Transition Steps to Orthogonal Unidirectional Air Traffic Controller Monitoring Display

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***Abstract*—Current displays of Air Traffic Controllers (ATCO) do hardly support future tasks of a time-, trajectory- and performance-based approach. The "Orthogonal Flight Monitoring with Unidirectional Controller HMI (OFMUCH)" shall assist ATCOs with small consecutive learning steps corresponding to iterative display revisions without broad big bang integrations. Ten different displays succeed each other with only minor changes, but resulting in a broad change comparing the first with the last display. A study with ten controllers showed improved acceptability and usability of new display concepts with a row of changes guiding from the current to a future ATCO display.**

Keywords — air traffic controller; human machine interface; migration tolerance; transition; display step; time-based; trajectory-based; performance-based; ATC; controller working position

I. INTRODUCTION

The human machine interface (HMI) is a central component of the controller working position (CWP). Future controller role change is expected due to technological improvements and organizational restructuring. Next to controller roles their HMIs will have to adapt to support new tasks and challenges in the air traffic management (ATM) environment as today's displays are not feasible for future tasks anymore [1][2][3]. Especially the display as a graphical visualization instrument will experience modifications in the course of future changes to enable controllers handling their additional tasks with best possible machine support.

SESAR (Single European Air Traffic Management Research Programme) and NextGen (Next Generation Air Transportation System) plan three operational timely overlapping steps going forward from the current radar based control to a trajectory based system [4][5]. The actual distance-based air traffic control (ATC) approach will be changed via a time-based, and a trajectory-based to a performance-based [6][7][8] ATC approach (see Figure 1).

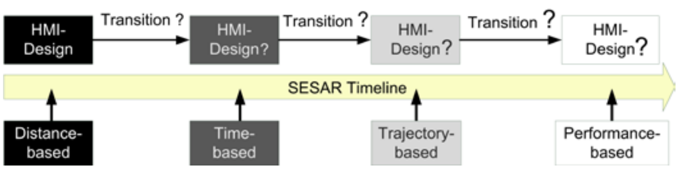

Figure 1. SESAR timeline with defined steps for new ATC approaches and corresponding uncertainty in HMI design [9].

This figure shows the uncertainty (from left to right lighter gray frames from black for "known" to white for "only vaguely known") in single steps for future HMI designs (question marks in boxes) and the transitions on the way in between (question marks at arrows). A possible solution would be the development of completely new HMIs for each step in combination with intensive controller trainings. Therefore it becomes a challenge how to smoothly get from the current to a future state of controller displays without complete redevelopments and how those transition states should look like.

This paper consists of related work in chapter II followed by the concept of migration tolerant display steps, which will be explained in chapter III. The evaluation design is pointed out in chapter IV. Chapter V evaluates the presented migration tolerant displays. The results of the related study are discussed in chapter VI, whereas chapter VII summarizes and gives an outlook for further work.

II. RELATED WORK

Horizontal and vertical minimum separations between aircraft are defined by the International Civil Aviation Organization (ICAO) [10]. These values shall avoid flight collisions and disturbances between preceding and crossing aircraft and their wake vortices [11]. Minimum values are given in feet for vertical separation and nautical miles (NM) respectively minutes for horizontal separation depending on aircraft weight category, used technical surveillance equipment and capabilities or flight region.

Separation of aircraft will remain important in all future ATC approaches. However, the tools to achieve this safety goal will change. The current distance-based ATM-procedures shall now be transferred to time-based due to the first step of SESAR. Separation with distances in nautical miles will be replaced by separation duration in seconds primarily during approach. In case of head wind weather a separation in miles causes greater loss of time if aircraft fly at same indicated airspeed. However, the prescribed separation in miles is not necessary because of the wake vortex dispersion in a certain amount of time [12]. Distances between aircraft in seconds would generate a more homogeneous and wind independent arrival flow. This kind of separation management also avoids capacity loss in head wind approach scenarios [13]. Focusing on timely separation is also a basis for the second step to trajectory-based air traffic control.

