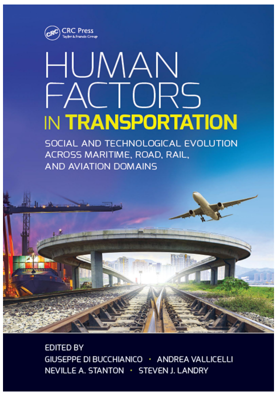

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What about the Next Generation? Assessing Experts' Judgments of Human Abilities Required for Working in a Future ATC Environment

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What about the Next Generation? Assessing Experts' Judgments of Human Abilities Required for Working in a Future ATC Environment

Dirk Schulze Kissing

CONTENTS

24.1 Introduction

The future roles of air-traffic controllers (ATCOs) are supposed to change significantly especially in the terminal maneuvering areas (TMAs) of large airports. Due to a system-wide information management, automated planning systems will be able to utilize complex optimization algorithms to keep flight plans synchronized with constraints from network plans and airport processes on a tactical level.

Although ATCOs are conceived to remain a central element within future air-traffic management (ATM) (cf., Single European Sky ATM Research Program [SESAR], 2012), it still has to be clarified how the difficulties for human operators to coordinate agents whose intentions are hard to comprehend (Sarter et al., 1997), because their behavior is based on decisions which result from complex optimization algorithms, can be overcome and automation biases (Cummings, 2004) prevented. The contribution of personnel selection is to proactively assess not only how such evolutions of the human role may affect the human operator, but also how abilities required to fit into the new job profile will change, so selection profiles for ATCOs will be modified accordingly in time.

This chapter focuses on analyzing the job requirements and their corresponding abilities in a potential future approach control setting. A simulation experiment is conducted with different levels of ATCOs' assistance up to the point where the humans have to supervise a self-executing automation (cf., Willems, 2002). The roles under scrutiny all refer to the tactical level. The ATCOs are focused on traffic situations in a terminal maneuvering area (TMA) as displayed at the controller working position (CWP). With monitoring skills getting an even more central requirement in future air traffic control (ATC) tasks due to automation (Broach, 2013), and empirical indication that this is accompanied by changes in monitoring behavior (cf., Voller and Low, 2004), a focus is set on the assessment of the ATCOs' eye-gaze behavior to explore the way information is scanned contingent with role changes.

24.2 Theory

24.2.1 Requirements of Controlling Air Traffic in TMA

ATCOs in a high density TMA often have to handle 10 and more aircraft (a/c) at a time (Freed and Johnston, 1995). Certain cognitive mechanisms supposedly accomplish the coordination and supervision of many a/c, that is, the control of air traffic.

The key for enabling an ATCO (air-traffic controller) to handle so many is that the task for any a/c usually is entire routine (Freed and Johnston, 1995). The inbound traffic into the TMA is guided over only a few sector inbound fixes, and is normally kept on a standard arrival route (STAR) before handed over to the referring tower at a final approach fix. This allows the ATCO to rely on well-trained routines for handling the individual a/c and consolidating these into an overall sector-control plan. In a well-trained routine the ATCO identifies an inbound a/c on the radar screen when it calls over radio telephony (r/t), naming the call sign and the current level. Acknowledging radar contact via r/t by then the ATCO formally accepts responsibility for the a/c. The ATCO then checks for the correct destination on the flight progress strip, then selects a path, routinely the STAR, and instructs the pilot to follow it or alternatively, vectors to the nearest fix on the flight plan are given. The pilot acknowledges all clearances. The ATCO observes when the a/c is approaching a cleared fix and then clears the plane to an altitude that is required for the descent to the airport, and then vectors it to the final approach. The pilot again acknowledges all clearances. When the ATCO observes the a/c approaching the final approach fix, she/he provides the pilot with a clearance for an ILS (instrument landing system) approach, and hands-off responsibility for the a/c to the tower ATCO by instructing the pilot to change to tower frequency, and contacting the tower when passing the final approach fix, which the pilot acknowledges. With the acknowledgment of the a/c the ATCO intends to act according to the plan routine, namely to provide adequate clearances in time. With its moving along to the sector center, that is, the area of the final approach the a/c receives higher priority.

In order to have a high level of situation awareness, ATCOs have to continually sample the airspace on the radar display to ensure that no separation conflicts occur which may require them to take actions, check for flight progress strips and other information displays, as well as information obtained through radio communications and phone lines. The ATCO therefore regularly scans the sector from inner to outer areas to frequently update the information on location, speed, heading, and altitude of these a/c, and to continuously combine this information with other context information, like weather, into a coherent mental representation of the current situation (Sheridan and Parasuraman, 2005; Loft et al., 2007). The ATCO also regularly scans relatively consistent spatial locations (cf., Wickens et al., 2001, 2003) for critical events. An example for such a spatial hot spot would be TMA fixes where down-winding traffic streams on different standard arrival routes (STARs) are merging. This task is also called monitoring and comprises of deciding on a moment-to-moment basis which information is most important to attend for the updating of the mental model (Redding, 1992; Seamster et al., 1993).

Based on this mental model of the situation the ATCO builds up a sector-control plan and decides about clearances given to pilots on speed, heading, and altitude for the different a/c to maintain separation, and thus to guide the a/c safely through their sector (Loft et al., 2007). ATCOs also have to delay intentions and regularly check how far the plan has proceeded, if conditions for the action implementation are met, like providing a clearance for an altitude necessary to descend to the airport only after a following a/c with a higher speed on the level below has passed, or turning a northbound a/c to final only after a preceding south-inbound a/c is established on the final approach.

As the mental model is supposed to provide the structure for an efficient retrieval of sector-control plan routines (Seamster et al., 1993), it can be assumed for the level of cognitive processes that once a routine is retrieved from long-term memory it gets activated as an intention and is thus transferred into working memory (cf., Cowan, 1999) to await the appropriate set of conditions so that it can become selected to control action (Norman and Shallice, 1986). As long as the conditions are not met the routine remains active as an intention until its execution is completed (cf., Miller et al., 1960). The active routines, or intentions, respectively, have special ways of being remembered that are necessary for coordinating the parts of the sector-control plan under execution (cf., Miller et al., 1960). Triggers allow suitable activated schemas to be initiated at the precise time required (cf., Norman and Shallice, 1986). Conscious prioritization provides additional activation to the intentions according to their subjectively experienced importance, so there is a higher probability they receive attention first when it is distributed. Mechanisms of time-based prospective remembering (cf., Harris and Wilkins, 1982; Ellis, 1996; Block and Zakay, 2006) supposedly also come into play to control attention to frequent and timely flow back to the different intended tasks. And finally, an overall metacognitive management of the sector-control plan, with assessments on how far the plan has progressed, which action is of utmost priority, or if contextual changes make plan revisions necessary, shall be executed by deliberate, conscious control processes (for further reading, see Norman and Shallice, 1986). Once the mental model and the sector-control plan are set up, their revisions are closely coupled as changes in the situation often require changes in the sector plan (Redding, 1992; Seamster et al., 1993).

As illustrated by this the current ATC in a TMA can be conceived as a visually and cognitively demanding task with the core requirement to build-up and maintain situation awareness (Redding, 1992; Seamster et al., 1993).

