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ATTENTION: TARGET AND ACTUAL – THE CONTROLLER FOCUS

Jürgen Rataj[1], Oliver Ohneiser[1], Gabriela Marin[2] & Roxana Postaru[2]

[1] German Aerospace Center (DLR), Institute of Flight Guidance, Braunschweig, Germany
[2] Romanian Air Traffic Services Administration (ROMATSA), Bucharest, Romania

Abstract

The main task of an air traffic controller (ATCO) is to ensure safe and efficient air traffic control (ATC). Therefore, the ATCO needs to have his/her attention at the right place at the right time on the controller working position's displays. This will be even more challenging in the future with increasing information diversity, growing levels of automation, more complex air traffic mix, new technologies, and bigger screens. However, to deal with these challenges an attention guiding assistance system is developed to support the ATCO. This system needs to determine the area of target attention due to relevant upcoming ATC events. It should also evaluate the current area of attention as a function of the ATCO's gaze, e.g., via eye-tracking, and evaluate it. If there is a mismatch between target and actual area of attention, the attention focus of the ATCO has to be appropriately guided to relevant areas via cues. Based on an analysis of attention and situation awareness, attention guidance mechanisms have been developed and successfully validated in human-in-the-loop trials. ATCOs felt well-supported by visual non-intrusive guidance cues and even wanted to have such functionality in today's working positions.

Keywords: Attention Guidance; Air Traffic Controller; Eye-Tracking; Human-Machine Interface

1. Introduction

Having attention in the right place at the right time is a key element for safe and efficient air traffic control (ATC) by human operators. Increasing information diversity, various flight profiles from manned and unmanned vehicles, new technologies, a higher density of information on bigger screens, complex traffic patterns, new guiding concepts, and many more changes in the working environment increase air traffic controllers' (ATCOs) search times and result in unfavorable processing sequences. At the same time, ATCOs can only consider a limited amount of information to plan their prioritization and guidance tasks. Therefore, in the near future, it will be necessary to support the ATCO in the collection of information for processing his/her tasks. Even today, as determined, ATCOs would appreciate this support. This increased automation would further change the ATCOs' working environment significantly from actively guiding and acting to more of monitoring and supervising. In a highly automated environment, procedures, trajectory calculations, conflict resolution, and many other tasks are done automatically. Here, the task of the ATCO changes, which involves monitoring and reviewing the automation and intervening in the event of automation failures. However, the ATCOs' vigilance decreases over time if they just "watch" the automated ATC scenarios [1]. Hence, it is a growing challenge for ATCOs to keep focused on the right spot of the human machine interface (HMI). Thus, modern controller working positions (CWPs) should integrate means to guide ATCOs' attention to relevant spots if necessary in highly automated environments.

Based on experiences from the SESAR Exploratory Research project *MINIMA* (Mitigating Negative Effects of Monitoring High Levels of Automation [2]) on a lower technology readiness level (TRL) and on expert judgment in the SESAR Industrial Research project *CWP HMI AG*, an attention guidance (AG) system was developed on TRL4 to overcome the described challenges.

The goal of the developed AG system is to actively guide the ATCOs' attention along an effective processing sequence. During this guidance, the prioritized handling of the most urgent and important ATC task has to be ensured. In order to guide the ATCO's attention, three different questions need to be answered for the system design: (1) the area the ATCO should look at, (2) the area of the ATCO's current attention, and (3) the methodology as to how to guide the ATCO's attention in an acceptable manner if needed.

To answer the first question, it must be determined what the ATCO should look at in the near future. This was analyzed with the help of a questionnaire about attention and situation awareness. The related questions comprised of the maintenance of situation awareness and attention during shifts and shift takeovers, scan methods, prioritizing of events, and reactions in case of immediate attention requirements, as well as working orders at a specific CWP. This questionnaire was answered by 85 ATCOs, 59 from area control and 26 from approach control center, of the Romanian air navigation service provider ROMATSA. The findings from the questionnaire are used to develop AG functionalities. It also helps better understand the usual working methods and thus influences the decision regarding which guiding mechanisms are applied in different situations.

The task of determining the ATCOs desired area of attention is performed by an electronic ATC assistance system considering manifold data such as radar data, flight plans, meteorological data and hypotheses about future states in air traffic. On this basis, the system prioritizes relevant ATC events and action areas with respect to urgency and importance. The aircraft, airspace region, waypoint, or other artefacts on the HMI involved in the prioritized events are assumed as required spots of attention in a certain order. Some ATC tasks and operational conditions (e.g., critical events) may impose higher demands on the attentional resources than others due to their safety-critical nature and importance.

To answer the second question, it needs to be analyzed where the ATCO is currently looking at and also where he/she looked previously. Therefore, it is assumed that the area of the ATCO's gaze spot, the fixation on the HMI is the area of his/her attention. This area can be detected via cheap consumer eye-tracking products such as infrared eye-trackers mounted to the bottom of the screen [3]. The detected area or the related ATC event for this area, respectively, is compared with the highest prioritized ATC event. Comparing the considerations of the first two questions leads to the third one, i.e., to guide the attention of the ATCO with reasonable means if necessary. The necessity of guidance and the time to guide are dependent on the discrepancy between target and actual attention of the ATCO, the ATC event priority, and event resolution activities. If AG is needed, there are different ways to perform visual or auditory cues. For a good operator acceptance, the guidance must be as smooth and unobtrusive as possible.

This paper describes theoretic considerations about operator attention and situation awareness in section 2. Section 3 presents the results of an attention related task analysis of ATCOs via questionnaire. Attention guidance mechanisms which are already implemented and validated are described in section 4. Section 5 summarizes and sketches a way forward towards appropriate guidance of ATCO attention at their CWP.

2. Related Work on Attention and Situation Awareness of Operators

Controlling air traffic is a very challenging task for a human which is why the personnel hired for this purpose is subjected to a tough selection process. The ability to correctly perceive a traffic situation in an area, predict future traffic and influence it in such a way that it corresponds to the ideas of a future development of the traffic situation is a core element. Since a given traffic situation consists of many individual events, it is of great importance to correctly distribute one's attention which can be seen as a filter to the environment [4]. However, due to the posed requirements, active control must be exercised with due caution. Due to the high taxation of auditory and visual channels, the ATC domain is a good example for the compromise between obtrusiveness and inconspicuousness of cues that needs to be found [5]. The latter article shows that the ATC environment is special, which is why an air traffic controller's attention guidance should be as unobtrusive as possible. Hence, it is crucial to achieve a balance between obtrusiveness and inconspicuousness with the different elements to control the ATCO's attention.