Ground and on-board systems like four-dimensional flight management systems (4D-FMS) may negotiate times via data link for significant waypoints in a cooperative process to establish a holistic optimized flight path. A four-dimensional trajectory containing latitude, longitude, altitude, and time is called business trajectory in the SESAR concept, if airline requirements regarding their preferred flight profiles with resulting target times are integrated and held [14]. The timely accuracy is about five to six seconds using a modern 4D-FMS [15]. Thereby, a four-dimensional trajectory may be optimized to parameters such as flight time, kerosene consumption, arrival time, maximum climb and descent rates. With more automated ATM operations, the business trajectory shall lead to better predictability and thus safety, cost efficiency, and environmental friendliness. If controllers have to consider these additional key performance indicators, strategies how to stick to them should also be integrated in future CWPs.

Accurate position data of aircraft in controlled airspace for a reliable supervision of conformance between planned and flown trajectory is only possible when using technical capabilities. Furthermore, the use of electronic decision support and planning systems like operational state-of-the-art or even better assisting state-of-the-science systems is assumed [16] in the course of a growing degree of automation.

Furthermore, ATCOs' tasks and methods of working will be influenced by focusing on timely discrete flight route points and after that also on economic and ecological factors. The sole active air traffic control function will be extended with multifaceted monitoring functions, supervision of deviations and intervention activities in abnormal situations [3][17][18]. Further innovative processes that are discussed and may influence future controller tasks are the concepts of late merging respectively point-merge, as well as sectorless air traffic control. If applicable, flows of aircraft will be considered more contrary to single aircraft [19][16]. Current human machine interfaces do hardly support controllers by actively considering those aspects or by migration tolerant design according to changing requirements. This leads to the question: "Is it possible that users become accustomed faster and easier to modified user requirements with a migration tolerant design of human machine interfaces for controllers?"

There is some research existing on time-based ATC and corresponding information representation [20][21]. Research has been executed to simplify controller displays with aircraft that only move in one direction on screen [22]. Lateral information could be removed. The focus then lies on flight altitudes and distances to significant waypoints. Distance to threshold (on x-axis) may in a trajectory-based ATC world also be used for a timely controller diagram (y-axis) for conflict resolution purposes as well as altitude and speed commands [23]. Especially changing ATC strategies will affect CWP's HMI design like tower or approach/center displays to a different extent. The focus will lie on approach controllers here. There are lower separation minima because of slower aircraft and better surveillance equipment compared to the upper airspace. The use of radar display is essential compared to tower controllers. In addition, the dynamic of aircraft when merging to a single arrival stream is higher. Possible generalizations for other CWPs may be drawn later on.

III. Concept for Iterative Steps in "OFMUCH"

User acceptance is one of the most important aspects when modifying a controller HMI due to external changes in the ATC environment. Therefore, quick learnability of new HMI assistance functionalities and adaptation to new conditions is necessary. The design of different consecutive steps of display software from an actual to a future state has to take into account smooth transitions to accompany changes of the HMI. Thus, long timespans with iterative user centered adaptations of displays may be supported instead of broad big bang integrations at a single point in time [24][25]. Currently, HMIs in the ATM domain have lifecycles of decades. Technical preconditions are given for integrating changes into active controller HMIs. Following responsible persons from DFS (DFS Deutsche Flugsicherung GmbH), the German air navigation service provider, the pressure on this issue has significantly increased during the last few years. However, such modifications are seldom implemented with very small impact. Nevertheless, DFS managers like to avoid immense changes as experienced with the introduction of the system VAFORIT (Very Advanced Flight Data Processing Operational Requirement Implementation) [26]. The old system was replaced in a big bang integration after 34 years of operation. Prior to this, extensive training of controllers in a non-productive environment for one year and with only 70% of normal operational ATC capacity was necessary.

Human beings do not like permanent changes when using human machine interfaces from a psychological viewpoint [27]. Psychological shaping is known as a systematic stepwise harmonization of behavior. Similar to this, the new migration tolerant concept of the OFMUCH work shall help learning new functionalities. However, no positive or negative intensification is forced via stimuli. The concept described in this paper shall not create an immediately operational deployable system. It bases on assumptions that will only become valid a few years in the future. The degree of modifications in a display plays a central role. This degree should be kept as small as possible, but as large as necessary for floating transitions. Innovation will be introduced in a row of consecutive steps in which elements may also be eliminated if not needed any longer. The learning step size is crucial for HMI users. It decides on being able or willing to follow each next step.

