Visualizing Workload and Emotion Data in Air Traffic Control - An Approach Informed by the Supervisors Decision Making Process

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***Abstract*—The work of a supervisor, working in an area control center in air traffic control, seems to be rarely addressed by research. Within this paper, we present a preliminary study that deals with the supervisors decision making process, current practices and interfaces. Based on this study, we derived design guidelines to the development of a visualization, displaying the air traffic controllers' workload and emotional state, thus supporting the supervisors decision making.**

***Keywords*–air traffic control supervisor; visualization, workload data, emotional data, decision making**

I. Introduction

Usually known for having one of the most stressful jobs or causing huge delays when being on a strike, air traffic controllers provide a safe, orderly and fluent handling of the air traffic. Not only do tower controllers coordinate departing and landing aircraft on airports, but also while being airborne, air traffic is constantly monitored, managed, and sustained by area center controllers. In order to overview the whole air space, it is divided into sectors, where each one is overseen by two controllers. In fact this job can be very demanding, so someone is needed to keep an overview of what is going on across sectors and prevent them and the assigned controllers from getting overwhelmed.

This task goes to the air traffic controllers' supervisors, who administer air traffic on a bigger scale, mostly by supporting and directing controllers. Especially since the controller's job is taxing and emotions can have a big impact on ones condition, it might help supervisors to know about their controllers' mental states, in order to balance out their workload and to offer better support to them.

Within this paper, we present preliminary studies, that analyze the supervisor's work and point out the usefulness of an emotion data display. We end up with the design requirements for such a visualization.

We start in Section II by introducing the StayCentered project that frames this piece of work. In Section III, a brief description of air traffic control supervisors' work is presented, followed by some related work in Section IV. The methodology and the results are presented in Sections V and VI. Finally, we give our interpretation regarding the emotion display in Section VII and finish with the conclusion and aims for future work in Section VIII.

II. the StayCentered project

The main goal in air traffic control is to assure safe, orderly and fluent handling of the air traffic. This is a highly demanding task. Thus, the project "'StayCentered - Methodenbasis eines Assistenzsystems für Fluglotsen (MACeLot)"' at the university of technology Chemnitz aims for giving support to air traffic controllers in stressful situations. The resulting system should be capable of identifying the emotional and cognitive state of the air traffic controllers and simulating their state with regard to upcoming air traffic some hours in advance. 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. The assistance of the air traffic controllers will be realized by self-adapting interfaces [1] and by providing this information to their supervisors. Such a visualization of the controller's emotional and cognitive state may support the supervisors decision upon the opening of a sector, in order to reduce the controller's workload. This paper presents preliminary studies of the supervisors work and the resulting design requirements.

III. The Air Traffic Control Supervisor

Before going into detail of our studies, we want to give a short description of what an air traffic control supervisor does and what tools and general environment he is provided with.

As a superior and shift leader of air traffic controllers, the main work of a supervisor is to manage assignments and shift-structures of controllers, while regulating their workload by handling air traffic flow across sectors.

The regulation of traffic flow is done by splitting or merging sectors, permitting or forbidding special maneuvers (like, e.g., skydiving or air force trainings) and in extreme cases even regulating sectors by setting a maximum number of allowed planes and rejecting any exceeding traffic, which usually leads to delay. However, the amount of traffic that can be handled is limited by the number of present controllers and the Supervisor's job is to assign them in such a way that simultaneously no employee is overexerted and air traffic can flow undisturbed.

We experienced that supervisors do not work alone but divide their work by region, where each one can operate independently but still help each other if necessary.

The actual work place is located within the area air traffic control center, often in the middle of the operations room or a little elevated, providing a good overview. Other non-controller positions can be found alongside. These include technical surveillance, data assistants, flight data agents/operators, flow management position, and the technical supervisor.

Each supervisor's workplace comes with a computer, equipped with two monitors, serving as their main working tool. Among other work specific software, the most important one is a shift management program, where active sectors are scheduled, air traffic controller's shifts are organized and controllers can be notified by publishing the current plan on a separate screen.

In addition supervisors have several information systems, specific to each center, as well as communication devices, such as an email program, a land-line telephone and a direct-dial telephone.

IV. Related Work

This section presents literature related to various aspects of the topics tackled in this paper.