2.1 Cues for ATCO's Attention Guidance

To guide the attention of an operator in an appropriate way, different cues based on different sensory channels are possible in today's working environment of air traffic controllers. An attention guiding cue, in the sense here is in a modality, e.g., a sound, which helps the human operator to detect another cue in another modality, e.g., a visual event [6]. The following sensory channels for different cues have been studied in the literature. Visual cues are investigated for example in [7]. The main findings of this paper address the components of visual orientation and discuss the finding of an inhibitory effect following a shift of attention. When applying visual cues in the air traffic control environment, care must be taken to not overload the display in the controller working position. As the radar screen already contains a great deal of information, the cues should be such that they do not cover them nor distract the ATCO from relevant information. A possible solution would be an adjustment of salience as proposed in [8]. Also, auditory cues have been considered to guide the attention of an operator [9]. Auditory cues were used to examine the conditions necessary for covert orienting and inhibition of return (IOR) to occur. Considering the ATC environment, auditory cues are difficult to apply because the main task of an ATCO is to talk to pilots. In some cases, like in an approach environment, the ATCO communicates almost continuously with the pilots. This implies that the auditory cues must prevail in this noisy and loaded environment. This quickly leads to the auditory cues being perceived as annoying and distracting which will be rejected by the controller. Tactile cues are examined in [10]. The article unveils that tactile cues are particularly useful in the case of discrimination responses, e.g., binary scenarios. In an ATC environment, tactile cues are in principle possible but the implementation in the CWP could be difficult. As hardware changes are expensive and regular maintenance is required, this modality does not rank first. A solution proposed by [5], where the test persons were equipped with a wireless tactile control unit on a flexible band around their torso. The tactile attention guidance resulted in an overall higher performance with attention guidance. But this system also adds hardware to the CWP which needs maintenance and may be recognized as obstructive. A tactile attention guidance system would have to have a superior utility value to be considered for implementation. In general, attention is guided by an external automated assistance system where human operators receive information about an important event occurring in another location [11].

With increasing automation, attention guidance becomes more and more important as the operator is less directly involved in the work environment. Therefore, the analysis of works that deal with far-reaching automated environments is also important. For the present case, related work from the field of flight guidance which is addressed in the next section is crucial.

2.2 Influencing Vigilance and Attention of Controllers

In highly automated air traffic scenarios with less active involvement of the ATCO, it is important that the ATCO does not lose the mental picture of the air traffic situation. A decrease in ATCO vigilance has been measured during longer periods of observing highly automated ATC scenarios by ATCOs [1]. Therefore, the SESAR Exploratory Research project MINIMA developed a vigilance and attention controller (VAC) based on electroencephalography and eye-tracking data [12]. As soon as the VAC detects a change in ATCO's vigilance, automation functions will be adapted [13]. If the ATCO's vigilance decreases, the system will, e.g., switch off some automation support, enlarge the ATCO's area of responsibility, require more manual tasks, or ask artificial comprehension questions about the current situation. If the ATCO's vigilance increases again, the automation might gradually be reverted back to the former mode. It was shown that the VAC can revert a decrease in vigilance [1]. This functionality amongst others resulted in higher vigilance, lower time-to-first-fixation and less mind wandering of ATCOs. These measures go along with an attention guidance as an important mean to guide the ATCOs attention in this dynamic environment.

The SESAR1 WP-E research project NINA used neurophysiological measurements to classify cognitive states of air traffic controllers [14]. Furthermore, adaptive functionalities for controller support have been developed [15]. Four of those functionalities were used for validation with 21 ATC students and 3 ATC professionals (for a detailed description see [16]):

1. Adapt SA-Monitoring by reducing or removing alerts (HMI)
2. Highlighting of calling station (voice recognition of pseudo pilot's messages) (HMI)
3. Adapt STCA alert design (HMI)
4. Reduce visual load (HMI)

Finally, 12 advanced adaptive solutions for future ATC research projects on adaptive automation have been developed [14]. However, the eye-tracking technology was not used to classify attentional states of controllers as this was done by their Brain-Computer Interface, but vigilance and attention are coupled. In both projects the measures go along with an attention guidance as an important mean to guide the ATCOs attention in this adapting environment. In MIMINA, the attention guidance is done by highlighted aircraft with semi-transparent circles in case of longer non-attentiveness by the ATCO. This functionality amongst others resulted in higher vigilance, lower time-to-first-fixation and less mind wandering of ATCOs. DLR's multimodal CWP prototype includes eye-tracking for the selection of aircraft to issue clearances. This CWP was designed to offer natural and fast interaction and was evaluated as efficient, also attracting ATCO's gazes and attention on purpose. All in all, in the past visual cues have been predominantly used in ATC-projects for AG related aspects.

3. Study on Attention, Situation Awareness, and ATC Task priorities

Attention guidance mechanisms need to support handling the most urgent and important ATC tasks [17]. To enable this, three different questions need to be answered as mentioned before. The first one addresses the area the ATCO should look at, the second question addresses the area of the ATCO's current attention, and the third question focusses on how to guide his/her attention. To gather necessary information for the area the ATCO should look at, a questionnaire for Cognitive Task Analysis (CTA) has been developed to determine how ATCOs normally behave at their CWP. This questionnaire is used to investigate if there are visible patterns in the way ATCOs work and how they execute their tasks.

Figure 1 shows a CWP at ROMATSA with the main operational window containing radar data displays, menus, and lists in the middle. On the right side is the secondary operational window, where ATCOs can drag items from the main window to clear some space and so that they don't overlap with the main radar picture or to display a secondary radar picture. On top, in the middle, there is a fallback surveillance system that also displays composite images from weather radars, overlapped with the traffic. On the top left side is the screen of Voice Communication Switching System (VCSS). On the bottom left side is the New Information Display System (NIDS) where ATCOs receive all kinds of information such as frequencies, notices to airmen (NOTAM), Meteorological Aerodrome Report (METAR), QNH values, satellite weather map, Doppler radar weather map, letters of agreement, procedures, manuals, other documents and info, etc. On the table, in front of the ATCO is a panel for phone lines with adjacent sectors.