Furthermore, the way of introducing modified visualization or information is important for HMI learnability. In OFMUCH approach, enhanced displays always look very similar to its preceding version to simplify controllers' familiarization with new elements due to rigidity of the human mind. This means that only one logical element experiences a modification from one display revision to the next. All other elements of a display are not changed. Logical units could be an aircraft radar screen symbol or certain air route sections. Those elements will be modified due to the future shift of air traffic control strategies. Some basic design requirements, also relevant in other controller displays, have to be incorporated. Small either static or dynamic symbols shall not cover full or partly the screen background. Fast and easy recognition as well as distinction of objects is also essential for air traffic controllers. Reducing complexity to simple structures and clarification of different states of visualized objects can be beneficial, too.

For OFMUCH research current controller working position displays of pickup or feeder controllers are taken into account for the design of HMI transitions.

The number of transitions between different display revisions needs to be linked with individual user requirements. The defined SESAR steps for shifting of ATC guidance approaches [6] are only seen as milestones and the necessary number of development respectively learning steps cannot be derived directly. Nonetheless, controller HMIs could get more consistent regardless individual airspace requirements. It would be possible to work from different initial situations with individual migrations towards a common end status.

Basic assumptions for the migration tolerant concept [28] are the defined premises in the previous chapter: shift in three steps from to a time-, trajectory-, and performance-based ATC strategy; precise navigation and ranging of aircraft; air-ground data link negotiated four-dimensional trajectories; a growing degree of automation; new flight respectively approach procedures; and a change of controller roles from active managing to more active monitoring.

Today, controllers use their situation data display mainly for estimating relative distances between visualized aircraft positions. With the shift to a time- and trajectory-based approach, the monitoring of negotiated target times or flight routes will move into focus. To preserve actual controller skills, an artificial back migrating of display revisions could be reasonable. Controllers could use both, their current and future skills, if a bidirectional adaptable migration, dependent on current tasks, is possible.

In this paper some example HMI transitions of a CWP similar to the pickup position are presented. Display revision 0 has a negative display representation (light symbols on dark background) with the TMA airspace layout of Frankfurt/Main in a single runway configuration. This prototypic display that is very similar to todays controller radar screens will be modified in 9 steps to get to future states. In this paper only revision 1, 3, 5, 7, 8, and 9 are presented (figures from [29]). The skipped steps can be comprehended with the next display iteration.

During the whole development process, feedback of ATM experts, controllers, and ATM responsibles was included similar to rapid prototyping. Therefore, the implementation followed user centered [1] development loops (Develoops) with improvements after each prototype feedback [30].

From evaluations of further prototypic display implementations the distance marking mileage on the centerline was annotated from controllers as very helpful to separate aircraft. As a first transition step the marking of every nautical mile with a special marking for every fifth mile is enlarged to all standard arrival routes (STAR) in the controlled airspace (see Figure 2). The task of separating air traffic will maintain the most important one for safety. Nevertheless automation tools will defocus this task from the controllers' work. Thus relative separations of aircraft on the same route and even at merging points of different routes can be appreciated better.

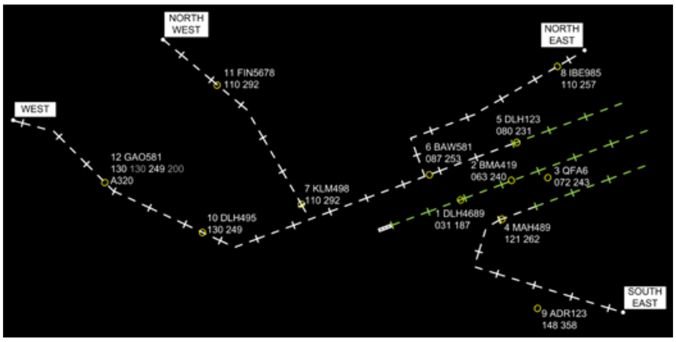

Figure 2. Distance marking at STARs on a currently usable controller display with a runway in the middle and four initial approach fixes (Display 1).

