The Mental Organization of Air Traffic and its Implications to an Emotion Sensitive Assistance System

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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 our paper "'Aircraft in Your Head: How Air Traffic Controllers Mentally Organize Air Traffic"' [1] we presented first results on air traffic controllers' practices, their information processing (mental models), potential stressors, and related emotional effects. These were collected during semi-structured interviews and observations at the facilities of the German air traffic service provider DFS in Munich and Langen. The observations were limited to experiences with the P1/ATCAS air traffic management system. As there is a second air traffic management system (VAFORIT) in use at DFS Deutsche Flugsicherung we decided to conduct further observations. This article discusses the expanded results and their implications to the StayCentered project. In the first sections we will introduce the air traffic controllers work, outline related work in research, describe the interfaces currently in use at Deutsche Flugsicherung and introduce the StayCentered project and our goals. Section IV outlines the methods used to gain the findings that will be discussed in Section V. The following sections relate findings to the project context in terms of the future mental and emotional model as well as future interfaces. Section VIII summarizes and concludes the paper.

II. THE WORK OF AN AIR TRAFFIC CONTROLLER DYAD AS A POTENTIAL STRESSOR

German airspace is divided into sectors of differing size and form. By traveling on an airway an aircraft passes several sectors. In the state of normal operation, a dyad of two air traffic controllers is responsible for such a sector. Both have access to task relevant information, such as radar data, weather reports, and flight schedules. 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 not just depending on team coordination regulations but on a good internal communication and a transparent work situation. Expediting and maintaining orderly traffic flows, without infringing separation minima, 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 [2, 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 [3] [4]. 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 [2, 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 [5] 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 and the abilities of the individual to cope with the situation [6]. 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 [7] [8]). Therefore, the reduction or rather avoidance of stress inducing situations is an important goal in the daily work of air traffic controllers.

III. STATE OF THE ART

Within this section we will have a brief look on related research on modelling human emotions as well as on worload and emotion sensitive user interfaces. We will consider the state of the art in practice and, thus, describing the current workspace of a German air traffic controller.

A. Modeling Emotion

Albeit our own research within the domain of modeling emotions via the simulation of the real world scenarios [9] [10] [11] [12], there are numerous other attempts of calculating human emotions. The range of applications in this field varies greatly. For example, the correct pronunciation of text to speech software depends on the software being able to carry affective states [13], and the ability to correctly identify human affective states might even increase social amicability in human-robotic-co-existence [14]. In order to compute affective states, emotions are viewed as values within the dimensions of either valence, being positive (good emotions, e.g., joy) or negative (bad emotions, e.g., fear, disgust) as well as the energy provided to fuel an emotion by stating a factor for arousal (high or low, the subject being either excited or calm) [15]. Analysis of emotional states in human subjects lead to the conclusion that there is a correlation of self-reported arousal and the activation of the sweat glands, leading to a higher level of electronic conductance (galvanic skin response - GSR). Since there is no correlation regarding the direction of the valence, the GSR is a valid indication of the arousal level and thus can be used as an objective measure [15] [16] [17]. The objective measurement of a valence, however, is right now only possible by implementing the Facial Action Coding System as proposed by Ekman [18], since other measurements like fMRI or fNIRS studies yielded varying results [19] [20]. Main points of criticism about the modeling of human emotions, however, are the missing experimental validation of models and the sheer complexity of different psychophysiological processes involved in establishing a certain emotional affect [21]. As Marinier and Laird point out, established computational emotion models either rely on appraisal theories and the step-by-step analysis and predictions of reacting to an event to compute a corresponding emotion. Since these events can be compared to self-reports and objective measurements like the aforementioned skin conductance [22] they are exceptionally well suited for a valid implementation. Neural Networks, on the other hand, attempt to model brain activities related to the emergence of emotional affections which can be linked to actual observable processes as they happen inside the brain [23] [24] and could be evaluated using brain imaging techniques.