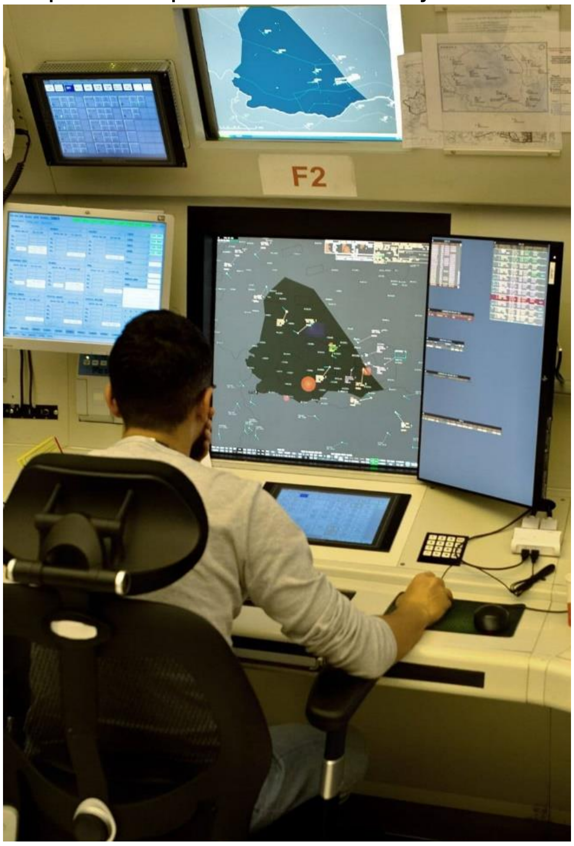

Figure 1 – ACC CWP at ROMATSA with radar screen as the main operational display in the middle.

85 ATCOs from the Romanian air navigation service provider ROMATSA participated in a study about different aspects of attention, situation awareness, ATC task priorities and methods, as well as order of working tasks. 59 of them were from area control center (ACC), 26 ATCOs worked in an approach control center (APP) in Bucharest and Arad, respectively. All of them filled out a questionnaire consisting of 13 questions with multiple answers or answers needing to be ranked. The first four questions refer to Executive or Planner controller working positions. The questions and results – split per center type (ACC/APP) – are shown in the following sub-sections along with the frequency of answers for every offered option.

3.1 Checking Order in case of taking over Service for Awareness of Operational Situation

The first question addresses the checking order to acquire operational situation awareness in case of taking over service. This helps to understand which displays or display parts are most relevant with respect to the ATCO's attention. The *sector* refers to the ATCOs' area of responsibility (AoR). The adjacent sectors around the AoR belong to the area of interest (AoI) with current restrictions in place. Some restictions are permanent, others are activated by NOTAM. Controlled traffic could be in the ATCO's sector or in an adjacent "previous" sector. The ATCO responsible for an adjacent sector could transfer traffic into the ATCO's AoR, e.g., five minutes before the aircraft enters the ATCO's allocated sector. Also, the ATCO could transfer his/her controlled traffic in the AoR to the next sector five minutes before the aircraft leaves the allocated sector.

Question 1.1 for Executive ATCO:

- To obtain awareness of the operational situation *when taking over the service*, what is the *order* in which you *check* the CWP as an Executive?

  A. Controlled traffic and transferring traffic [Traf-Control]

  B. The allocated sectors and adjacent areas with restrictions in place, on the main operational display [Sectors]

  C. Functional status of ATM system [ATM-Status]

  D. Lists / windows on the main operational display [Windows-1]

  E. Secondary displays (Meteorological situation, New Information Display System, surveillance fallback system, etc.) [Windows-2]

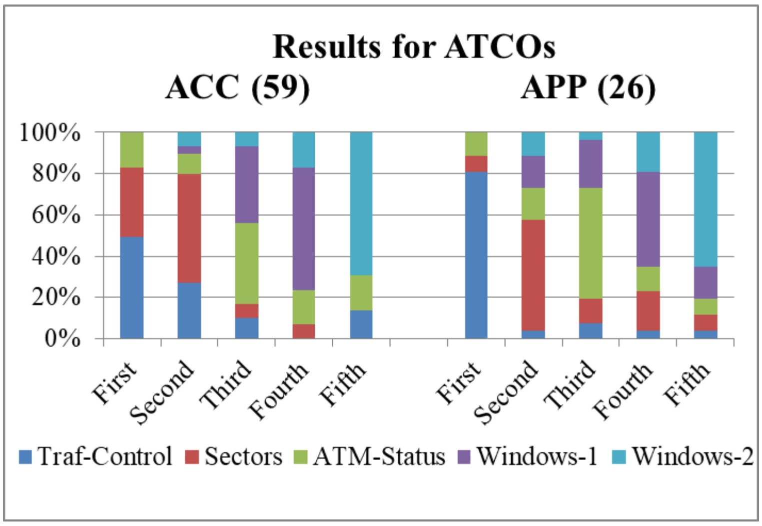

Figure 2 – Checking order in case of taking over service as an Executive ATCO.

In Figure 1 the order, referred to as first, second, third and so on as well as the displays color coded in blue, red, green and so on are depicted. ACC and APP ATCOs check the information prior to taking over the service as an Executive predominantly in the same order (see Figure 2), i.e., the color of the largest column for each of the five steps is the same. Both prioritized the task "controlled and transferring traffic" the highest, followed by the sectors and the ATM system status. The least important tasks prior to the shift are monitoring of lists and windows of the main and secondary displays. Hence, for AG mechanisms, the focus should be on the radar display that shows air traffic and sectors.

Question 1.2 for Planner ATCO:

- To obtain awareness of the operational situation *when taking over the service*, what is the *order* in which you *check* the CWP as Planner?

  A. Controlled traffic and transferring traffic [Traf-Control]

  B. The allocated sectors and adjacent areas with restrictions in place, on the main operational display [Sectors]

  C. Traffic from adjacent areas [Traf-Adjacent]

  D. Functional status of ATM system [ATM-Status]

  E. Lists / windows on the main operational display [Windows-1]

  F. Secondary displays (Meteorological situation, New Information Display System, surveillance fallback system, etc.) [Windows-2]

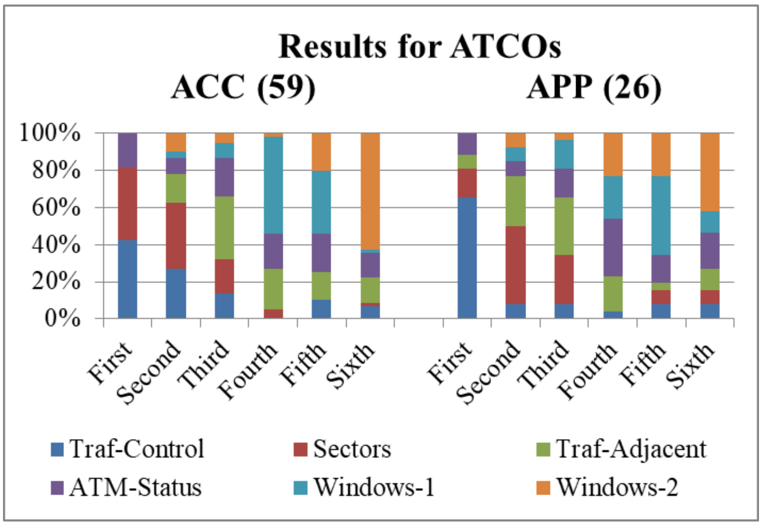

Figure 3 – Checking order in case of taking over service as a Planner ATCO.