To enhance the aspect of relative positions, straight routes could be preferred. However, real routes have several inflection points. A comparison with the domain of road traffic or train (e.g. subway or railway supervision) reveals straight and often right angular routes in their supervision plans and displays whereas real routes can differ heavily. Only the topology of objects is correct. This is very helpful for the co-ordination of different routes. Indeed, means of transport have fixed routes from which they cannot deviate. An aircraft only has virtual ways to follow in the air. There may also be various entry points into the TMA before joining a route. This can reduce often flown path detours and therefore avoid delays and minimize fuel consumption. Thus, deviation marking is very important to recognize potential non-conform states, conflicts and deviations from the planned and negotiated trajectory.

The second transition includes arrow symbols for original cardinal directions or standard arrival routes to the runway (route ends of Figure 3). The third transition consists of straightening routes from the initial approach fixes to the elongated downwind routes used for path stretching (Figure 3). This view shall for example simplify conflict recognition at merge points due to a first step of homogenized conflict geometry [31].

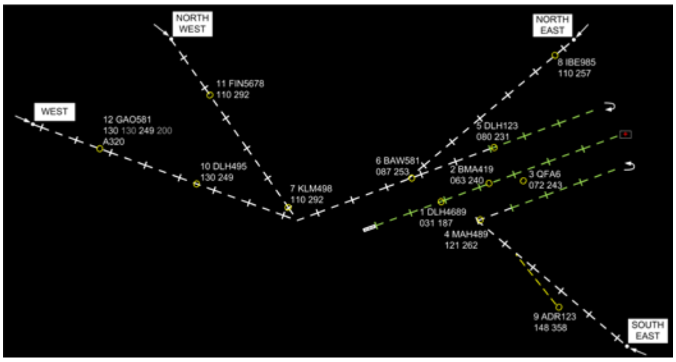

Figure 3. Straightened display routes for improved detection of merge point conflicts (Display 3).

However, some challenges raise due to non-complete lateral resolution. Distances between routes may appear smaller or greater than they are in reality. This is a result of modified displayed route angles at inflection or merge points. It is also true for distances between aircraft on those routes or next to them.

A reliable automated conflict display mechanism is essential especially for those flights that seem to be far away from each other in the display but are close in reality. Conventional air traffic control via speed and altitude is still possible due to quite similar effects of controller commands on the screens. But heading commands may be very hard to devise and instruct. Therefore a change of current controller positions is reasonable. Instead of actual assignment of divided areas of responsibility, the positions of a more strategic monitoring and a tactical executive controller could be installed. The migration tolerant display would be the standard display for the monitoring controller. The executive controller further works with a radar screen and could also be assigned to more than one monitoring controller due to its expected less activity regarding more automated air traffic. A monitoring controller could delegate a recognized conflict to his executive controller or even make a suggestion to solve. Controller positions in upper airspace act very similar as a planner/coordinator with a greater lead time and an executive who work as a team [32][33].

When the controller got used to aircraft being displayed on the correct position on routes but incorrect positions in the TMA, a fourth step is possible. To optimize recognition of relative distances and therefore free cognitive resources for supervising times and trajectories a rectification of the straightened routes is possible as depicted in Figure 4. In this case conformance monitoring tools become essential [34]. Aircraft flying east of a west route and west of an east route may be in conflict despite of looking alike at the display. The marking of conflicts and the visualization of a conventional radar display is still very important to solve potential separations lacks.