24.2.2 Measuring Scanning Behavior as a Means to Assess Monitoring Abilities

Broach (2013) presumes that with the introduction of advanced automation, scanning of visual sources will be one of the abilities which will become more important for future ATC job performance. The appraisal that virtually nothing is known of how ATCOs scan visual sources (Stein, 1992) does no longer fully hold true today as considerable work has been done on this topic since the early 1990s (e.g., Wickens, 2000; Wickens et al., 2001, 2003; Willems, 2002; Parasuraman et al., 2008; Moore and Gugerty, 2010; Rovira and Parasuraman, 2010). However, because of the technological progress on the accuracy and robustness of eye-tracking measurement systems in recent years, there now seem to be new opportunities to push the topic of ATCOs' visual information sampling further.

The position of the eye is supposed to reflect the current direction of attention, with spontaneous and task relevant looking as two different types of eye movement (Kahneman, 1973). Occurring independently from intentions, spontaneous looking is regarded to be a bottom-up process driven by salient features of events, like movement or novelty, and serves the function of information seeking (cf., Kahneman, 1973). Task relevant looking on the other hand is related to top-down decisions in which an area of interest (AoI) on the radar screen is likely to be richest in relevant information. These decisions require a quick and unconscious weighing of expectancies, effort, and value (cf., Senders, 1964). The sequential allocation of glances called visual scanning is mediated by both bottom-up and top-down processes, and thus comprises both spontaneous and task relevant looking. According to the model of scanning behavior proposed by Wickens et al. (2001), the four factors that influence the frequency of scanning are the physical salience of an event, the physical distance between two consecutively attended AoI, the expectancy for a change of information, and the value of processing or the cost of not-processing that information. The model predicts that an AoI, like a flight data block (FDB), will be visually scanned to the extent that it is expected to contain new information, but even in the absence of high expectations will be sampled more frequently when the AoI is related to a high priority task. Finally, visual sampling may be inhibited by excessive effort requirements, which may cause a complacency bias in scanning behavior (cf., Parasuraman and Manzey, 2010).

An alteration of attention between phases of focused and distributed attention is a characteristic of skilled scanning (Moore and Gugerty, 2010). Even while ATCOs are focusing on a specific area of the radar screen, they must continue to be aware of what is occurring around their sector. Consequently, ATCOs should not neglect to utilize both focused and distributed attention strategies to achieve and maintain situation awareness.

Scanning behavior is assumed to change with ATCOs assigned to the supervisory control (SC) role with high requirements on system monitoring. Parasuraman et al. (2008) suppose that operators scan the raw information sources less frequently when tasks are delegated to an advanced automation, and Rovira and Parasuraman (2010) assume that ATCOs will invest the unbound cognitive resources to focus on secondary tasks, indicated by fewer fixations exhibited to the radar display compared with manual control (MC) conditions. According to Voller and Low (2004) ATCOs reported to be aware of changes in their scanning behavior under simulated future task conditions, without being able to specify this further. Willems (2002) reports on a reduced visual scan structure under conditions of higher levels of automation.

It is an open question what the main characteristics of visual scanning behavior within a TMA task setting are, and in which ways these may change with the introduction of advanced automation. Before moving on to this question, a short introduction into the topic of automation in ATC is provided.

24.2.3 Perspectives on Automation in ATC

An increased level of automation (LoA) support for ATCOs appears to be mandatory to maintain safety and efficiency in a future time-based environment (cf., Kirwan, 2001). As technology tends to push to automate tasks as fully as possible (Miller and Parasuraman, 2007), the future locus of control in ATM is expected to switch from human to automation (Smith et al., 2001). ATCOs supposedly will become traffic managers responsible for resolving exceptional situations instead of controlling every a/c individually like it is today (Dekker and Woods, 1999). Arnaldo et al. (2012) discuss the question whether humans will remain within the future trajectory management processes and will perform some strategic functions where their skills come into play, or if tactical decisions in the future may imply autonomous and fully automated processes. In some far-reaching concepts, it is supposed that in the long-term future automation will take over (Truman and de Graaf, 2007). Truman and de Graaff (2007) also envisage that human intervention and control will be at an absolute minimum in such a self-monitoring and self-controlling future ATM system, with the ATCOs in the role of supervisory controller.

On the other hand there are good reasons to keep the human ATCO within the decision loop and not let automation take over the whole task set of trajectory management within the TMA. Cummings (2004) warns that in time critical environments like ATC, with many external and changing constraints, higher levels of automation are not advisable because automation today, and maybe also in the future does not show the adaptability, flexibility, and problem-solving skills the human operators show to cope with these changing circumstances. Mogford (1997) pointed out that removing the mental picture of the situation from the human domain into automation by keeping the human out of the decision loop would disable ATCOs to bring their problem-solving capabilities into play (see also Bainbridge, 1983). High levels of decision-making automation (LoA) reduces the operators awareness of system dynamics (Miller and Parasuraman, 2007). Humans tend to be less aware of changes when those changes are under the control of another agent. Expert panels therefore recommend that automation efforts in ATC should stop at the level of suggesting decision or action alternatives (Wickens et al., 1998).

When thinking of future ATCOs as monitors of a system it has to be considered that the mechanisms of goal-directed behavior to generate and maintain a sector-control plan, as explained above, would no longer take effect when the ATCO is out of the decision loop, with all the drawbacks this might have on the monitoring behavior and the referring situation awareness.

The current study addresses the following problems: What do experts assess to be the main changes in job requirements when the locus of control in TMA air-traffic control gradually switches from human to automation?

What is guiding ATCOs' scanning behavior when no underlying plan to activate intentions can be assumed to create expectations? What are the observable differences in monitoring behavior in different LoA task settings? Are there gaze-behavioral correlates indicating out of the loop performance?

24.3 Method

24.3.1 Prospective Job Analysis

With the effort that is put into the deployment of advanced automation into ATC, the prognosis of abilities for future ATCOs is co-emerging as a related human factors topic. Alexander (Ammerman et al., 1987; Alexander et al., 1989) conducted a job analysis to assess how future ATCO work would change after the introduction of advanced automation into ATC. Nickels et al. (1995) developed a list of future ATC-work requirements which was the foundation of a selection system for the hiring of ATCOs. At EUROCONTROL Voller and Low (2004) developed a technique named *Solutions for Human Automation Partnership in ATM* (SHAPE) to predict how new automated systems might affect ATCOs' skill requirements. Manning and Broach (1992) at the FAA (Federal Aviation Administration) conducted a strategic-job analysis to assess the changes of the ATCO job as it is predicted to exist in the future as a result of increasing automation. After an analysis of the present job, they gathered information about the kinds of issues, like technological and organizational developments which may affect the job in the future. Broach (2013) conducted a strategic-job analysis for the tower CWP. He used the overall profile of abilities derived by Nickels et al. (1995) to compare current with future ability requirements. He performed an extensive review of current ability profiles and of assessable documentation on technology changes which are expected to be introduced until the year 2018. Based on the current profile and the expected technology changes, he infers a future ability profile. Broach resumes that scanning of visual sources will be one of the abilities which will become more important for future performance.

Eissfeldt et al. (2009) used a technique for future-oriented job analysis first introduced by Schneider and Konz (1989). They held several workshops with subject matter experts (SMEs) to discuss future issues of ATCOs' and pilots' jobs. After being primed with the discussion outputs, the SME filled out the Fleishman Job Analysis Survey (F-JAS, Fleishman and Reilly, 1995) once rating the current job requirements and once the requirements for the job as it is considered for the future. Eissfeldt et al. (1999) used a simulation-based approach to assess future job requirements. The simulation features were data-link communication, a stripless system, planning tools, and automatic conflict detection aids. In a 1 h exercise four brief ATC simulation scenarios were performed by the SMEs. Before and after a session, they filled out the F-JAS. Eissfeldt et al. (1999) found a general decrease of cognitive requirements for future ATC, with the strongest effects occurring for oral expression and oral comprehension, written expression, and number facility. These decreases were attributed to the effect of data-link communication.