A. Supervisors

In order to assess the supervisor's work, research in this field should be taken into consideration. Broach et al. [2] showed the importance of the supervisor's position. They found a correlation between the supervisor-controller-ratio and the number of errors made by air traffic controllers. Unfortunately we did not find any further literature on air traffic control supervisors, suggesting we might be first to focus on this group.

However, research shows that the general supervisor-employee relationship has a direct impact on the employees work motivation, organizational identification, and perceived career relevance [3]. Furthermore, emotional intelligence on both, a personal and a group level, has been proven to improve collaboration and communication, while emotional contagion can increase efficiency and decrease conflict potential [4][5].

B. Decision Support System Design

As the emotion visualization should support the supervisors decision making, some general work about decision support systems and design implications is introduced here.

The design process of decision support systems should always go from the "inside" to the "outside", meaning desired functions should get identified first and then restrictions of the outside world should be taken into account. Ariav et al. [6] propose to start with analyzing task characteristics and making a decision on the intended level of support.

Different implications for a visualization can be derived from the task. Well-structured problems, are best supported by showing possible outcomes and eventually the underlying model. Whereas a lot of visualization techniques can help to explore and evaluate available data, when a person is required to base a decision on this data. Sometimes conclusions are based on previous experience, domain knowledge, and situation awareness, where the last two could get enhanced visually [7].

Researchers keep stressing the importance of adequately including users during the whole process. As Miah et al. [8] report many projects fail because of different goals of users and designers as well as insufficient involvement of stakeholders. And when the systems do not get used in the intended way, the reason often is a mismatch of requirements between users and designers or unfamiliarity with the provided functions [9].

Benbasat also recommends to consider cognitive styles of users. As for example analytic decision makers might trust mathematically or quantitatively supported reports easily, while heuristic decision makers usually like to explore and analyze,

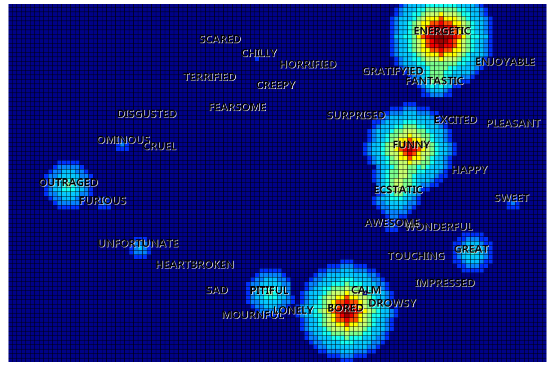


Figure 1. A visualization of the value and amount of emotional connections to a movie as a heat map on a valence-arousal-coordinate system [10].

suggesting the implementation of the possibility to switch between different levels of detail.

C. Emotion Visualizations

A lot of work has already be done in the field of visualizing emotions, especially in the context of social media.

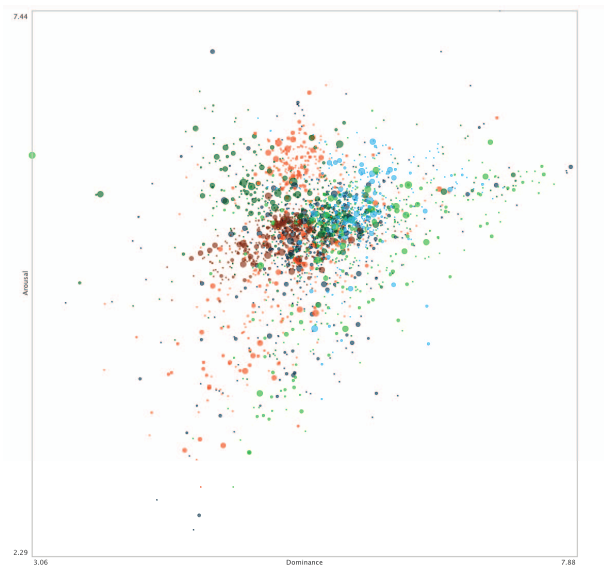
For example Ha et al. [10] visualize sentiments connected to movies with their focus on easy recognition of clusters and intricate network structure. The visualization in Figure 1 is a detail view for one node within that structure, showing emotions connected to a single movie as a heat map on the valence-arousal-coordinate system. Additionally some points in the coordinate system are labeled with the common name of that emotion.