Tasks with highest priorities were nearly the same for ACC and APP ATCOs when taking over service as a Planner (see Figure 3). However, information about controlled and transferring traffic is obtained first of roughly two thirds of APP ATCOs, but only 40% of ACC ATCOs. There were also slight differences among Planner ATCOs within ACC and APP with respect to the priority of checking lists and the functional status of ATM system. The latter was viewed as more important in APP (priority 4) than in ACC (priority 5). Again, secondary displays had the lowest priority for both types of ATCOs. Thus, appropriate AG mechanisms should also consider the working environment of controllers as ACC ATCOs seem to focus more on their sectors (AoR) as compared to APP ATCOs who focus on traffic under control first. Hence, AG mechanisms should not only focus on the ATCO's AoR, but should also consider the ATCO's AoI.

3.2 Checking Order during Service for Awareness of Operational Situation

The second question is very similar to the first but focusses on the order of preferences during the service and not at service take-over. This shall reveal different preferences regarding attention when the ATCO is already in the loop after service take-over.

Question 2.1 for Exceutive ATCO:

- To maintain awareness of the operational situation *during the service*, what is the *order* in which you *check* as Executive?

  A. The allocated sector, on the main operational display [Sectors]

B. Lists / windows on the main operational display [Windows-1]

C. Functional status of ATM system [ATM-Status]

D. Secondary displays (Meteorological situation, New Information Display System, surveillance fallback system, etc.) [Windows-2]

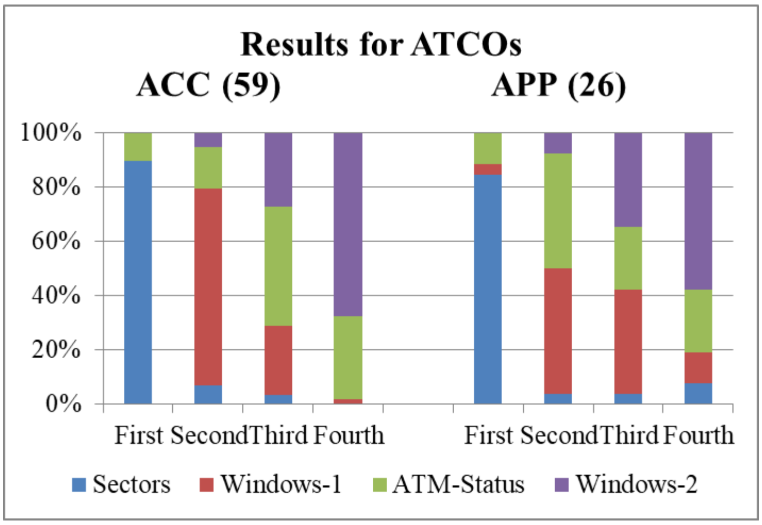

Figure 4 – Checking order during service as an Executive ATCO

Question 2.2 for Planner ATCO:

- To maintain awareness of the operational situation *during the service*, what is the *order* in which you *check* as Planner?

A. The allocated sector, on the main operational display [Sectors]

B. Lists / windows on the main operational display [Windows-1]

C. Traffic on adjacent sectors [Traf-Adjacent]

D. Functional status of ATM system [ATM-Status]

E. Secondary displays (Meteorological situation, New Information Display System, surveillance fallback system, etc.) [Windows-2]

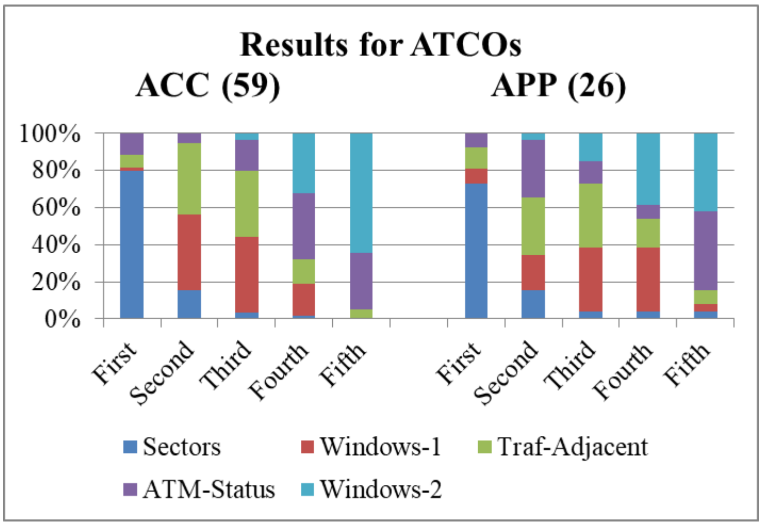

Figure 5 – Checking order during service as a Planner ATCO

The prioritized order in which the ATCOs carry out the tasks in order to check information is described as follows: a clear majority of Executive ATCOs in ACC (52 of 59 ATCOs) and APP (22 of 26 ATCOs) first check the allocated sector on the main operational display (see Figure 4 and Figure 5). Executive ATCOs consider monitoring of the secondary display to be of least priority (ACC: 40 of 59 ATCOs, APP: 15 of 26 ATCOs). For Planner ATCOs, one task which is (usually) not part of the Executive ATCOs' work relates to the monitoring of traffic of adjacent sectors. This particular task has the second highest priority for Planner ATCOs in ACC (25 of 59). Clearly, the allocated sector on the main operational display should be the main focus of AG mechanisms because this is what ATCOs are most concerned about. However, adjacent traffic and additional information on the operational display might also be subject to attention and AG mechanisms in case the allocated sector information is already checked.

3.3 Task Orders of Air Traffic Controllers

The third question addresses the order of the tasks the ATCOs usually apply. This order should be strongly aligned with the priorities determined for the AG mechanism.