In the current experiment ATCOs' judgments about future job requirements are assessed after they experienced working in some future ATCO role settings. To allow a prognosis of what changes are up to come, the key features in the European ATM Master Plan (SESAR, 2012) were taken into consideration. Time-based operations are the key concept to be introduced with SESAR Step 1 (interval-based metering). In a time-based environment the initial synchronization of the traffic arriving in high traffic density TMA will be generally ensured via the allocation of a controlled time of arrival (CTA) on initial approach fixes (IAFs). The introduction of a/c capable of meeting a CTA with appropriate accuracy improves the performance and reliability of an Arrival Manager (AMAN) system. In the time-based environment proposed in the SESAR ATM target concept (SESAR Consortium, 2007), automation is assumed as a means to expand the ATCOs functional envelope, for example, by calculating a/c trajectories with respect to the a/c landing times and providing the ATCO with tactical guidance advisories accordingly. Another SESAR concept envisages the ATCO in the role of a central decision maker who still manages air traffic, but delegates the execution of certain spacing and positioning tasks to the pilots of ASAS (airborne separation assurance system) equipped a/c. Such a change in roles and responsibilities is envisaged in the SESAR concept of self-merging and -spacing, where pilots now take the responsibility for identifying target a/c and establishing separation based on instructions from the ground.

With the delegation of specific tasks to other agents, it is assumed that ATCOs will be relieved from the task load so they are able to adjust to a more strategic work style (cf., Willems, 2002; SESAR Consortium, 2012) in trajectory management, as it supposedly is required within a time-based environment.

The interaction of ATCOs with the simulation environment is assessed by tracking their eye movements to gain further objective indication for changes in their operational monitoring behavior. As the most important information for an ATCO is related to the moving targets on a situational display, the analysis focuses on attentional switches (transitions) between dynamic area of interests (dAoI) which are defined by the moving zone each a/c blip with related FDB covers on the radar screen (cf., Willems, 2002; Gross et al., 2010). The analysis of fixation transitions within experimental runs is supposed to reflect the monitoring activities to build and retain situation awareness. It is claimed that transitions between a/c indicate the activation of meaningful relations within this overall traffic representation, with the total transition number reflecting the priority of that constellation (but see Ellis and Stark, 1986 for a critical discussion of this assumption).

Research Question 1: What do experts assess to be the main changes in job abilities required for their working position after performing new roles in scenarios with advanced automation within their familiar TMA environment?

Research Question 2: Is there objective evidence for fundamental changes in monitoring (measurable by behavioral correlates) when the new roles imply that central task of TMA management is delegated to cockpit and/or to automation?

24.3.1.1 Hypotheses

H1: For multiagent conditions, the ATCOs experience higher job requirements with regard to monitoring capabilities. Accordingly, significantly higher ratings on the situation awareness job-ability scale (regarded as the ability to perceive the current automation–traffic interaction, understand the reasons behind it, and project future development; cf., Fleishman and Reilly, 1995) are expected.

H2: For multiagent conditions, the ATCOs delegate tasks and use released resources to switch to prolonged phases of distributed attention (cf., Moore and Gugerty, 2010), that is, focusing their visual scanning to what is occurring around their sector. Accordingly, more transitions of fixations between distant a/c on the radar screen are expected. A more strategic work style should also be reflected in a comparably higher level of situation awareness. The release of resources should also be indicated in lower levels of experienced workload.

24.3.2 Experimental Design

AMANs normally are a means to avoid overcrowded TMA by controlling the flow en route before reaching the IAFs, where a/c are handed over from area control centers (ACCs) to TMA. However, the DLR AMAN research prototype 4D-CARMA (four-dimensional cooperative arrival manager) (Ehr and Uebbing-Rumke, 2013), which is classified as a strong executing system which is compliant to SESAR requirements, is also calculating trajectories with respect to the landing time on ground and accordingly generates tactical guidance advisories. These advisories are shown in timely and precise manner to the approach controllers at all approach phases on the radar screen.

Several kinds of future scenarios are constructed with 4D-CARMA as the central element to create different role settings for ATCOs. 4D-CARMA is configured to various levels of automation (Sheridan and Verplank, 1978; Endsley, 1987; Endsley and Kaber, 1999). On the five-level LoA hierarchy proposed by Endsley (1987), the AMAN is configured to the LoAs “manual control,” “decision support,” and “monitored AI” (these are the experimental conditions also selected by Willems, 2002). This corresponds to the LoAs “manual control” (MC), “decision support” (DS), and “supervisory control” (SC) as the second highest LoA (cf., Endsley and Kaber, 1999). The taxonomy proposed by in the RHEA (Role of the Human in the Evolution of ATM systems; Nijhuis, 2000) project is used to assign the ATCOs’ roles accordingly:

- Experimental run 1 (baseline): ATCO handles traffic according to the first-come-first-serve principle.
- Experimental run 2: ATCO delegates responsibility of certain tasks to suitably-equipped a/c and aircrew.
- Experimental run 3: 4D-CARMA predicts what needs to be done for certain tasks and makes suggestions to the ATCO.
- Experimental run 4: 4D-CARMA controls—ATCO monitors only, and overrides when necessary (management by exception).
- Experimental run 5: Automation controls—ATCO monitors only, and overrides 4D-CARMA when necessary, with both working together in the control loop during an emergency event.

Experimental run 1 (baseline) resembled current operations in which ATCOs had standard systems support. 4D-CARMA was running during the baseline scenario because it is a standard tool in all Langen ACC sectors. Experimental run 2 (ATCO delegates control to a/c) also resembled current operations from the point of system support, but the concept of a/c controlled merging and spacing was introduced for the three piloted a/c. From the pilots’ perspective, the new requirements during in-flight procedures were to (1) meet the target time of overflow at the IAF (initial approach fix), calculated on ground by 4D-CARMA and displayed in their CDTI, and (2) to follow the merging and spacing instructions given by ATC, which comprises to maintain distance and time to their target a/c ahead. In experimental run 3 (ATCO controls—4D-CARMA suggests) 4D-CARMA supported the ATCO by recommending level, speed, and turn-to-base advisories and their timing to meet time-based criteria for the incoming flights. The 4D-CARMA advisories for ATCOs were displayed within the corresponding flight data blocks (FDB) on the radar screen. From the cockpits perspective run 3 functioned as a repeated measurement with the same requirements as in experimental run 2. In experimental run 4 (4D-CARMA controls—ATCO monitors) all of the ATCO’s tasks, that is, determining speeds, headings, and levels to the a/c and building an arrival sequence, are delegated to 4D-CARMA. The work of the ATCO here moves toward SC. From the pilots’ perspective in comparison to the baseline requirements change in receiving ATC advisories from ground-based automation via data link and reading it back via r/t to keep the supervising controller informed about their intent. The ATCO monitored the r/t and always was able to intervene via r/t. In experimental run 5 (4D-CARMA and ATCO in control loop) again, the ATCO was in the supervisory role but had to intervene due to a simulated emergency. From the pilots' perspective the requirements were analogous to experimental run 4.