B. Emotion and Workload Sensitive User Interfaces

The detection and simulation of the humans emotional and cognitive state is quiet useless without an adequate system reaction. Emotion and workload sensitive user interfaces are key issue of a whole research area (affective computing [25]) and are present in a multitude of areas of application. They are widely considered within intelligent tutoring systems. Ranging from piano teaching systems, increasing difficulty,when the students workload is low, [26] to emotion sensitive systems that support learning of the Japanese language by adapting the difficulty of tasks to the emotional state of the student. The effects of emotion and motivation on learning performance are a well known relationship within educational research. [27] So, within the last decade there was plenty of research done on emotion sensitive tutoring systems. An overview can be found in [28] and [29]. Even in application areas crucial to safety there is a trend to affective system support: a minimal invasive surgery robot controlled through a speech interface, initializing safety feedback loops, when negative emotion is detected in the surgeons command [30]; a mobile robot on exploration tour with an astronaut, that reacts on the astronauts anxiety level by assisting with hints or by triggering an alarm and hurrying to the astronaut [31]; or a simple application that redirects incoming calls to the mailbox, during high workload in driving situations [32]. Emotion and workload sensitive interfaces in air traffic control are mainly part of the so called adaptive automation research. Within adaptive automation the tasks are dynamically allocated to the system and the human controller. Thus, it is expected to counteract the out-of-the loop performance problem and the loss of situational awareness [33]. Parasuraman et. al compared a workload adaptive Automation with an non-adaptive and a reverse workload automation. They found an improved performance within the workload adaptive situation [34]. According to Langan-Fox et. al there is a huge corpus of research on measuring workload and situational awareness in the area of air traffic control [35]. In projects like NINA - Neurometrics Indicators for ATM [36] workload measurement and the development of workload adaptive interfaces are/were investigated. So far, emotions were rarely considered for triggering adaption within the air traffic control context. We are seeking an adaptive user interface sensitive to workload as well as to emotional and air traffic situation aspects.

C. The Layout of an Air Traffic Controller's Workspace

We had the chance to observe controllers at three control centers of the German air traffic service provider DFS. The systems and the available visualizations and tools in use differ between control centers. Working spaces in Langen and Munich (Fig. 1a) were comparable using the P1/ATCAS system, whereas in Karlsruhe the VAFORIT system is used (Fig. 1b). This section outlines obvious similarities and differences between the controllers workplaces.

What tools have these work spaces in common? Every controller is working with a radar screen, that is showing a top-down view on the sector. Each aircraft is shown as a little icon (square) followed by some dots, indicating the aircraft's former positions. Each target is accompanied by a label, showing the most important information (an example is shown in Fig. 2). (Semi-)Static sector characteristics as beacons, airways or restricted airspaces may be shown or hidden. Tools for distance measurement on radar screen are available and direction vectors of aircraft (a function of time adopting constant ground speed and direction) are displayable. Additional screens show on demand additional data, as aircraft properties, meteorological data, or a status display. The status display is a tool for communicating the own stress level to other controllers and the supervisor. For further communication

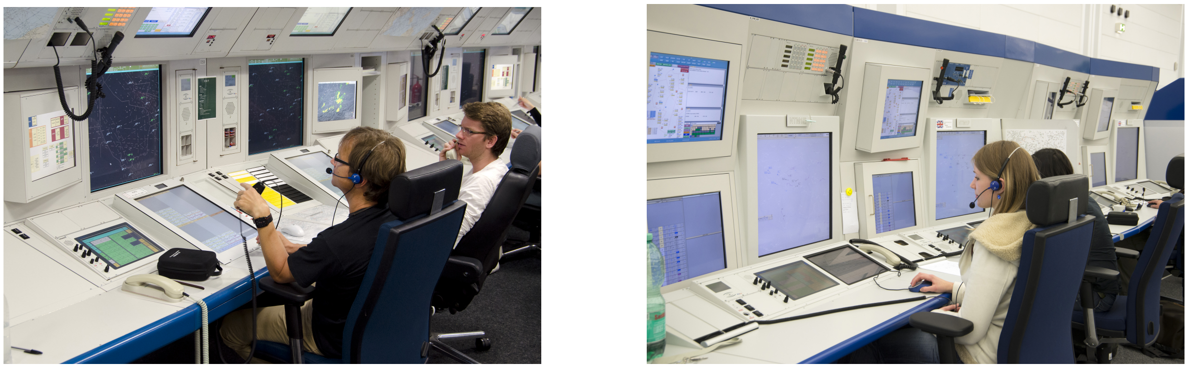

Figure 1. The air traffic controllers workspace at the air traffic control centers in Munich (P1/ATCAS system) and Karlsruhe (VAFORIT system). The major differences regard display polarity and the presence/absence of digital flight progress strips. (Sources: DFS Deutsche Flugsicherung GmbH).

with other controllers and pilots each workplace includes a phone and a radio communication equipment.