Steed et al. [11] constructed a similar view, shown in Figure 2a, within their visual application to dynamically analyze twitter sentiment. Their coordinate system uses arousal and dominance as axes while showing valence in color (orange for negative and blue for positive). However, this again is just an additional display, next to a geographical depiction of tweets, while the main view is a visualization of the amount of tweets (divided in binary valence) over time, shown in Figure 2b. This view is designed interactive to select time intervals for further inspection in the other images.

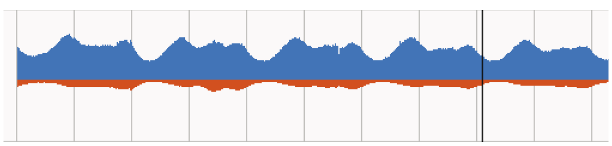
Working on the same problem, of analyzing twitter sentiments over time, Wang et al. [12] came up with a solution integrating valence, arousal and time into a single visualization, as shown in Figure 3. Each ring in the circle represents a different step in time (designed to resemble the view in a tunnel) while the amplitude within the ring is defined by the valence-arousal-coordinate-system. Since the curve is additionally color coded by valence and arousal, the rings could also be displayed as straight lines, which might be a little less disorienting for some users. Thus, the amount of tweets, currently shown by the bar on the left, could also be aligned.

A completely different application is that of Cernea et al [13], who designed an emotion visualization on touch displays, giving users direct feedback in the color and shape of the selection highlighting. However, they also created a separate view, showing the different emotions of the touch events over time, in order to let users reflect and compare themselves with other users (Figure 4). They displayed time on the horizontal axis while valence is shown in direction and size of the bars and arousal is color coded (blue is little and red is much).

The program in Figure 5 [14] was developed to directly track user emotions while they are watching or listening to



(a)



(b)

Figure 2. A sentiment visualization concerning a specific topic on twitter [11]. (a) The emotion is shown as arousal and dominance on the axes, the valence is color coded and its amount is shown as the size of each dot. (b) The number of positive and negative posts is shown over time.

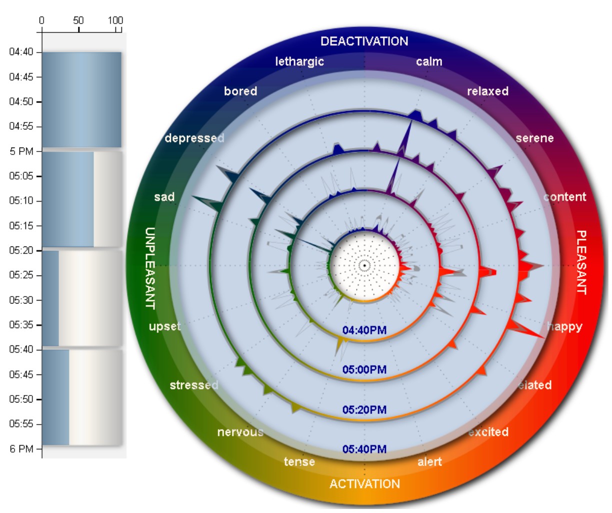


Figure 3. Another twitter-sentiment visualization [12]. Each ring is a step in time, while the curve depicts the valence and arousal.

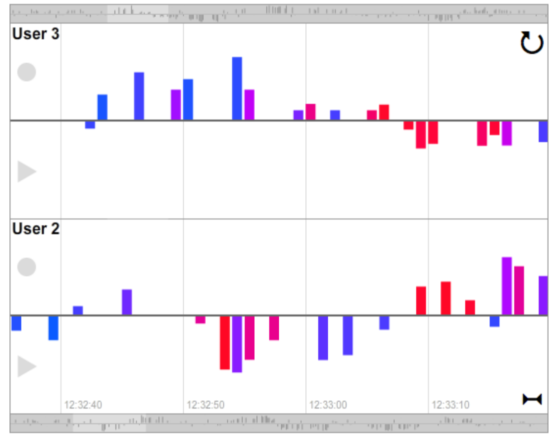


Figure 4. An emotion visualization over time for individual users by Cernea et al. [13].