The ATCOs tasks were to receive incoming traffic at the IAF, coordinate these a/c according to the traffic flow and provide sufficient lateral and vertical separation between a/c, as well as guiding them to the final approach. In the baseline scenario 4D-CARMA was active, but just displaying a planned sequence on a time ladder. To the subsequent experimental runs the CTA and merge-&-space operation, 4D-CARMA, and ATCO–pilot data-link communications (CPDLC) were selectively introduced. For the first future condition (experimental run 2) 4D-CARMA was active, but not in a strong executing mode. The job includes all core tasks of the baseline condition, added to by the tasks related to the merge and space procedures, such as instructing the pilots and monitoring the on-going operations. For the next, more advanced future condition (experimental run 3) 4D-CARMA was set into strong executing mode. In this setting the ATCO is advised to generally instruct the pilots with the 4D-CARMA clearances, if no safety concerns stand against them. Also the core tasks to determine headings, level, and speeds according to the intended approach sequence where suspended as 4D-CARMA made recommendations to follow. However, the list again was expanded by the new core task to evaluate AMAN advisories before communicating them via r/t. For the most advanced future condition (experimental run 4) 4D-CARMA was set into a self-executing mode. Almost all core tasks are now performed by 4D-CARMA via data-link communication with the pilots. In the role of supervisory controller, the new core tasks are to monitor 4D-CARMA performance on the referring display, monitor a/c behavior on the radar screen, monitor r/t communication, and to intervene to take MC in case of an exception, such as an emergency. This most advanced future scenario was performed a second time with shuffled a/c signs and a provoked emergency event that forced the ATCO to perform tactical interventions (experimental run 5).

In the experimental runs only incoming traffic was simulated. All conditions were simulated within the structure of the Frankfurt approach sector, which is the sector in the TMA for all incoming a/c with destination Frankfurt, in its configuration valid until October 2011 (i.e., no third landing runway integrated). These flights approach the area via four different (STARs) and IAFs. The latter are coded as OSMAX (western sector inbound), ROLIS (northern sector inbound), GEDERN (eastern sector inbound), and PSA (southern sector inbound). The arriving a/c are lined up on the downwind and then "fed" onto the final approach. The sector controls all levels from surface up to flight-level 115. The arrival routes are designed in a way so as not to interfere with each other. In the experimental trials, only a sector configuration for using runways 25 is applied.

In all experimental task settings the participants were advised to control or monitor the incoming traffic for the whole TMA. Generally the participating ATCOs were advised to guide the down-winding traffic via the STARs. All ATCOs reported being very familiar with this assignment, as this is a standard setting in real-life during periods of lower traffic load. The participants also worked in a one-man setting without the assistance of a coordinate ATCO. The experimental baseline scenario (experimental run 1) is oriented at the actual method of operations for approach control.

24.3.3 Simulator Preparation

The human-in-the-loop simulations were performed at DLR's integrated air-ground simulator AviaSim (Schulze Kissing et al., 2010; Bruder et al., 2013). AviaSim comprises one ATCO working position and three pilot WPs, two pseudo-pilots, and one pseudo-ATCO console, as well as an experimental-control console. The ATC working position is equipped with a SmartEye® Pro remote eye-tracking system using a five-camera layout. The ATCO is seated in front of four displays with the radar screen as the main window in front. On the left the electronic flight strip bay is located. On the right the 4D-CARMA generated timeline for the arriving a/c is shown. The timeline displays advisories the automation currently is sending to any a/c. In addition, a so-called mileage-metering scale shows the distances between a/c on the final approach. The head-up display shows labels of a/c approaching the TMA on a timeline according to their controlled times of overfly (CTOs) at the referring IAFs. All a/c are simulated by pseudo-pilots except for three that are simulated by fully equipped simulation cockpits operated by airline pilots. Pseudo-pilots operate the non-piloted a/c according to standard procedures until they are transferred to the TMA. At the beginning of the scenario a pseudo-ACC-controller overtakes communication with the piloted a/c and handing it off to the ATCO when the a/c reaches the TMA border.

24.3.4 Dependent Variables and Procedure

The experiment was conducted in five sessions over 3 days. In total five ATCOs from Deutsche Flugsicherung GmbH (DFS) ACC Langen with valid licenses for TMA Frankfurt and 15 pilots from various airlines participated. Only ATCO data will be reported here. The ATCO sample was all male with a mean age of 32.5 years (SD: 6.42), and a job experience of 10.8 years in the mean (SD: 6.85). A session comprises four runs of a future scenario, one baseline scenario, and five training runs for the ATCOs or three training runs for pilots, respectively. A single simulation run involved one ATCO, three pilots, and two pseudo-pilots. The ATCOs were controlling the air traffic of the whole Frankfurt TMA in a one-man operation modus. Pilots were starting airborne within the lower airspace and entered TMA via three different IAFs. The ATCOs, pilots, and pseudo-pilots communicated using r/t or CPDLC/data-link transmissions.

For the ATCOs the first exercise day started with an introduction of questionnaires, calibration on the eye-tracking system, and an about 90-min in-depth walk-through the F-JAS dimensions. The second part of the first day included two initial training runs of about 1 h to get acquainted with the simulator and the 4D-CARMA AMAN interface (first training run) and to familiarize with pseudo-pilots interactions (second training run). The second day started with a recapping training session in which the merging and spacing procedures were practiced with pseudo-piloted a/c. Afterward the first joint training scenario with ATCO, pilots, and the pseudo-pilots was conducted. This was followed by a second joint training in which merging and spacing procedures were practiced with the piloted a/c. The measured traffic sample contained 24(+x) flights with destination Frankfurt, with at least six a/c entering the TMA on each of the four IAFs during the scenario run. The scenario contained a mix of a/c of heavy and medium weight class planned to land in staggered mode on the two parallel runways 25R and 25L, which have to be operated dependently. Next, the ATCOs took part in the five experimental runs, one at the end of day 2 and four on day 3. For comparison reasons, one traffic sample was used for all runs. However, to avoid familiarization with the traffic sample, all a/c signs were shuffled or substituted between each run. Furthermore, pilots switched working positions after each run to let them experience different traffic situations. Experimental run 4 and 5 were always performed consecutively (en bloc) and the baseline run was always performed first, that is, at the end of day 1. The runs 2, 3, and the block 4 + 5 were counterbalanced to avoid practice effects. Each run was performed only after a break.

Quantitative and qualitative data were gathered during and after each simulation run. As a subjective measure of workload and situation awareness, the instantaneous self-assessment (ISA; Kirwan and Flynn, 2001) was used. ATCOs were prompted four times during a scenario (appointed according to the flight phases of the piloted a/c, that is, RTA IAF, merge, follow, and turn) to give their ratings on current situation awareness and workload on two three-point scales. During the simulation runs, eye movements of the ATCOs were tracked to gain indication for participants' visual sampling behavior. Immediately after each simulator run, the participants filled out (a) a 14-Component Version of the Situation Awareness Rating Technique (SART; Taylor, 1990), (b) the NASA Task-Load Index (Hart and Staveland, 1988), a questionnaire to assess the impact on mental workload (AIM; Dehn, 2013), and the SHAPE Automation Trust Index (SATI; Dehn, 2013). At the end of the last experimental run of exercise day 2 and exercise day 3, the participants filled out a modified version of the Fleishman Job Analysis Survey (F-JAS; Fleishman and Reilly, 1995) and cognitive interviews were held directly afterwards to gain in-depth information about experienced job requirements. Additionally, a questionnaire on user satisfaction and acceptance was completed at the end of day 3.

24.4 Results

On several usability scales the ATCOs evaluated the system as easy to learn, the time needed to learn the system operation to be adequate, the simulation scenarios to be interesting and inspiring, and regarded their traffic load to be comparable to current real-life traffic demands.