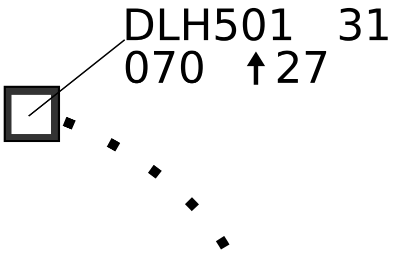

Figure 2. An aircraft target on a radar screen. The label shows callsign, groundspeed, flight level and rate of climb/descent. The history indicates the speed and the aircraft's tendency.

There obviously are differences in workplace design. The radar display of the VAFORIT system has positive display polarity. This means, in contrast to a negative display polarity, that dark symbols are shown on a light background (Fig. 3). With positive display polarity, there are less changes in pupil dilatation, because the secondary screens have nevertheless positive display polarity and surroundings are also rather light. With a work place design, that needs less adaptions between light an dark, there is less eyestrain [37]. Furthermore, a positive display polarity provides better legibility of small letters [38].

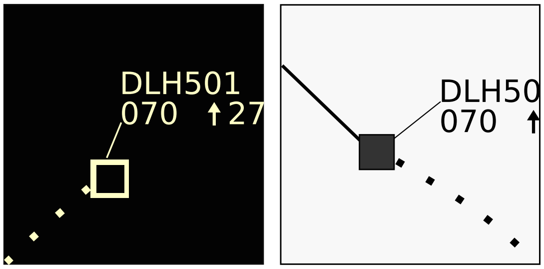

Figure 3. Example for negative (left) and positive display polarity (right).

The main difference between the systems is the use of flight progress strips for displaying flight plan data. The advantages of paper flight progress strips, digital flight progress strips and systems without strips were discussed since the 1990s. Vortac and Edwards et al. recommended, after analysis on flight progress strip activities, an automation of these, in order to decrease controllers effort [39] [40]. Albright et al. investigated the contollers operation methods, while paper flight strips are missed [41]. They found that there was a gain in time due to the loss of strip marking, but that the presentation of flight plan data on every flight at a time was perceived as more informative. Scince then, systems with digital flight progress strips have been developed [42] [43] as well as systems without any flight progress strips. In contrast, MacKay advises against replacing paper strips [44]. They take advantage of visual and tactile memory, they are flexible, reliable and support cooperative work due to their physical presence and visual forms of interaction. The advantages of automation bring the necessity of electronic flight strips about, while the reliability and the whole functionality of paper flight strips should be kept [45]. A possible back door would be the use of augmented flight progress strips. Hurter et al. combined in their system Strip'TIC the advantages of the digital and the physical world [46] [47]. In Munich and Langen air traffic controllers are facing digital strips shown on a screen lying on the desk and edited by a digitizer pen. (Fig. 4). The air traffic controller

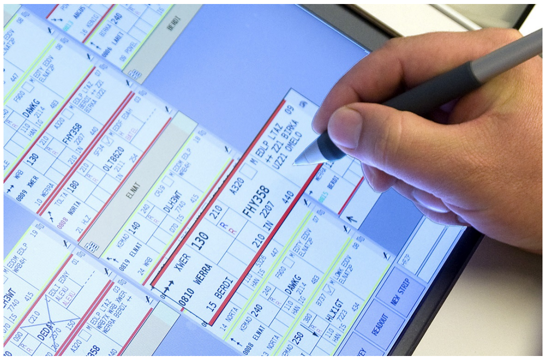

Figure 4. Digital flight progress strips of the P1/ATCAS system at DFS Deutsche Flugsicherung. Each aircraft is referenced by its callsign. Data as flight plan and cleared flight level is provided by texts. The arrows at the upper left corner indicate the overall direction of the aircraft's route in 3 dimensions. (Source: DFS Deutsche Flugsicherung GmbH)

in Karlsruhe has the possibility to access flight plan data via extended labels on the radar screen. Thus, making the use of flight progress strips (nearly) redundant. This difference is resulting in slightly different routines in the air traffic controllers ways to reach their goals. Thus, making different aspects of their work observable. There are further quite small differences in interfaces, e.g., a different visualization of the status display, but a complete analysis of them goes beyond this section.