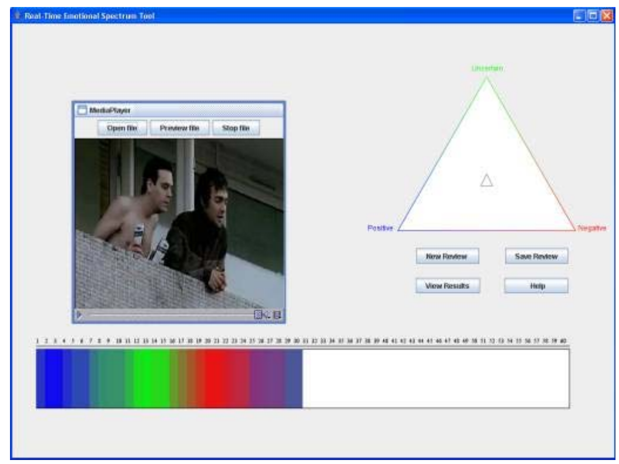


Figure 5. An emotion input interface concerning a video [14]. The bottom bar shows collected emotions on a time line, while the color shows the value of each step.

some kind of media playing. Thus the media player box on the left. On the triangle to the right the recipient is supposed to report current emotions by accordingly placing his mouse within that triangle. Thus, valence and uncertainty are measured. The input gets tracked and displayed in the bottom bar as visual feedback of the opinion development. Time is the horizontal axis in the bar while the color gets computed as the distance to each corner of the triangle mapped on the opacity of one of the base colors in RGB. It is also possible to render the results of multiple users on top of each other, showing the mean opinion of all of them.

Yet another approach is to use some kind of emoticon, like the manikins in Figure 6, designed for visual feedback, e.g., in questionnaires. Sonderegger et al. [15] even found in a user study, comparing different pictographs, that the ones shown in Figure 6 could be further enhanced by using an animated heart as arousal indicator instead of the rather abstract shape depicted here. This might be the most intuitive way for emotion visualization. However, research shows that the bigger the set size and complexity of the icons, the harder they are to identify, even more so when they are rather similar [16][17].

Finally, there is also the work of McDuff et al. [18], who created a very detailed visualization of emotions connected to work. Their goal was to use the device for personal reflection over longer periods of time. The result is shown in Figure 7.

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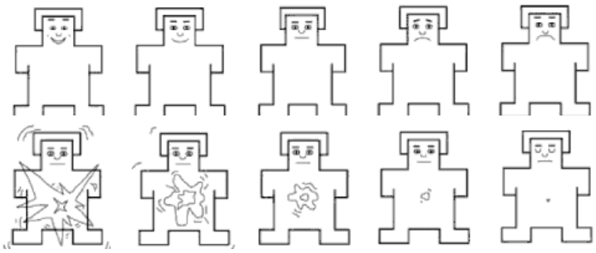

Figure 6. An emotion visualization in manikins [15]. The facial expression shows valence while the shape on his chest depicts arousal.

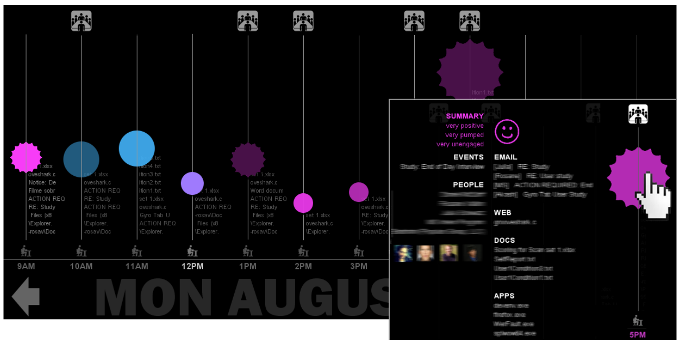

Figure 7. A visualization of emotion during a work day for personal reflection [18].

They encoded emotions in the bubbles with color showing valence (pink is positive, purple neutral and blue negative), shape showing arousal (calm is round and aroused is pointy) and opacity showing engagement. Work related information is given by the height and size of the bubbles (desktop activity), by little icons at the top and bottom of each bar (meetings) and text (further work related information).

The summary in Table I gives an overview of the just described visualizations and how different variables are presented.