24.4.1 Questionnaire on Job-Ability Requirements

The ATCOs' judgments on the abilities required for future job performance were assessed once for the presented future scenarios (overall) and compared to the ability-requirement profile the experts initially identified for the baseline scenario. These profiles are put together from a set of 37 ability-requirement scales the ATCOs filled-in, with 32 of them selected from the F-JAS, supplemented by five scales covering additional requirements developed by DLR in a format similar to F-JAS.

A paired-sample *t*-test on the single scales revealed a significant effect of future changes (versus baseline) on required problem sensitivity (cognitive scale; future increase) and number facility (cognitive scale; future decrease) abilities (see Table 24.1). With respect to practical relevance the marginal differences in required spatial orientation (cognitive scale; future decrease), perceptual speed (cognitive scale; future increase), situation awareness (interactive/social scale; future increase), resistance to premature judgment (interactive/social scale; future increase), and vigilance (future increase) abilities will also be considered (see Table 24.1). A Wilcoxon signed-rank test on the rank of means for the 38 ability requirement scales showed no fundamental change in the ability requirement profiles from current (baseline) to future scenarios. Figure 24.1 presents the means and standard errors of SMEs' F-JAS-type scale ratings related to the baseline and the future scenarios on the 37 ability requirement scales. For the baseline scenario, time sharing received the highest mean rating and is thus considered as the most important ability required for the current job.

TABLE 24.1

Mean Ratings of F-JAS Type Scale Ratings for the Baseline and Future Scenarios

	ATC				
F-JAS Scales	**Baseline**	**Future**	**T**	**df**	**P (2 Way)**
Problem sensitivity	4.92	6.44	–3.919	4	0.017
Number facility	4.04	2.56	2.929	4	0.043
Spatial orientation	4.20	2.46	2.400	4	0.074
Perceptual speed	4.66	5.56	–2.535	4	0.064
Situation awareness	6.56	7.00	–2.269	4	0.086
Resistance to premature judgment	3.90	5.42	–2.513	4	0.077
Vigilance	4.76	6.56	–2.126	4	0.066

Note: Only those scales are listed for which a paired-sample *t*-test yielded a significant or marginal within-group effect (N = 5).

In the resulting future ability-requirement profile, situation awareness[*]—which received the highest mean ratings—followed by stress resistance,[†] vigilance,[‡] problem sensitivity,[§] emotional control,[¶] selective attention,[**] auditory attention,[††] resilience,[‡‡] and perceptual speed[§§] received higher values than the ability of time sharing[¶¶] (cf., Figure 24.1). The increasing importance of situation awareness, vigilance, problem sensitivity, and perceptual speed should be considered as important developments in task requirements, as they are newly listed in the top 10 required future abilities when compared by their mean ratings (cf., Figure 24.1). Significant future decreases (see Table 24.1) were only determined for scales of minor importance (namely number facility and spatial orientation).

24.4.2 Gaze Analysis

24.4.2.1 Transitions

In Figure 24.2 for each experimental condition the state-transition matrices containing the total number of gaze transitions between a/c are displayed. The referring a/c are labeled and ordered according to their final position in the landing sequence. For each experimental condition the degree a/c were attended to in succession can be read out by first tracing the respective line and then the respective column of the a/c. For example, to determine for the baseline condition the degree the a/c in the fifth position of the landing sequence is coactivated with other a/c, the counted transitions for the preceding a/c can be read out

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[*] Ability to perceive the current automation–traffic interaction, understand the reasons behind it, and project the future development.

[†] Capability of dealing with stress situations in such way that control is maintained and the objective achieved.

[‡] Ability to maintain attention and alertness over prolonged periods of time.

[§] Ability to tell when something is wrong or likely to go wrong.

[¶] Ability to stay in self-command in emotionally challenging situations, when irritating, unexpected, difficult, or stressful factors occur.

[**] Ability to concentrate on a task without getting distracted.

[††] Ability to focus on a single source of auditory (hearing) information in the presence of other irrelevant and distracting sounds.

[‡‡] Ability to rapidly recover normal energy and enthusiasm following a discouraging situation.

[§§] Involves the degree to which one can compare letters, numbers, objects, or patterns, both quickly and accurately. This ability also includes comparing a presented object with a remembered object.

[¶¶] Ability to shift back and forth between two or more sources of information.

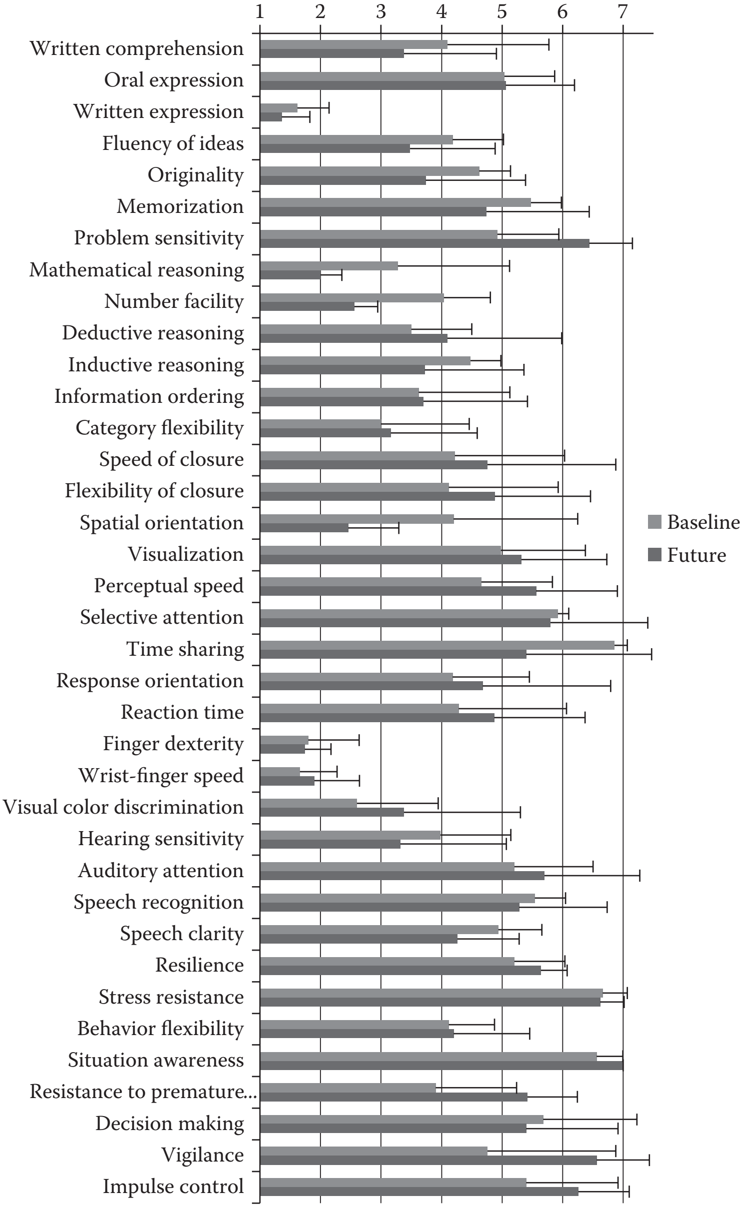
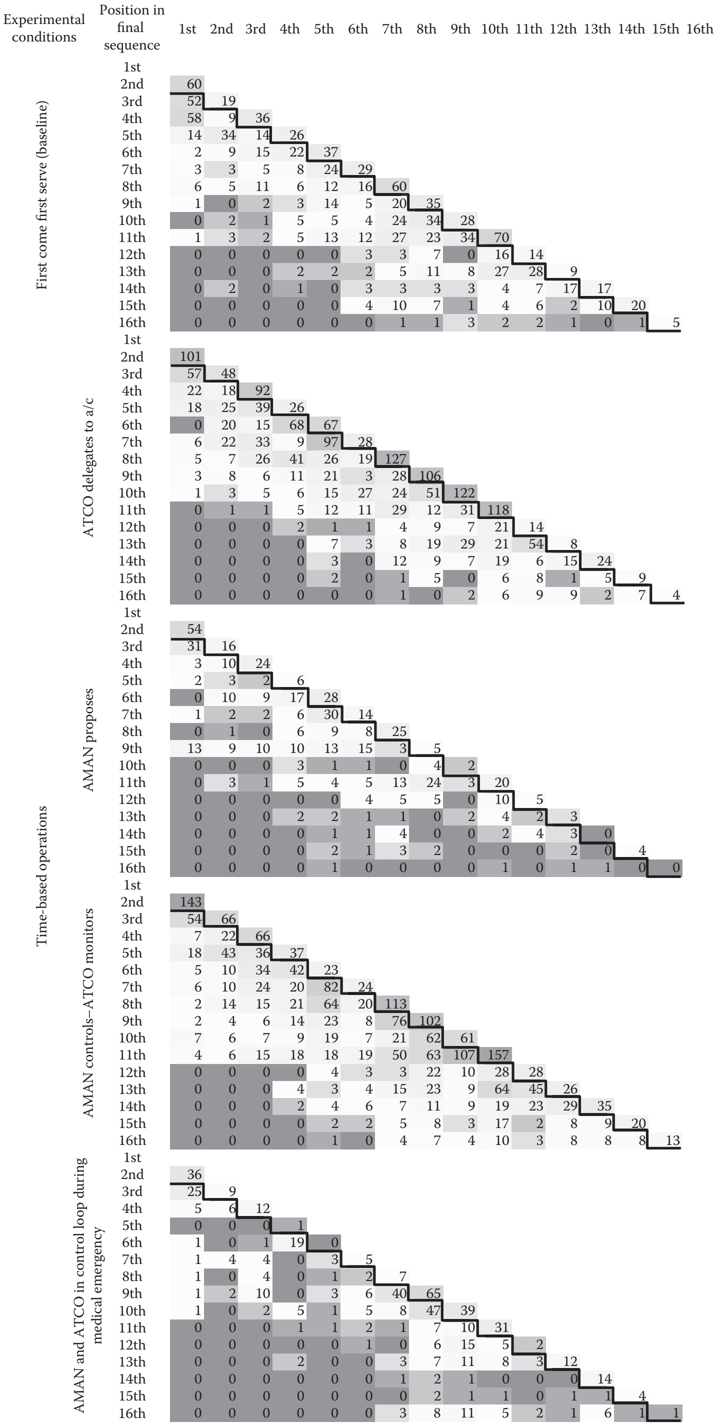