Question 3.1 for Executive ATCO:

- What is the *order* in which you perform the following *tasks* as Executive?

  A. Communicate verbal instructions to the pilot [Verbal Instruction]

  B. Inputs to the system [System Input]

  C. Update trajectory [Traj-Update]

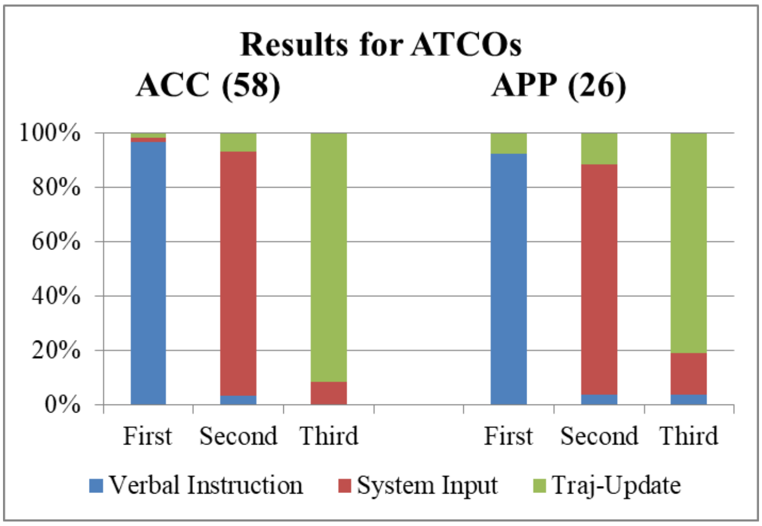

Figure 6 – Performing order during service as an Executive ATCO.

The answers from executive ACC and APP ATCOs revealed the same order (see Figure 6). Both types of executive ATCOs, i.e., executive ACC (56 of 58) and APP (24 of 26) ATCOs unambiguously prioritized communication with pilots the most. Inputting information into the system was viewed as the second most important activity and performing trajectory updates was voted as the least important one. Hence, the Executive ATCO should not be pointed to perform a trajectory update if he/she is actively giving verbal instructions or performing system input.

Question 3.2 for Planner ATCO:

- What is the *order* in which you perform the following *tasks* as Planner?

  A. Voice communications and data exchange with the downstream adjacent ATS unit [Comm. Down ATS]

  B. Inputs to the system [System Input]

  C. Voice communications and data exchange with the upstream adjacent ATS unit [Comm. Up ATS]

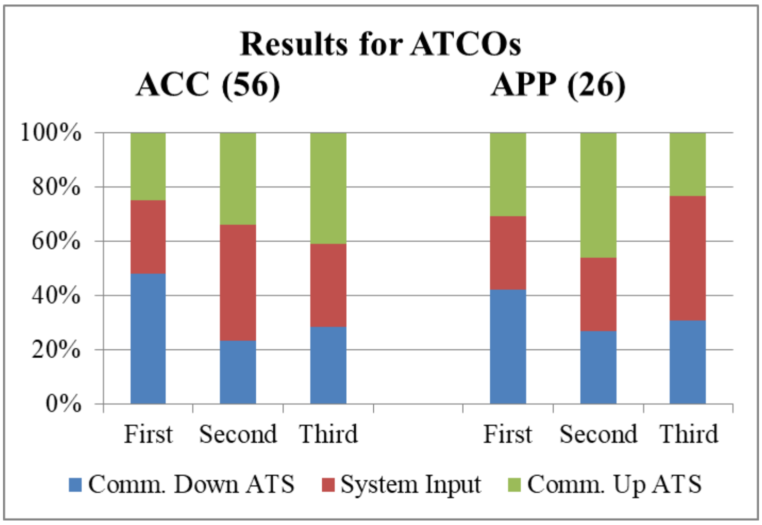

Figure 7 – Performing order during service as a Planner ATCO.

The Planner ATCOs were asked to rate slightly different tasks in the decreasing order of their priority. For ACC ATCOs, the answers clearly indicate the order of tasks executed by a majority of ATCOs (see Figure 7). The answers from APP ATCOs differ, such that inputs to the system have a lower priority against the voice communications and data exchange with the upstream adjacent ATS unit. Thus, for a Planner ATCO, the order of tasks suggested by an AG mechanism may not play an important role.

3.4 Prioritizing Alerts and Alarms

The fourth question deals with already existing interruptive alerts and alarms. This shall give further evidence to additional AG mechanisms for the already existing alerts.

Question 4 is the same for Executive and Planner ATCOs:

- In prioritizing tasks, what is the *order of importance* you would give to *alerts / alarms* generated by?

  A. STCA (Short-Term Conflict Alert)

  B. MSAW (Minimum Safe Altitude Warning), DAIW (Danger Area Infringement Warning, Safety net)

  C. MTCD (Medium-Term Conflict Detection)

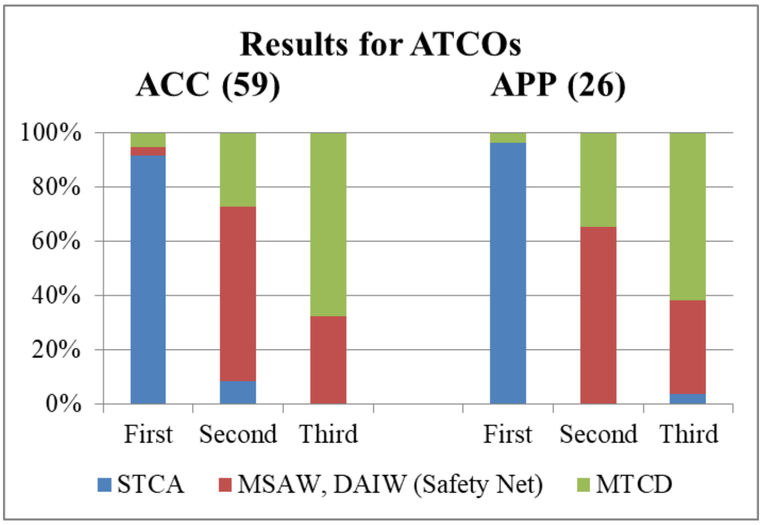

Figure 8 – Prioritizing order for alerts during service as an Executive ATCO.

Clearly, the STCA alerts were given utmost importance by both Executive controllers for ACC (54 of 59 ATCOs) and APP (25 of 29 ATCOs) working positions (see Figure 8).

