of a duty roster. Change requests, rapid updates, and the like encourage both to move to and talk to each other, although telephone connection is available. Most of the communication is happening within the dyad responsible for a sector. Both, the executive and the planner have to build up a shared picture of the situation. In order to do so and to solve potential conflicts, they communicate using gestures (pointing gestures to guide the others attention onto the screen, sometimes they are also using the other one's mouse), and the flagging of (digital) flight strips (to highlight potential conflicts), but also in this case is speech the dominant communication channel. In times of high traffic load, controllers are sitting up straight, speaking concisely about traffic concerns. In times of low traffic load they are more relaxed and they are chatting with each other and the surrounding controllers. Usually, the planner is talking to other dyads via telephone, except for the ones sitting spatially near to him. Another tool for controller to controller communications is the so called "'Geneva traffic light"'. In German control centers there is a display assigning a color (green, yellow, red) to each sector with green being the default color for normal traffic load. By setting this color, controllers can communicate their actual workload to other controllers and the supervisor. However, if there is really high traffic load controllers are so focused on their work that they often don't think about changing the color.

Emotional aspects within the air traffic controller's work include awareness of own sentiments and awareness of the emotional state of others. Generally, controllers stated that there are no crucial emotional situations. Sometimes private problems cause the controller to "concentrate a little more" but usually they know how to act out of them. After a critical situation at work they are in need of someone to talk to. Often they prefer talking to their colleagues about it. During follow-up discussions some other situations were identified. Air traffic controllers said they are feeling proud, after managing a tricky situation smoothly. They have a sense of delight, when pilots thank them for satisfying their wishes (e.g., a direct). During long periods of low traffic the predominant sense is boredom. The most important indicator for the others emotional state is the sound of their voice and their choice of words, especially during communication using telephone or radio. Succinct answers indicate elevated concentration. During communication with their spatial neighbors, gestures and poses can be accessed additionally for emotional awareness.

V. Implications for the Mental and Emotional Model

From a psychological point of view, it is not surprising that the mental and emotional states of air traffic controllers are influenced by personal as well as situational characteristics. However, without a detailed analysis of the air controllers work, it is impossible to specify the relevant variables and their parameter values. Based on the collected data we are now able to consider precise variables in our model. Regarding the situational aspects, the number of aircraft as well as their flight characteristics are the main aspects for potential workload, and of course the available time is also relevant. Further research is necessary to identify the concrete relationship between those variables. However, it is already clear that there is limit on how many interactions can take place between the air traffic controller and pilots, because every interaction takes several seconds. Considering the well-known relationship between arousal and performance on difficult tasks [16], such as the work of an air traffic controller, we assume that the optimal efficiency lies far below the physical limit of interactions. It has still to be determined how to express the comfort zone of air controllers by an index. One potential solution is the indication of interactions per minute with the option to weight interactions depending on the situation's complexity. The model requires two kinds of critical values for the index that signals a possible overload: One is relating to situational peaks which can be understood as episodes of high workload in a rather short time frame. The other one is applying to longer periods of time with an increased workload that is higher than the optimum but lower than the situational peak. Both kinds of overload can result in mistakes, incorrect decisions or just slower reactions and must be prevented. Even though German air traffic controllers can be considered a homogenous group of specialists who are able to work under pressure, the critical values must be personalized due to differences in personality related factors. Our data suggest that many typical personality variables affect the work of air traffic controllers, such as mood, alertness, work experience, private problems, absence due to vacation, or sickness, etc. The main problem for the consideration of those variables is their problematic measurement: Many of them are only available to the air controllers themselves, and even they are not always able to fully specify all factors that might influence their performance or to quantify them. Furthermore, many of those variables are changing on a daily basis, even though they should not fluctuate that much. The personality factors can therefore be used to improve the index based on the situational variables. Simply put: The critical values can be adjusted depending on how an air traffic controller feels - if this information is available - or based on objective information like the absence of a controller for several weeks which lets him experience the work as more demanding during the first days of his work. For a short-term evaluation of the air controllers state, additional diagnostics will further improve the determination of the personality variables influence. Additionally, a cross-validation and combination, respectively, with psychophysiological parameters, eye-tracking, voice characteristics, facial emotion expression as well as poses and gestures will also

 ISBN: 978-1-61208-447-3

help to classify flight situation regarding their complexity. For instance, a more complex problem will result in longer times of fixation on the involved flights, an increased skin conductance, shorter voice-commands, a straighter body position and a stern facial expression. Our model must therefore take many variables into account, some global and some situational. Things become even more complicated, since the air traffic controllers are usually working together as a dyad. The model has to take into consideration not only the individual parameters, but also the specifics of the team. The same flight situation in a sector might result in excessive demands for one dyad but present an acceptable challenge to a team of veterans. This additional set of team related variables complicated the model, since questions about the structures and relationships between all the variables contained in the model are not fully answered yet.