FIGURE 24.1
Mean and standard errors of SMEs (N = 5 ATCOs) F-JAS-type scale ratings on the 37 ability requirement dimensions plotted for the simulated baseline scenario and the simulated future scenarios.

in the line labeled "5th" (counts for a/c ordered in their spatial distance to the a/c under consideration are 26, 14, 34, and 11), the transition numbers for the succeeding a/c can be traced in the column correspondingly labeled "5th" (counts for a/c ordered in their spatial distance to the a/c under consideration are 37, 24, 12, 14, 5, 13, 0, 2, 0, 0, 0). To simplify the interpretation the gray shades additionally indicate the suspected strength of these relations in the ATCOs mental picture, from bright-gray with higher numbers (indicating



Experimental conditions		Position in final sequence	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th
First come first serve (baseline)		1st																
		2nd	60															
		3rd	52	19														
		4th	58	9	36													
		5th	14	34	14	26												
		6th	2	9	15	22	37											
		7th	3	3	5	8	24	29										
		8th	6	5	11	6	12	16	60									
		9th	1	0	2	3	14	5	20	35								
		10th	0	2	1	5	5	4	24	34	28							
		11th	1	3	2	5	13	12	27	23	34	70						
		12th	0	0	0	0	0	3	3	7	0	16	14					
		13th	0	0	0	2	2	2	5	11	8	27	28	9				
		14th	0	2	0	1	0	3	3	3	3	4	7	17	17			
		15th	0	0	0	0	0	4	10	7	1	4	6	2	10	20		
		16th	0	0	0	0	0	0	1	1	3	2	2	1	0	1	5	
Time-based operations	ATCO delegates to a/c	1st																
		2nd	101															
		3rd	57	48														
		4th	22	18	92													
		5th	18	25	39	26												
		6th	0	20	15	68	67											
		7th	6	22	33	9	97	28										
		8th	5	7	26	41	26	19	127									
		9th	3	8	6	11	21	3	28	106								
		10th	1	3	5	6	15	27	24	51	122							
		11th	0	1	1	5	12	11	29	12	31	118						
		12th	0	0	0	2	1	1	4	9	7	21	14					
		13th	0	0	0	0	7	3	8	19	29	21	54	8				
		14th	0	0	0	0	3	0	12	9	7	19	6	15	24			
		15th	0	0	0	0	2	0	1	5	0	6	8	1	5	9		
		16th	0	0	0	0	0	0	1	0	2	6	9	9	2	7	4	
	AMAN proposes	1st																
		2nd	54															
		3rd	31	16														
		4th	3	10	24													
		5th	2	3	2	6												
		6th	0	10	9	17	28											
		7th	1	2	2	6	30	14										
		8th	0	1	0	6	9	8	25									
		9th	13	9	10	10	13	15	3	5								
		10th	0	0	0	3	1	1	0	4	2							
		11th	0	3	1	5	4	5	13	24	3	20						
		12th	0	0	0	0	0	4	5	5	0	10	5					
		13th	0	0	0	2	2	1	1	0	2	4	2	3				
		14th	0	0	0	0	1	1	4	0	0	2	4	3	0			
		15th	0	0	0	0	2	1	3	2	0	0	0	2	0	4		
		16th	0	0	0	0	1	0	0	0	0	1	0	1	1	0	0	
	AMAN controls–ATCO monitors	1st																
		2nd	143															
		3rd	54	66														
		4th	7	22	66													
		5th	18	43	36	37												
		6th	5	10	34	42	23											
		7th	6	10	24	20	82	24										
		8th	2	14	15	21	64	20	113									
		9th	2	4	6	14	23	8	76	102								
		10th	7	6	7	9	19	7	21	62	61							
		11th	4	6	15	18	18	19	50	63	107	157						
		12th	0	0	0	0	4	3	3	22	10	28	28					
		13th	0	0	0	4	3	4	15	23	9	64	45	26				
		14th	0	0	0	2	4	6	7	11	9	19	23	29	35			
		15th	0	0	0	0	2	2	5	8	3	17	2	8	9	20		
		16th	0	0	0	0	1	0	4	7	4	10	3	8	8	8	13	
	AMAN and ATCO in control loop during medical emergency	1st																
		2nd	36															
		3rd	25	9														
		4th	5	6	12													
		5th	0	0	0	1												
		6th	1	0	1	19	0											
		7th	1	4	4	0	3	5										
		8th	1	0	4	0	1	2	7									
		9th	1	2	10	0	3	6	40	65								
		10th	1	0	2	5	1	5	8	47	39							
		11th	0	0	0	1	1	2	1	7	10	31						
		12th	0	0	0	0	0	1	0	6	15	5	2					
		13th	0	0	0	2	0	0	3	7	11	8	3	12				
		14th	0	0	0	0	0	0	1	2	1	0	0	0	14			
		15th	0	0	0	0	0	0	0	2	1	1	0	1	1	4		
		16th	0	0	0	0	0	0	3	8	11	5	2	1	6	1	1	