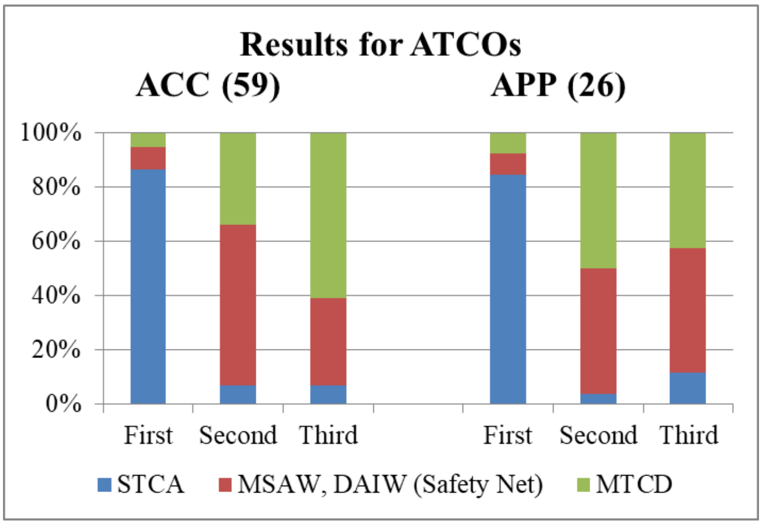

Figure 9 – Prioritizing order for alerts during service as a Planner ATCO.

The same was the case for Planner ATCOs in ACC (51 of 59) and APP (22 of 26 possible answers in Figure 9). Except for the Planner ATCOs working in APP working positions, all other ATCOs prioritized MSAW and DAIW as the second most important type of alerts. Least attention is paid to MTCD alerts, except by Planner ATCOs in APP where 13 of the 26 ATCOs voted MTCD as the second most important alert. Therefore, AG mechanisms should draw one's attention to STCAs if the ATCOs have not paid attention to them yet. With lower priority, attention should also be drawn towards less urgent safety net functionality.

ATCOs also answered that they evaluate the operational situation and take warnings / alarms into account instead of just relying on alerts / alarms. Only two ATCOs stated that they rely only on evaluating the operational situation on their own. Hence, AG mechanisms should make sure that the given warnings / alarms are paid attention to in order to let the ATCOs evaluate the operational situation with these hints.

3.5 Prioritizing items to accomplish tasks

The fifth question addresses the way in which relevant information is presented in the ATC displays which is also relevant for AG mechanisms.

- What *items* associated with an aircraft will help you the most to *accomplish a task*? (more than one answer checked for the majority of filled questionnaires)

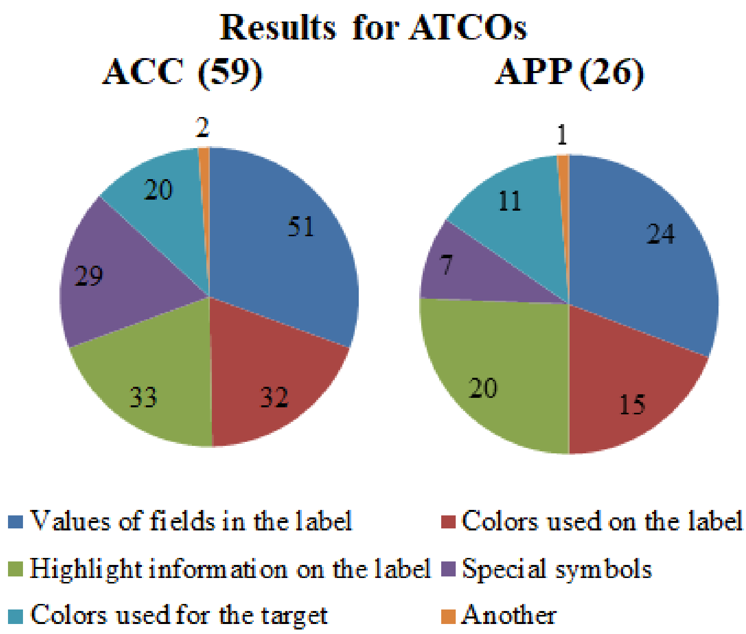

Figure 10 – Helpful items to accomplish tasks.

A majority of 51 ACC and 24 APP ATCOs viewed the display of values in labels as the most valuable item (see Figure 10). Since multiple answers were allowed other items that were viewed as important for display design related to the highlighting of information on the label (ACC: 33 ATCOs, APP: 20 ATCOs), colors used in the labels (ACC: 32 ATCOs, APP: 15 ATCOs) as well as the usage of special symbols (ACC: 29 ATCOs). 11 APP viewed the coloring of the target as more helpful than the usage of special symbols. Three other items that were mentioned were a 5NM circle around target (for ACC) as tactical tool function, “line 4 of the label” always open (when activated), and a speed vector. The results indicate that the radar label as the central HMI elements requires particular attention for the label design. In general, AG mechanisms should smoothly guide the ATCO’s attention to relevant information, e.g., to values in radar labels. Hence, the AG mechanism should use different colors and highlighting functionalities to guide the ATCO’s attention to relevant display positions.

3.6 Scan Method for Radar Display

The sixth question deals with the applied scanning methods employed by ATCOs [18]. These methods should be taken into account to not disturb the ATCO with his/her ATC tasks and that he/she would see it soon anyway due to the scanning cycle. In other words, some ATC tasks that just came up shortly after scanning might need some AG mechanisms to be considered by ATCOs before proceeding further.

- Do you have a *scan method* you usually prefer to use when evaluating air traffic on the radar display? (multiple answers allowed)

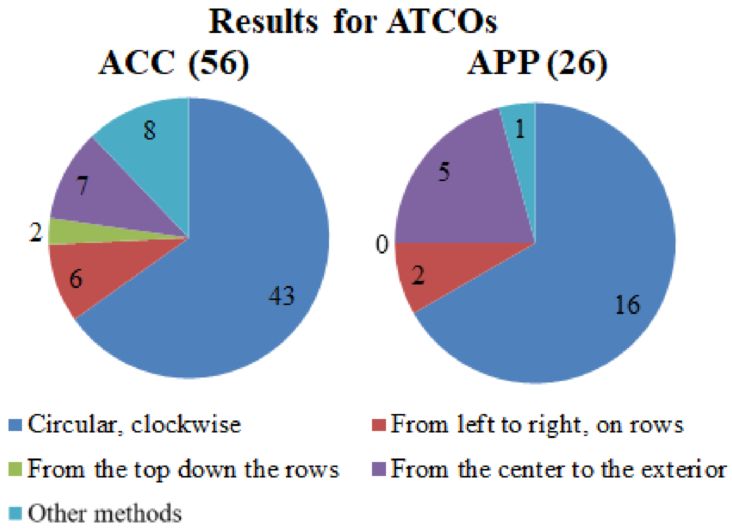

Figure 11 – Scan methods of ATCOs.