V. METHODOLOGY

Main goal of the preliminary studies was the identification of design requirements such that the intended visualization serves the supervisors needs best. This implies first establishing an understanding about the supervisors tasks and their way of decision making. Furthermore, we wanted to find about the qualities of stress and emotion data needed by the supervisors and we wanted to learn from the use of the current interfaces and from its positive and problematic impact on the supervisors work.

We did two full-day observations at the end of September 2016 of the supervisors working place in the Munich area control center. The researchers had the chance to ask clarifying questions during the observation and collected the data by handwritten notes. Furthermore, we interviewed seven supervisors, each interview lasting 18 - 51 minutes on their decision-making process, their information needs, as well as on the role of the air traffic controller's workload and emotional situation in their decision-making process and the data's level of detail favored by the supervisors. During the interview, we invited the supervisors, to sketch their decision process and the considered information, this was done to make them reflect their decisions structured and not forgetting anything. The data was audio recorded during the interviews and transliterated. For analysis, the data was coded and categorized. We did not use a standardized coding scheme, because of the exploratory nature of the research questions.

TABLE I. OVERVIEW OF ENCODINGS OF DIFFERENT VARIABLES IN THE GIVEN EMOTION VISUALIZATIONS.

Vis.	Valence	Arousal	Time	No of Persons
1	horizontal axis	vertical axis	-	multiple
2a	color	vertical axis	-	multiple
2b	direction + color	-	horizontal axis	multiple
3	horizontal amplitude + color	vertical amplitude + color	rings (tunnel view)	multiple
4	size + direction	color	horizontal axis	single
5 Triangle	horizontal axis	-	-	single
5 Bar	color	-	h. axis	single
6	facial expression	shape	-	single
7	color	shape	horizontal axis	single

VI. RESULTS AND DISCUSSION

Our first step in preparation of designing a well suited stress and emotion visualization, was to understand the supervisors tasks. The supervisors task area includes tasks concerning ongoing operations and tasks beyond. Beyond ongoing operations, the supervisors have to fulfill tasks in human resources management. Each supervisor is responsible for 15 to 20 air traffic controllers. Additionally they may have optional special tasks like the participation in research projects or committees. As our visualization is most beneficial in ongoing operations we concentrated on this part of the supervisors work.

The principal task of a supervisor is to keep ongoing operations fluently going. This means, doing everything, so that the circumstances allow the air traffic controllers safe, orderly and fluent handling of the air traffic. The supervisors called themselves well-paid secretaries, in order to express that they are responsible for every concern in the operation room. The principal task can be divided into sub tasks. At the one hand there are somehow formalized tasks and at the other hand more informal tasks. Even the formalized tasks are rarely provided with clear instructions, allowing for a multitude of alternatives. The only task with clear instructions is the documentation of events, that happened during the supervisors shift. This task is not very favored by the supervisors, according to them they are spending too much time documenting insignificant events. This may be a task that is very suitable for automation. Each day, there are two briefings scheduled, wherein the supervisor updates the controllers. Most of their time the supervisors spend on planning the day's shift schedule and solving occurring bottlenecks and problems. We observed two ways of planning: some supervisors prefer planning of the whole shift and changing the schedule if necessary. Others avoid this strategy, because of the numerous changes and prefer a piecewise planning. On the other hand, there is the solving of bottlenecks and problems, that may put the safety of aircraft in risk. This is a very creative task, because of the numerous possible solutions. Sometimes supervisors even consult their colleagues and the air traffic controllers on this behalf.

The informal tasks are rather some kind of good practice and skills. Their implementation depends on the individual supervisor. Over the entire shift, even if the supervisor seems to relax a while, he is observing the current situation at the operation control room and looking for abnormal situations. Each abnormality may induce safety problems. A controller speaking to the technician holding his interaction device in his hand, may be an indicator for a malfunction of equipment. Especially if a controller switches his status on the status display to a warning level, the supervisor will go to the controllers working position to asses the situation. In order to assure the controller's ability to work under pressure, the supervisor is trying to determine their daily emotional state and basic stress level, thus he can consider this in the shift schedule or, in extreme cases, advising a controller to rest. Generally, the supervisor tries to prevent controllers from stress by using formal means, like splitting up a sector or by regulating the number of aircraft that are allowed to enter the sector, or by using more informal means like warning the controllers of a short high traffic peak. Usually the supervisor complies with flat hierarchies. This has practical effects, like asking the controllers for their opinion about suggested solutions or by considering the controllers wishes in the shift schedule. They are also trying to support the air traffic controllers on their issues, even if they are not in their field of responsibility, e.g., they check for the location of a meeting. Altogether, a supervisor needs interpersonal skills, he should be sensible to individual communication patterns. It is a well known issue in leadership studies, that the political skills of a supervisor, including social asturence, may have a positive impact on the team performance [19][20]. The ability to identify the others needs by observation and to attune to divers social situations allows for better communication and improvements in supporting the controllers.