D. 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 data, 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 [48], as well as for a workload regulation [49]. 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 [50]. The paper at hand presents a set of initial exploratory studies. The identification of parameters to the emotional model as well as issues for an emotion sensitive user interface in this context were possible.

IV. 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. There was a situation containing 8 aircraft described, 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 German air traffic service provider DFS in Langen and Munich and in August 2015 at the center in Karlsruhe. 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=37 air traffic controllers (age: 18 to 57). 21 of them are used to the ATCAS system and 16 to the VAFORIT system. 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.

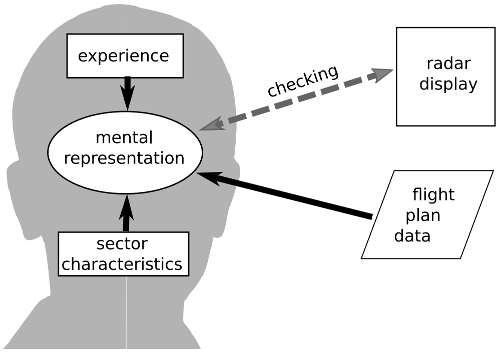

Figure 5. Schematic diagram of the air traffic controllers mental situation representation and its sources. Access to flight plan data depends on interface design.

V. 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. We were able to identify procedural, communicative and emotional aspects that form the controller's course of action.

A. Procedural Aspects

Procedural aspects deal with the mental organization of air traffic by a controller. This includes their work organization, their information processing and their internal representation of the flight situation. In order to ensure save and fluid traffic flows the air traffic controller has to have a good overview of the air traffic situation. Thus, he constructs and continuously updates a mental representation that is mainly based on flight plan data, the controllers experiences and internalized knowledge on sector characteristics. This representation includes more than just the current situation but also a prediction future air traffic situations. The controllers stated that their prediction reaches about 3 minutes into future in order to proactively control the traffic. The current situation, as shown by the radar screen, is continuously cross-checked against the mental representation (Fig. 5). In the whole process of building and updating the internal representation and cross-checking the role of the radar screen differs between systems. This depends on the place where flight plan data is presented. In a system with digital or paper flight progress strips the radar screen is rather a secondary tool that is used for cross-checking. But the inclusion of flight plan data into radar screen makes it the most important tool for the air traffic controllers work. We also asked the controllers to describe the structure of their mental representation. While in literature mental representations of air traffic situations are often described as somewhat three dimensional models [51] [52], our controllers explicitly stated that they do not build up a three dimensional model of the situation. They described it as two dimensional, similar to the radar display that is expanded by a variable indicating vertical layers. Other studies revealed that air traffic controllers [53] [54] and already controller students [55] do not necessarily build up a three dimensional mental model. Each of them develops an individual mental structure to represent the three dimensional data over time. In situations where the controller first constructs his representation (e.g., during a handover) he has to consider flight plans as well as current positions. The first variable controllers focus on, while scanning the radar display, is altitude information and whether an aircraft is climbing or descending. After this, aicrafts heading and position are considered and lastly, ground speed gives a hint on the existence of a potential conflict. Likewise, Rantanen et al. identified in their experiments [2] altitude as the information that is processed first for conflict detection. Mogford et al. emphasized altitude and heading as the most important information for air traffic controllers situation awareness [51]. In standard situations, when a flight strip appears that represents an airplane that is about entering the sector soon, the controller is first looking for the route the aircraft 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 about a potential 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.