The majority of both types of ATCOs clearly prefer the circular, clockwise scan method. This was followed by methods such as ”from center to the exterior“ and “from left to right, on rows”. All other methods have a maximum of two votes including the following examples provided by ATCOs under “Other methods”: “Exterior to the center; in cross, from the center; priority on "hot spot" areas; circularly, counterclockwise; eastbound/westbound; on flight levels; randomly, depending on the actual busy flight level or that will become busy; trajectories, conflict areas”. Hence, AG mechanisms should not interrupt clock-wise scanning while deriving information when a relevant ATC event would be noticed by the ATCO, given the current progress in the scan cycle.

3.7 Keep up Situation Awareness

The last question analyses low-traffic situations and the methods to keep up situational awareness. Such methods could also be automatically applied or considered by AG mechanisms.

- How do you keep your *attention* in *low-traffic situations*? (more than one answer checked for the majority of filled questionnaires)

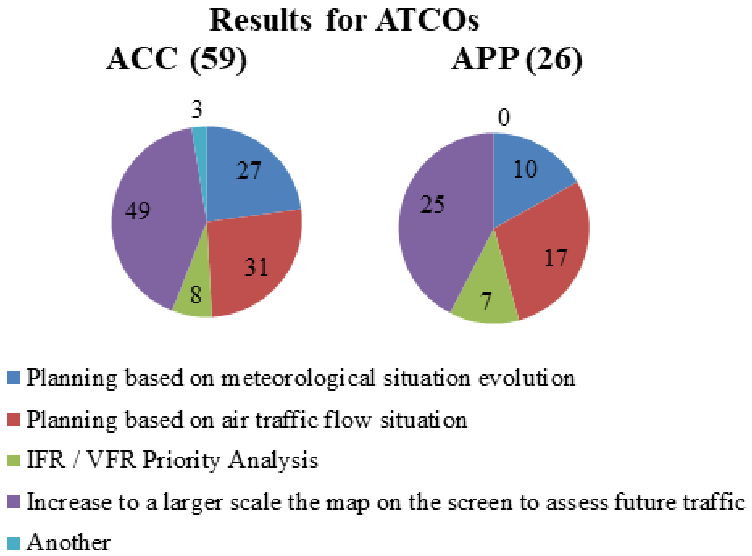

Figure 12 – Keeping up situation awareness in low-traffic situations

This item deals with the countermeasures that ATCOs take in order to keep attention up in low-traffic situations. Both ACC and APP ATCOs unanimously voted increasing the main operational display's map to a larger scale as the most effective and applied measure to sustain attention (see Figure 12). In second place, planning based on air traffic flow situation (ACC: 31 ATCOs and APP: 17 ATCOs) was viewed as an effective measure to sustain attention, followed by planning based on meteorological situation evolution (ACC: 27 ATCOs and APP: 10 ATCOs). Three examples have been described under "Other methods": "imagining different possible scenarios; continuously scanning the radar screen; analyzing existing situation at the same flight level". Hence, in situations with few ATC tasks, AG mechanisms could drag the attention to more tactical tasks such as weather, flow, and air traffic characteristics analysis in a broader view.

3.8 Conclusions on Questionnaire about Attention, Awareness, and ATC Task Priorities

The answers in the questionnaire differ depending on ATC unit and working position. When taking over service, APP ATCOs have a stronger focus on checking controlled traffic prior to adjacent sectors as compared to ACC. This difference does not exist during the service. However, the traffic of adjacent sectors is more relevant to the Planner controller as compared to the Executive controller. As an Executive, verbal communication with pilots is the most important aspect compared to inputs to the ATC system and trajectory updates. However, for Planners, system input and voice communication with down-and up-stream adjacent ATS unit seems to be almost equally important.

STCAs hold the most attention of ATCOs followed by safety net alerts. Planner ATCOs are the only ones with enhanced interest in MTCAs. However, ATCOs evaluate the operational situation themselves and only then consider alerts. Colors, symbols and other coding of information primarily in the aircraft radar labels support the ATCOs in accomplishing their tasks. Color is seen as an effective method to follow the evolution of traffic. Majority of ATCOs scan the radar screen circularly clockwise. In case of low-traffic situations, ATCOs keep up their situation awareness by increasing the radar screen scale, planning air traffic flow and considering the meteorological situation.

Derived from the above findings, several aspects need to be considered when conceptualizing and implementing an AG mechanism. First priority should be given to the situation data display, especially to the allocated sector comprising relevant air traffic. Adjacent sectors are of second priority. Furthermore, the working environment and the type of ATCOs need to be analyzed, i.e., if an ATCO is working in ACC/APP or as an Executive/Planner, because they have different task priorities and order in which they are carried out. However, ATCos should not be interrupted from important tasks and also from their individual scan cycle if possible. Attention should be drawn primarily with visual cues to radar labels and values. This attention guidance should be done with different emphasis, but as smoothly as possible with respect to alarms, safety net functionalities, warnings, ATC events, and even tactical tasks depending on urgency, importance and situation. The ATCOs will then evaluate the operational situation based on all CWP system's hints.

4. Guiding the ATCO's attention

4.1 Actual Area of Controllers' Attention

In the following, we assume that the area of the ATCO's current gaze on the HMI is the area of his/her visual attention [19]. In reality, the visual attention can be different from the cognitive attention if the ATCO, e.g., stares at the screen, thinking about something else. Even in the case where the ATCO stares at a fixed position on the screen without having any perception, an attention redirection is useful if a task with a certain priority occurs. The probability of the controller accidentally staring exactly at an important position without perceiving anything would be extremely low. However, for ATCOs using a radar screen, the assumption is a very good approximation. Therefore, it is possible to approximate the current area of ATCO attention by measuring it with an eye-tracking system.

Furthermore, it is necessary to recognize the importance of the situation that the controller is currently looking at and to infer the importance of his/her current task from this situation. This information is necessary so as to not interrupt his/her current processing unnecessarily. Thus, when the controller stares at a particular point of high importance and does not react, as a consequence the attentional guidance intensifies its efforts to increase the controller's attention. Thus, the non-attentive stare at an important point leads to just a short delay in attentional guidance.