FIGURE 24.2

State-transition matrices containing the total number (summed up for N = 5) of gaze transitions between dynamic areas of interest (blip and data block) representing the single a/c on the radar monitor during an experimental run.

high strength) to white with lower numbers (medium strength) to dark-grey with low numbers to zero (minor or no strength). The top line of cells is separated by a black line to emphasize that these numbers supposedly indicate data comparisons related to distance, level, and speed between neighboring a/c at merging STARs or near to the final approach as well as strategies to sequentially scan moving objects from the inner to outer sector areas, whereas the values displayed in the cells below that line supposedly indicating the monitoring contingencies produced by other mechanisms of distributed attention monitoring (e.g., switching from a/c on final to relevant airspace structures, reacting to a/c calls via r/t, or a switch to a somehow pre-tactical work style). Obviously, for all experimental conditions the ATCOs allocated much of their attention to relations between a/c neighbors on the final approach. Maximum transition numbers between neighboring a/c are counted for experimental run 2 in which the ATCO delegated responsibility of certain tasks to suitably-equipped a/c and experimental run 4 when 4D-CARMA controlled and the ATCO monitored only. However, for both these conditions, and especially for the SC condition, even relations between distant a/c (preceding and succeeding) received more attention than in the baseline condition.

24.4.2.2 Fixations per Screen

The numbers of fixations counted for the radar display for all experimental conditions are all higher compared to the baseline (cf., Figure 24.3). This is contrary to the directed hypothesis predicting that the number of fixations counted for the radar display should decrease when trajectory management tasks are delegated to other agents (eher: closer monitoring). As the data was not normally distributed, the most appropriate way to statistically test the differences from the baseline was the Wilcoxon signed-rank test. There was a significant increase from baseline to the third condition (ATCO controls—AMAN proposes) in the number of fixations counted for the radar screen, $Z = -2.023$, < 0.05, and also to the fifth condition (AMAN and ATCO in control loop: $Z = -2.023$, $p < 0.05$). The fourth condition (AMAN controls—ATCO monitors) only marginally differed from the baseline ($Z = -1.753$; $p = 0.080$). Figure 24.3 shows that under all experimental conditions the ATCOs only rarely attended to this planning information. However, there was a significant increase from baseline to the fifth condition ($Z = -2.023$, $p = 0.042$) indicating some planning activity was involved during the emergency handling. As also can be seen in Figure 24.3, the AMAN (4D-CARMA) screen was more attended to under the fourth ($Z = -1.753$; $p = 0.080$) and fifth condition ($Z = -2.023$, $p = 0.043$).

24.4.3 Control Variables

Repeated Measures Analyses of Variance (rANOVA) were used to statistically compare the questionnaire outcomes for the various runs. Partial eta-squared (η_p^2) is given as a measure of effect size. For each analysis, $p < 0.05$ was used.

24.4.3.1 Workload

For each run workload, measures with NASA TLX were obtained (SME). An ANOVA on the NASA TLX overall scores for the five runs showed only a marginal effect [$F(4,16) = 2.694$, $p < 0.10$, $\eta_p^2 = 0.402$]. The within subject single contrasts showed *that experimental run 5 imposed significantly higher workload* compared to the baseline condition [$F(1,4) = 9.476$,

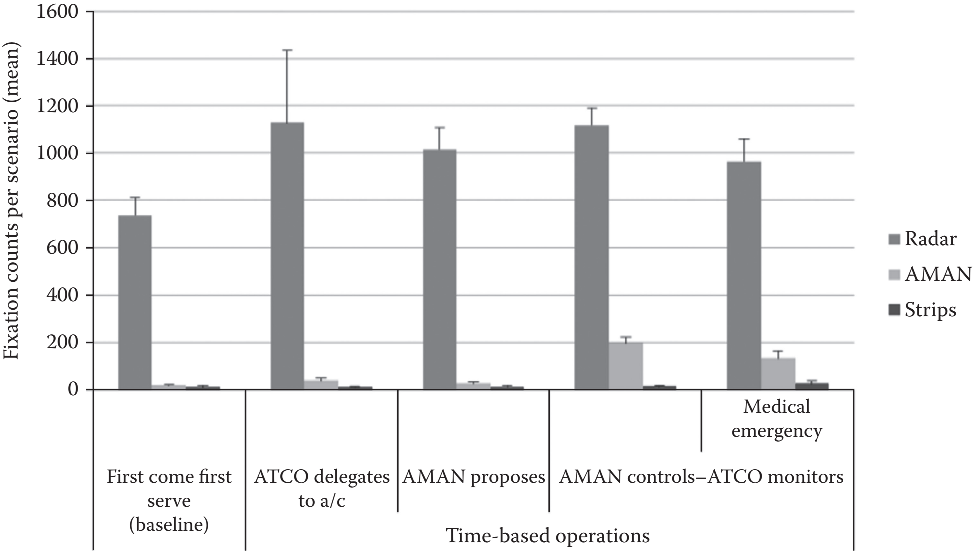


FIGURE 24.3
Number of fixations on each of the three monitors of the controller working position for each scenario run.

$p < 0.05$, $\eta_p^2 = 0.703$]. No effect for the five runs on the AIM total score was measured. Single contrasts indicate significantly higher demands on monitoring for experimental run 2 (ATCO delegates to a/c) compared to experimental run 1 (baseline), $F(1,4) = 16.000$, $p < 0.05$, $\eta_p^2 = 0.800$. A 4 (moment of measurement) × 5 (ATCO role)-factorial rANOVA for the ISA scores showed a significant effect for the factors "moment of measurement," $F(3,6) = 14.600$, $p < 0.05$, $\eta_p^2 = 0.880$. These findings contradict the hypothesis that trajectory management task delegation would release the ATCO. There is a distinctive trend for a workload increase with the scenario progressing (for all experimental conditions). The experimental factor (ATCO Role) had no significant effect on workload. Single contrasts revealed significant higher ISA workload ratings only for the experimental run 2 (ATCO delegates to a/c) compared to run 1 (baseline), $F(1,4) = 64.000$, $p < 0.05$, $\eta_p^2 = 0.970$. (Again, ATCO delegates to a/c; significant increase in workload; not for full automation.)

24.4.3.2 Situation Awareness

An ANOVA for the 5 runs showed a significant effect for the 10-D SART scale values, $F(4,16) = 4.063$, $p < 0.05$, $\eta_p^2 = 0.504$. Single comparisons with the baseline run revealed significantly lower situation awareness under the third experimental run (ATCO controls—AMAN proposes: $F(1,4) = 9.732$, $p < 0.05$, $\eta_p^2 = 0.709$), as well as under the fourth experimental run (AMAN controls—ATCO monitors: $F(1,4) = 24.500$, $p < 0.05$, $\eta_p^2 = 0.806$). This is contrary to the directed hypothesis which predicts the allocation of attentional resources released by tasks delegation to enhance situation awareness. A 4 (moment of measurement) × 5 (ATCO role)-factorial ANOVA for the ISA scores on "situation awareness" showed a significant effect for the factors "moment of measurement," $F(1.931, 3.861) = 8.826$, $p < 0.05$, $\eta_p^2 = 0.815$. There is a distinctive trend for situation awareness to decrease with the scenario progressing. There was no significant effect for the experimental factor (ATCO role).