However, the supervisor is not just concerned about the controllers issues, but he also tries to support his colleague. He stands in for his colleague during breaks and he reminds him of important tasks. This is appreciated by the other supervisor.

There are some typical decisions a supervisor has to face in his daily work. Besides the decision of the briefing topics, the most critical decisions are made in the tasks of planning the day's shift schedule and preventing and solving bottlenecks and problems. The planning task includes the decision which controller has to work at which position. This decision is guided by several constraints. The solution should be safe as well as cost effective. That means that safety rules need to be met, e.g., considering breaks, two controllers should be responsible for one sector, assuring that no controller is overstrained. Simultaneously every controller should be busy, taking special tasks, trainings and so on into consideration. Potential bottlenecks and problems may be caused by external demands or extraordinary circumstances. The supervisor has to decide whether to allow for external demands, like photo flights, gliding flight areas, or planned detonations. Other external demands are obligatory (e.g., activation of special air spaces or military trainings) and the supervisor has to decide on a suitable reaction to this. The decision on the reaction to extraordinary circumstances includes malfunction of the technical equipment, potential overloads in traffic quantity, which may result in splitting up a sector or a regulation of the number of aircraft. In addition there may occur staff concerns, like illness or spontaneous meetings, that force the supervisor to alternative solutions or looking for someone replacing the missing controller, and there other troubles may occur, e.g., fire alarms. None of these decisions can be seen separated. each decision on one variable of the system has impact on another and may result in new decisions to be made. For instance, the decision on splitting up a sector entails a change in the shift schedule or regulating the number of aircraft in one sector increases the number of aircraft in other sectors.

Based on their experience, the supervisors identified variables, that are affecting the capacity of a sector or constraining their scope of action. Information upon these variables should be available to the supervisors. They should know about the standard sector plan, that tells which sectors should be open. It is based on statistics of the past years and is the basis for the shift schedule. The available staff is a framing variable for the scope of action, this includes the air traffic controllers on duty as well as controllers, who are around but fulfilling other tasks (paperwork, trainings, meetings, and so on). The latter may be consulted in the case of staffing shortage, but usual the information is hardly available. Also, the staffs condition is a factor to the capacity of a sector: their daily performance, fatigue, their satisfaction. To keep satisfaction high the supervisors, try to assure that the controllers are facing variable demands, that they are sharing a position with someone with whom they accord, and that some of their preferences will be met. The information about alternative tasks a controller has to do is necessary in order to assure cost efficiency, but it is often incomplete. The main factors on a sectors capacity are the expected traffic load and the weather conditions. The weather forecast is needed 2 hours in advance, but up to this day, weather predictions are not always reliable. The quantity of the expected traffic is also automatically predicted, by considering the aircraft's flight plans. A 2 hours forecast is highly unreliable, but with each minute this estimation is getting more precise. In contrast, to the quantity predicting the traffic quality is even challenging for an expert. 15 aircraft flying straight in a line may be less demanding than 7 aircraft climbing and descending with a different headings. Extraordinary circumstances as safety issues in the area control center (e.g., fire alarms) and technical concerns (malfunction of equipment or the use of backup systems) may reduce the capacity of a sector extremely. Also, visual clutter on the radar screen, coming from a lot of aircraft below or above the sector, is limiting the sectors capacity. A variable that is consulted rather unconscious, is the own constitution, it has some effect on the consideration of external demands or controllers wishes. When a supervisor has not the full overview on the current situation he is not willing to generate any additional workload to his controllers or himself. This listing of variables is an attempt to get a structured view on the variables needed by the supervisors and is not complete, as every situation is unique and may require other information.