The observation of the air traffic controllers working these differing systems revealed some interesting aspects about the controller routines. Although the VAFORIT system can be operated without any flight progress strips, there is still a digital representation of them shown in an additional screen. All controllers stated that they do not need these strips. Nevertheless, they used them. The functionality of flagging a strip was still used as a reminder for oneself or the team partner. By sorting the strips by the cleared flight level the controllers gained an overview of the vertical situation in airspace. This fact shows the importance of the altitude information once again. There are small arrows on the flight progress strips in Karlsruhe, that indicate from which roughly direction the aircraft is arriving and where it is going (in 3 dimensions). These are also used by the controllers for an overview of movements. Furthermore, the number of flight strips is also an indicator for the amount of work coming up in the next 10 to 20 minutes. This is often influencing the controllers decision on allowing directs or the like. At some point during the air traffic controllers work (e.g., while considering a request) it is necessary to check the current position of an aircraft, that isn't visible in the current map excerpt, shown by the radar screen. In Munich and Langen it was observed, that controllers started zooming and moving the map while scanning the map with the eyes for this aircraft. In Karlsruhe the controllers used the functionality of showing the aircraft's intended route and thus, they found the target more rapidly. Controllers also stated that there are situations where the information is needed whether the handover to a following sector has passed successfully. This is also an information that was accessed through the flight progress strips in both of the systems. Another clearly observable point in between systems is the importance of handwritten notes. While in the P1/ATCAS system free strip marking can be used for communication with the team partner, there is no corresponding functionality in the VAFORIT system provided. But some controllers used pen and paper for writing notes, as a reminder for themselves or their team partner.

B. Communicative Aspects

The air traffic controllers work is a highly cooperative work. There is long term (e.g., with the team partner) as well as short term (e.g., with pilots) cooperation necessary to ensure save air traffic. Our communicative findings take the communication partners and the communication channels, as well as the controllers perception of cooperative groupings, into account. In order to figure out with whom the air traffic controllers affiliate themselves we asked them for 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 controllers 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 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 controllers 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 at any time constitute a dyad with any controller out of this group. Beyond these affiliations there are further cooperation necessary. We identified the following cooperation partners and the communication channels in between. An overview is shown in Figure 6. Short-term collaboration with pilots consists of speech over radio using predefined terms and routines in order to minimize the number of misunderstandings. If suitable equipped, there is also the possibility to send text messages to the aircraft. This is not yet common, but controllers like the decrease of misunderstandings in numbers about it. The supervisor communicates to the controllers through the display of a duty roster. Change requests, rapid updates, and the like are communicated via telephone connection. But it has been observed that both sides are often leaving their place, going to and talking to the other one about these concerns. 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 mental picture of the situation and keep it updated. 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 ones mouse), the flagging of flight strips (to highlight potential conflicts), and handwritten notes (either on digital flight strips or an extra sheet of paper), but speech remains the dominant communication channel. Nevertheless, both verbal and nonverbal communication within the dyadic team are crucial to good cooperation. The importance of nonverbal communication (strip marking and observation of the partners actions) additional to speech was also highlighted by Soraji et al. [56]. 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. For coordination in between sectors, the planner is talking to other dyads via telephone, except for the ones sitting spatially near to him, they are addressed directly. Similar to the communication with pilots, this cooperation is guided by regulations and routines. Additionally, in Karlsruhe controllers have the possibility to submit their requests via text messages. They like about it, that they do not disturb the other controllers line of thought at a specific moment. Another tool for controller to controller communications is the status display also called Geneva traffic light. This display shows a color (green, yellow, red) for each sector with green being the default color for normal traffic load. By setting this color, controllers can communicate their current workload to other controllers and to the supervisor.

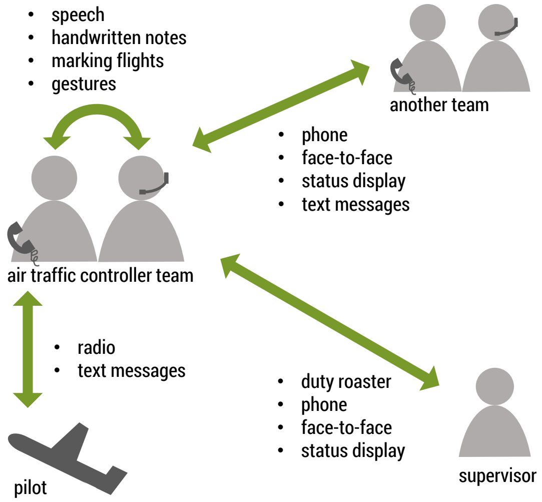

Figure 6. Overview of communication partners and channels. Beside cooperation within the dyadic team, the executive gives instructions to pilots and the planner coordinates handovers with the other sectors planners. The supervisor is responsible for the duty roaster and sector splitting.