24.5 Discussion

A prospective job analysis for the ATC task in future TMAs was performed. Potential future scenarios were simulated in a human in the loop experiment with current job holders performing the air-traffic control task in different role settings with the locus of control gradually switching to automation. The ATCOs assessed the future job-ability requirements experienced within the simulation on the F-JAS (Fleishman, 1992). Their monitoring performance was assessed by tracking their eye-gaze behavior during all experimental trials. Before coming to an interpretation of the results, some methodological reservations have to be made in advance. It may be questioned if it were future abilities we have measured, or simply the requirements to cope with the problems we have created by simulating a more or less clumsy automation setup. It may be questioned if receiving tactical advises from automation to comply with 4D-plan requirements is a means to expand the ATCOs' functional envelope (cf., Amalberti, 1999). Operators are rather compelled to adapt reactive strategies instead of anticipative strategies insuring long-term adaptation (cf., Cellier et al., 1997). It is also evident that the general problems arising with the introduction of higher levels of automation in ATC cannot be solved by focusing on personnel selection issues only. Another methodological weakness of the current study is the ATCOs' sample size, which is not large enough to reliably perform inferential statistic tests. Gaze transition data is only presented on a descriptive level. So the results presented above should not be treated as evidence, and any conclusion drawn on the results presented above should be treated as preliminary.

The ability analysis revealed the specific job requirements which occur for ATCOs when moving from the current to the monitor role. As hypothesized the ATCOs actually assessed the abilities to perceive the current automation-traffic interaction, understand the reasons behind it, and project the future development (labeled as situation awareness) as being of highest relevance when selecting future job holders. The SME also assessed that a higher sensitivity with regard to problems produced by automation will be required (problem sensitivity). It was conceived in post simulation interviews that the main demand in the system-supervising role was to continuously assess if the 4D-CARMA instructions were reasonable or not. This experience is reflected in the higher ratings for the ability to stay alert over a long period of time, that is, "vigilance." In the passive supervisor roles some ATCOs also reported they were unable to form expectations on traffic behavior on the basis of their own intentions, so they were more heavily occupied with tracing and integrating automation behavior into their mental picture to understand what is happening and project what the system is going to do. This uncertainty with regard to the actual traffic control processes they had to supervise induced stress to the monitoring ATCO, which is reflected by an increase in ratings on the stress-resistance scale, which is assessed to be an ability required at maximum for this future condition. It can be assumed that the ATCOs tried to counteract against this uncertainty by increasing their efforts in visual sampling. So, the answer to what experts regard to be the main changes in job abilities required when working with advanced automation comes as no surprise: they experience higher job requirements with regard to monitoring capabilities.

There also is some indication for changes in the monitoring behavior when the locus of control switches from ATCO to automation. ATCOs showed more transitions of fixations between distant a/c on the radar screen under high LoA, like it would be expected when they use free resources to widen or distribute their focus to attend to what is occurring around their sector (cf., Moore and Gugerty, 2010). However, this change in visual sampling behavior is accompanied by comparably lower levels of situation awareness and higher levels of experienced workload, as it is to be expected when ATCOs work with clumsy automation while they are kept out of the control loop.

The gaze transitions between dynamic AoI representing the single a/c on the radar monitor could be interpreted to reflect the relational structure of the ATCOs' current mental picture (cf., Eyferth et al., 2003) as well as the contingent flow of intentions for monitoring and control of goal-directed behavior, or in other words: the cognitive mechanisms of goal-directed behavior at work. The highest transition numbers are counted for relations between spatially close a/c. It can be assumed these are more closely monitored in relation because of comparisons of speed, level, and distance information, but also because of the strategy to recurrently move the attentional "spotlight" from the center line to the object near the sector borders, which according to an ATCO's report is performed about once in a minute. Transition counts between spatially more distant a/c may reflect scanning guided by goal directing mechanism of contingently active intentions, such as airspace structure checks or bottom-up activation (a/c calling into the sector), plus visual search for their identification.

The finding that the highest counts for transitions between all a/c (regardless of their proximity) were observed for scenarios where the locus of control for the separation task is transferred to other agents, human or automation, may indicate how monitoring behavior is changing when it is no longer guided by the ATCOs' intentions and mechanisms of goal-directed action control, but by their expectations and recurrent checks of other agents' actions.

In the baseline condition the eye-movements can be conceived to be affected by three factors: (1) the ATCOs' intentions when to give clearances to a/c, (2) their general strategies for sector monitoring, as well as (3) the salience of a/c entering the sector. The comparable higher number of fixations during the merge and space scenario could designate a closer monitoring of the decisions and actions of the three human agents within their room for maneuver. The comparable lower number of transitions counts measured under conditions of automation assistance may reflect some automation bias induced by the 4D-CARMA. Maybe 4D-CARMA's continuous provision of action proposals prevented the mechanisms of goal-directed behavior to unfold, causing that less intentions were contingently active to guide the ATCOs' monitoring. When in the SC condition the locus of control switched to 4D-CARMA, the transition numbers increased in combination with the high fixation frequency counted for the advisory window where clearances prepared by 4D-CARMA were displayed. It can be conceived that the observed changes in scanning behavior do not reflect a switch in monitoring strategies, but simply to the necessities to closely monitor the human-machine interface (HMI) element where the automation was displaying its instructions, and then for visual search to retrace the a/c to which 4D-CARMA was addressing the clearance. As an emergency occurred under the SC condition the ATCOs focused more attentional resources to the flight strips, indicating more planning activity. This came along with lower transitions numbers between a/c. As the ATCOs had to handle the emergency, gaze data suggest that they reduced their checks of the automation behavior considerably.

24.6 Conclusions

The data provide no indication for fundamental changes in the ability requirements profiles from current to the projected job setting for ATCOs. Behavioral data on the other hand once again show the problems arising when human operators are taken out of the decision loop. It simply is hard to remain involved into the events happening on a tactical level when ATCOs are not enabled to build up a state of intentionality by developing a shared understanding of the activities that are necessary to control sector events. For SC conditions the ATCOs reported they were stuck in the process of understanding the control principles the automation is following, but did not fully understand the algorithms. When ATCOs in our simulation were advised by automation when and how to act, they were hardly able to assess if the automation advisories were reasonably 4D-plan compliant. As the ATCOs actually had to decide on situational matters which they could not judge, they were only acting as a transducer of system advisories to the pilots. This might have caused their experienced decrease in situation awareness. One could argue the system could equally well directly interact with the receiver, in this case the a/c.

For follow-up studies it would be advisable to reach a participant sample large enough to draw conclusions based on statistical testing, although it is often owed to challenges in expert access that an optimal sample size is not reached, like in the current study. A further analysis of the scan paths could also shed some more light into the ATCOs' monitoring behavior. However, before starting any follow-up study an advanced automation setup that is gaining high SA ratings should be identified. This seems to be a condition sine qua non to validly carve out the requirements for working with advanced automation in ATC following a simulation-based approach. Candidate systems supposedly could be found in the area of cooperative human–machine interaction design (cf., Sarter et al., 1997; Hoc, 2000; Woods and Sarter, 2000). Systems designed according to the principles of cooperative automation supposedly would provide an ongoing understanding of the reasonability of its actions to its human team partner. Maybe it would be a fruitful approach to design a planning system that sketches out and follows plans in the way that humans do. This would give the human operator the chance to reenact, anticipate, and evaluate what the system is doing.

But whatever the design decisions may be, it is recommended here that the human performance assessment in the system validation activities should also encompass the use of job analysis tools. This is to ensure that ATCO selection will sooner rather than too much later look out for employees who are capable of filling in the roles the new ATM system assigns to the human operator.

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