Altogether the supervisors are facing complex problems [21][22]. They have to address many variables that are interrelated, the time for decision making is limited, and some events occur unexpected (illness, external demands, emergencies, etc.). They have to outweigh different goals (safety, cost efficiency, controllers satisfaction) and the information needed is incomplete and sometimes not reliable. They make decisions for the future based on current data, personal heuristics and unreliable predictions. The heuristics they use for problem solving are based on their experience. They are able to anticipate the effect of the variables on the sectors capacity and they know how to weigh the influence of a variable to a

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specific type of problems.

As we are interested in designing a stress and emotion visualization, we wanted to have a further look on the role of stress, workload and emotion data. As stated above, the supervisors already take the controllers basic stress level and severe emotional states into consideration. By now they have to look for this information during conversations with the controllers. The information on the controllers workload, stress and boredom is considered as useful in two terms: A prediction of the workload in a specific sector, is seen as alternative approach to current traffic quantity predictions and may thus help with the planning of the shift schedule. Moreover, an information upon the controllers former and current stress level may help in assigning suitable tasks to the controller. The relevance of detecting stress seems to be much more important than boredom. During periods of boredom, controllers lean back and start chatting. Thus, the supervisors stated, that they can easily observe boredom. In contrast, stress is sometimes not even recognized by the controllers themselves. The use of emotion data is seen much more diverging than the workload data. On the one hand the emotion data may be useful when the controllers emotional state in extremely emotional situations hinders him from doing his job. On the other hand they refuse using this data. This arises from the expected professionalism, from the fear of treating other controllers unfair, when someone is pretending to be in a bad mood, and from concerns about privacy. Both, showing the data linked to an individual controller and showing it linked to a sector, may be useful. Sector related data is similar to current traffic quantity predictions, whereas individual data may help by assigning each controller a suitable task. There are ethical concerns about showing the data person related.

As already mentioned in Section III, the supervisors working place offers a multitude of tools and information systems to support their decision making. The three main tools are the shift management program, an overview of the planned controllers and a notepad. This physical notepad, is an important tool since it allows for quick note taking and thus remembering important tasks and lines of thought. This is necessary because the supervisors thoughts are often interrupted by incoming demands and information. These main tools are complemented by a multitude of information and communication systems, where information can be retrieved and is pushed through. Conspicuous about the interfaces was the importance of clear arrangement. Consistency of representations and data between systems and tools are as important as unambiguous interaction strategies [23][24][25]. Using different time zones and coding same meanings differently led to misunderstandings and cognitive resources were occupied. The supervisors had to transfer data from one tool to another manually, this took time and cognitive resources. Further more several similar interaction devices, each of them belonging to another system, were confounded, thus slowing the progress down.

VII. IMPLICATIONS TO A WORKLOAD AND EMOTION VISUALIZATION

As workload and emotion data turned out to be relevant to the supervisors task, an automation of the detection of the controllers workload and emotional state seems to be promising. However, this data is useless without an effective visualization of the data.

Based on the findings of this preliminary study and completed by general visualization guidelines, we developed a set of design requirements to a workload and emotion visualization for supervisors working at an area control center:

- R1 In order to consider the controllers state during scheduling, the workload data needs to be accessible in an overview over a period of time ranging from 2 hours in the past to 2 hours in the future.
- R2 Emotion data will be restricted to extreme situations, in order to address ethical issues.
- R3 Extreme situations should be visible at a glance. Extreme stress, extreme boredom, as well as extreme negative emotions may hinder the air traffic controllers work, so that intervention of the supervisor may be appropriate.
- R4 The visualization should support the supervisors notional categories. Thus, the data should be available related to the individual controller as well as to the working positions.
- R5 The visualization must concentrate on a minimal set of primitives to produce an expressive and effective visualization [26] with minimal disturbance of the work flow. All important features should be easily identifiable and all visual elements should have an important meaning. Color should only be used when really needed to highlight very important features and taking into account human visual perception [27].

VIII. CONCLUSION AND FUTURE WORK

We presented a preliminary study on the work process of air traffic control supervisors. We investigated the supervisors tasks and decision making process as well as their current interfaces and ended up with design requirements for the development of a workload and emotion visualization.

Next steps in our project will be the design of the intended visualization within a human centered iterative process. It will be integrated into the StayCentered system and evaluated. Beyond that, further investigation of the application area and the design of a complete decision support system seem to be promising, as the application area is rarely addressed by research so far.

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