VI. Implications for the User Interfaces

One of the main goals of the StayCentered project is to identify and to offer assistance within cognitive stressful flight situations. Current interfaces have to be rethought in order to give access to the identified and simulated mental and emotional states. The StayCentered interfaces will be designed to give decision support to the supervisor, to facilitate cooperation, and to adapt with respect to the controller's current state. At the moment the supervisor's decision upon splitting up a sector is done by consulting workload predictions, mainly based on the expected number of aircraft, and controllers demands. The StayCentered supervisor interface will present the simulation's forecasts. Anticipated stressful situations should be visible at a glance and supporting decision making on resolving these situations. As described above, cooperation and communication are crucial elements of the air traffic controllers daily work. These communicative situations shall be supported by the interfaces. There should be adequate ways of communication so that controllers don't have to leave their position for consulting their supervisor. The controllers workspace should be designed in such a way that the actions of one controller are clearly visible to his partner in the dyad. Thus, we are expecting to support the creation of a shared mental model and enhancing communication. The most obvious advantage of the StayCentered system is that the mentioned "Geneva traffic light" can change its color automatically. However, also it's presentation could be enhanced. Currently, each sector is represented by a colored button (green-yellow-red) on a secondary screen. Additional short textual remarks for the sectors in stressful situations are available. A graphical integration of this information into the radar screen would make it accessible at a glance. The interface adaption with respect to the controller's state applies to the interfaces at the controllers workspace. Currently, German air traffic controllers get their information via a plan-view radar screen (aircraft related data), a digital strip board (flight plan data), and several secondary screens (additional information like weather data or the "Geneva traffic light"). For a more detailed description of the controllers workspace see [17]. The information presentation is independent of the emotional state of the controller, the workload, and the complexity of the actual flight situation. However, the importance of information objects differs from situation to situation. StayCentered controller interfaces will consider the identified emotional state of the controller as an indicator for the chosen representation. And it is not just about assisting the controller in stressful situations. In times of low traffic load, controllers often feel bored. Since boredom has a negative impact on their attention, we want to consider these situations within the design of the adaptive interface as well. Good user interfaces support the user's mental models. Recent research on air traffic controllers' interfaces often considers three-dimensional radar displays (for an overview on current research see [17]). According to our data, the controller's mental model of a flight situation is not necessarily three-dimensional. Therefore we would prefer a two-dimensional representation and allow for stepwise adaption to required accuracy. Nevertheless, the aircraft's altitude is still extremely important for detecting potential conflicts and should consequently be considered with high priority within the radar visualization.

VII. Summary and Conclusion

Within this paper we described the StayCentered project at Technische Universität Chemnitz that aims for assisting air traffic controllers' work by identifying and simulating the air traffic controller dyad's mental and emotional states. Within this context we presented the results of our preliminary study and discussed its implications for the mental and emotional models as well as for the user interfaces. We identified high traffic load with plenty of vertical movements, unexpected events and a malfunction of the equipment as the most relevant stressors in air traffic control. Furthermore, stress level is influenced by personal factors. Surprisingly, the controllers stated not to create a three-dimensional mental representation of flight situations. The information used to create the mental representation consists of internal knowledge about the sectors characteristics and standard routes, their experience and flight plan data. For checking the current situation, information is processed in the following order: altitude, climb/descent, horizontal position, heading, and speed on ground.

The order of information processing should be reflected within the user interfaces, as well as the structure of the air controllers mental model. Identified forms of communication should be supported. The automatic recognition of the air traffic controller's workload and emotional state allows for further improvement in the workflow.

Our findings suggest that sufficiently modeling the cognitive and emotional states of air traffic controllers requires the inclusion of many variables regarding the individual controllers as well as the dyad and the current workload. The next steps in the process of model building are the identification of other relevant variables and generally their measurement and further processing. Even though we already know that cognitive and emotional states can be recognized using our multidimensional approach, the relationships between the variables still needs further research. Possible methodological approaches include the recording of actual or simulated work sessions in combination with post-hoc interviews in order to identify critical or demanding situations. By comparing the measurement data with the information given by the controller, we can identify typical patterns that signal stressful episodes which can be used in our model.

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