The status display was introduced due to controllers wishes to communicate their stress level. The visual presentation differs between systems. However, the status display is rarely used. Some controllers do not even recognize it as a tool for communicating their stress level, but as a tool for getting an overview of the sectors that are opened or combined. The status display is experienced as neglected. Most air traffic controllers have no clue when to switch the color to yellow and if they do they feel as if the other controllers ignore their stressed state. However, in the case that they are really stressed then there is often no time left for remembering to switch their status to red.

C. Emotional Aspects

Regarding the emotional aspects of an air traffic controller and their impact on work results, there are numerous factors involved. Since we want to assist the controllers in stressfull situations in order to prevent negative emotional and psychological consequences, one focus was to identify the stressors in the air traffic controllers work. 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 with a higher priority, making them just another variable in the air traffic controller's mental model. Even closures of single airports are not 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 do not know about pilots' plans and are not able to forewarn them of an upcoming danger. For these reasons there are for each system independent fallback systems in use at DFS Deutsche Flugsicherung.

Other Things Indirectly Being Relevant

For efficiently building their mental 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 taskload can be experienced differently.

These results on potential stressors align with the five most stressful items found by Brink [57]. 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.

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. Except for the controllers wish to do so, they have to visit Critical Incident Stress Management sessions by regulations. 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.

VI. IMPLICATIONS TO THE 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 [58], 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. Therefore, the personality factors can 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 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. Therefore, our model must 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.

VII. IMPLICATIONS TO THE INTERFACES

One of the main goals of the StayCentered project is to identify and to offer assistance within cognitive stressful air traffic 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 and overall supporting the controllers routines and mental models.

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 on the air traffic controllers demands. The StayCentered supervisor interface will present the simulation's forecasts over time. Anticipated stressful or tedious situations should be visible at a glance and supporting decision making on resolving these situations.

As described, cooperation and communication are crucial elements of the air traffic controllers daily work. These communicative situations shall be supported by the interfaces. It is still an open point why controllers tend to leave their place for consulting their supervisor in situations of low traffic. This is a potential risky situation. There should be adequate ways of communication. 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 status display can change its color automatically and providing an objective measurement on the controllers stress level. However, also the displays presentation could be enhanced. Currently, each sector is represented by a colored button (green-yellow-red) on a secondary screen. This part may also be hidden by some other information. Additional short textual remarks for the sectors in stressful situations are available. A permanent visible graphical presentation of this information (possibly integrated into radar screen) would make it accessible at a glance. Another important feature of nowadays interfaces is the possibility to generate reminders, either through flagging of flight strips or through handwritten notes. This feature of communication shall be kept in some way. Additionally, notes can also be used for personal work organization and reminders.

The interface adaption with respect to the controller's state applies to the interfaces at the controllers workspace. The information presentation is independent of the controllers emotional and communicative state, his workload, and the complexity of the actual flight situation. However, the importance of information objects differs from situation to situation. We are currently conducting a survey to identify these differences. A positive effect of an automation degree adapting on the air traffic controllers workload was already presented by related work, e.g., [34] and [59]. Also, visual adaption of the interfaces has been investigated [60]. But an adaption on emotional state is still an open point.

StayCentered controller interfaces will consider the identified state of the controller as an indicator for the chosen representation. We want to pay special attention to situations of low traffic load, because in these situations 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 and their procedures. Recent research on air traffic controllers' interfaces often considers three-dimensional and even stereoscopic radar displays (e.g., [61] [62] [63] [64]). 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 with an implicit coding of altitude information. The interface should allow for stepwise adaption of conflict prediction to the required accuracy. Thus, it should also support distance measurement methods at a different granularity. The controllers need a good overview of vertical and horizontal movements in their sector. Furthermore, they need quick access to data about aircraft, not yet visible on their current radar view. Allover the air traffic controllers would be glad to have access to their own workload predictions. In order to have a more precise prediction that they can use for doing decisions upon pilots wishes. Thus, this information should be included into the controllers interfaces.

VIII. 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. 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, especially visibility of the partners actions. Workarounds, which are currently used by the controllers, should be included into future interfaces. 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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