The current ATCO gaze can be measured via eye tracking consumer products. A low budget eye-tracker mounted to the bottom of the display is also used for the multimodal CWP TriControl [3]. The ATCO's current gaze focus on the radar screen is analyzed in order to determine the aircraft radar label or the aircraft icon that the ATCO is currently looking at [20]. This aircraft is then assumed to be the next aircraft to receive an ATC command in TriControl [21]. The mouse cursor is often used by ATCOs to point to the spots they are currently dealing with and this can serve as an additional sensor to identify the actual attention. In general, the aircraft or area the ATCO visually focusses on or did focus on in the last seconds is assumed as being actively processed cognitively by the ATCO.

4.2 Target Attention Area of Controllers

The attention of the ATCO is usually based on urgency and importance of events. Various contextual information is considered to create weights for the events. Contextual information consists of the positions and moving vectors of an aircraft, the time-to-event, possible consequences and many more. Such information can also be considered by electronic decision support systems such as management systems for arrival, departure and en-route phase why this information is already available in systems. Based on the ranking of unsolved ATC events, the highest rated one is considered to be the target area of ATCO attention. ATC events can also be resolved even if the ATCO has not visually scanned the affected areas. Hence, the event weighting needs to be updated continuously considering all dynamic data. The target area of attention can comprise of just one object or multiple objects, e.g., 3 aircraft encountering a medium-term conflict alert and their conflict point. Thus, it needs to be decided if a visual scan of just one of the involved objects is enough to be aware of the whole event. For a short- or medium-term conflict, both involved aircraft should be scanned.

4.3 Guiding Attention via Visual Cues

Knowing the ATCOs' target and actual area of attention, they can be compared. If there is a mismatch between the two attention areas in present situation and in near past, the ATCO attention should be smoothly guided to the relevant spots. If the AG mechanism is triggered, different levels of escalation should be considered. In case of visual cues for example, they should become more salient after some time when the ATCO has still not scanned the target area. Four different escalation levels have been proposed in [19]. The basic level 0 does not change the appearance of the HMI. If an unresolved event exists, it is tracked until defined threshold times are reached. In case an ATCO action is deemed necessary, escalation level 1 initiates a first highlighting of involved objects, i.e., a frame around the aircraft radar label. After some time of non-observance and non-solving of the event, escalation level 2 adds a flashlight effect on the respective aircraft. This is complemented by a glowing flashlight effect later on in escalation level 3. If the controller's visual attention has been incorrectly "measured" [22] at a particular position on the HMI and some highlighting has disappeared, the escalation levels can be increased again if the ATC event remains unresolved.

The described attention guidance functionality has been validated in a Flight-Centric ATC use case in the course of SESAR2020's industrial research project PJ.16-04 CWP HMI [23]. The developed AG prototype was evaluated with ATCOs from HungaroControl in Budapest. They had to guide en-route traffic as ACC ATCOs in a highly automated environment. Due to different tasks shared between humans and machines in the Flight-Centric ATC environment, they played the role of a Planner ATCO supported by software tools, but had some remaining tasks of an Executive ATCO. The validation trials revealed promising results for the CWP, which was equipped with AG functionality based on human performance questionnaires, AG log files, and more general statements. ATCOs reported noticeably less workload and improved situation awareness with AG. The workload reduction addresses topics like multitasking, planning, decision making, team awareness, information processing, attention direction, problem solving, memory management, and maintaining awareness. From a usability perspective, ATCOs reported being able to prioritize alarms more quickly with AG. In the debriefing, the ATCOs mentioned that the AG functionality really helped them take a look at HMI items that they would not have otherwise seen in a timely manner. In addition, the AG mechanisms were described as truly non-intrusive but supportive and were found by the ATCOs to be ready for operationalization in their own CWPs. It was very encouraging that most ATCOs already want to use AG in their current CWP.

5. Summary and Outlook

It is essential for air traffic controllers to have their attention at the right spot at the right time. Thus, after analyzing the ATCOs' habits with respect to attention related working methods, concepts for influencing and guiding their attention have been defined, implemented, and validated. Those functionalities were well-appreciated by ATCOs in the tested setup. ATCOs also encouraged further work to enable early deployment of such systems in a CWP which is why the described investigation was carried out.

In this context, the European Air Traffic Management Architecture (EATMA) was updated as part of the Single European Sky ATM Research Programme (SESAR) Industrial Research (IR) project PJ.16-04 Controller Working Position Human Machine Interface (CWP HMI). The solution activity 02 Attention Guidance defined the new Functional Block (FB) "Attention Guidance" for CWPs of area control centers in approach and en-route. The resource orchestration view foresees input data that is processed by two new functions comprising of the methodology described in sections 4.1 and 4.3 for final output. The AG FB analyzes whether a given information is relevant for ATCOs in the current situation or not. If relevant, the information or the respective situation requires ATCOs' attention. Therefore, it should be considered where the ATCO actually looks to be able to guide ATCOs' attention to the target area of attention.

Radar data, flight plan data, and airspace data serve as initial inputs. However, additional data from sensors such as eye-tracking, automatic speech recognition or other HMI interaction data can be used to define the ATCO's current area of visual attention. All relevant data is considered by the first function "Attention Guidance Logic" to calculate weights for different ATC events. Attention should be paid to areas of individual ATC events such as short- or medium-term conflict alerts or handover events which are determined to be relevant (or important and urgent). If the target area of ATCO attention does not match with the actual area of ATCO attention for a relevant ATC event, the AG Logic informs the CWP to perform "Attention Guidance Measures" as defined in the second function. Different cues can serve as attention guidance measures depending on the escalation levels. Frames around aircraft labels and glowing flashlight effects around aircraft icons or airspace areas are some of the defined visual cues.

As a next step, the EATMA functional block and functions on attention guidance will be updated with respect to the tower environment in the course of the SESAR IR project PJ.05-97 [24]. Further research at DLR will focus on the use of auditory cues and even a soundscape to guide ATCOs' attention. This seems promising because it has been found that visually seeing and hearing sounds may give a more intense experience [25]. AG mechanisms become even more important facing the challenges of Single Controller Operations (SCO) and the collaboration between human and artificial intelligence in case of higher levels of automation. In addition, assistant based speech recognition [26] will be used as a further sensor to determine the ATCOs' current area of attention.

6. Contact Author Email Address

mailto: Juergen.Rataj@DLR.de

7. Copyright Statement

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