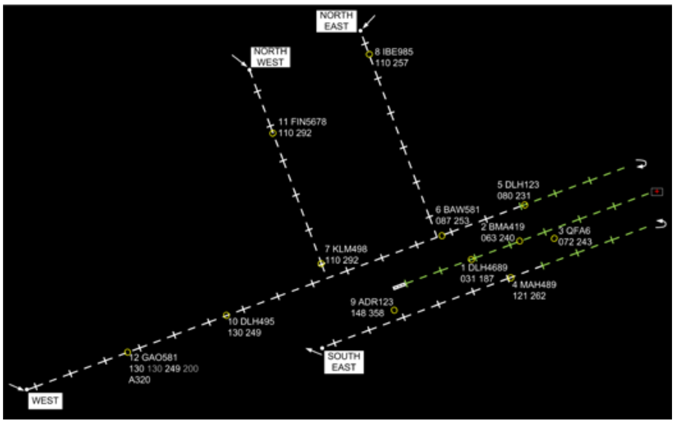

Figure 4. Rectangular display route structure for better comparison of aircraft on different routes (Display 5).

After adapting controllers' work on rectified structures, it is possible to rotate the whole airspace into a horizontal level. The horizontal runway now only has parallel and orthogonal routes (Figure 5). Afterwards color and shape coding of aircraft symbols can lead to performance relevant significant meanings. Every symbol contains information about the possibility of performance optimization at first sight on the screen. Using the three dimensional Pythagoras for the distance sum between calculated trajectory points in dependence of flight distance until touchdown compared to the minimum way, the optimization potential can be computed.

The result is shown in a non-complete symbol with missing edges of a triangle symbol (see Figure 5). The more edges missing (with maximum two) the more potential the aircraft has to be optimized. Aircraft with more precise navigating capability as for instance aircraft with 4D-FMS will be visualized as a circle because they do not have optimization potential if they already negotiated a trajectory with an arrival manager.

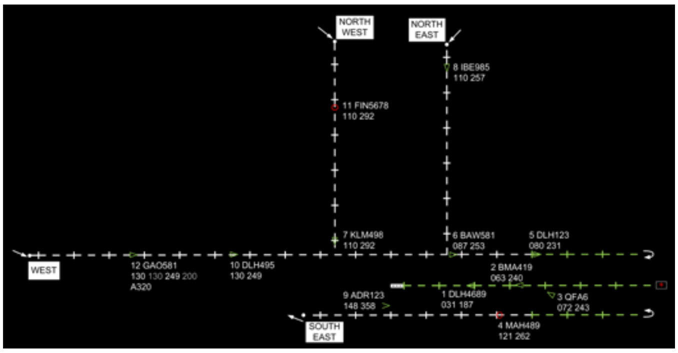

Figure 5. Orthogonal displayed route structure with aircraft symbology for optimization purposes (Display 7).

The eighth step includes a wrapping of the rectified routes to a parallel horizontal route structure which can be seen in Figure 6. The resulting route structure is cascading due to merging points where joining of several routes on one central on-going route is performed. Vertical white lines symbolize a merging point of standard arrival routes. Green lines symbolize the downwind for Standard-FMS aircraft where aircraft fly in the opposite direction and the elongation of the centerline for emergency flights. The symbols of the cardinal direction now become most important. All aircraft fly in the same direction of the display but in different directions in reality. The connection and the situation awareness between the orthogonal diagram and the basic radar screen shall be held by these static direction icons.

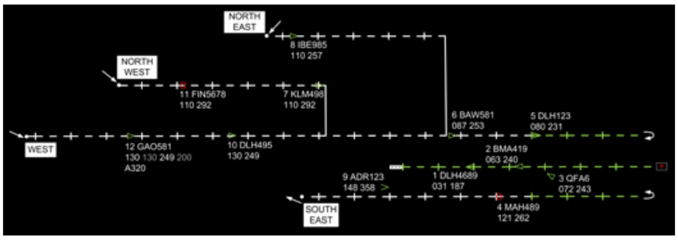

Figure 6. Parallelized displayed route structure with straightened merge points for comparison of all incoming routes (Display 8).

In the last transition to display revision 9, all arrival routes are arranged on only one side of the runway (Figure 7). Each displayed route now is parallel for better comparison of relative positions. The only area where aircraft fly from the left to the right side is the downwind. But this area shall be avoided anyway, because it means a plus in flight length, time and environmental inputs. Going beyond this last step it is also thinkable to only have straight routes representing the start and end airport at both ends with marking of aircraft deviations from its planned trajectory.

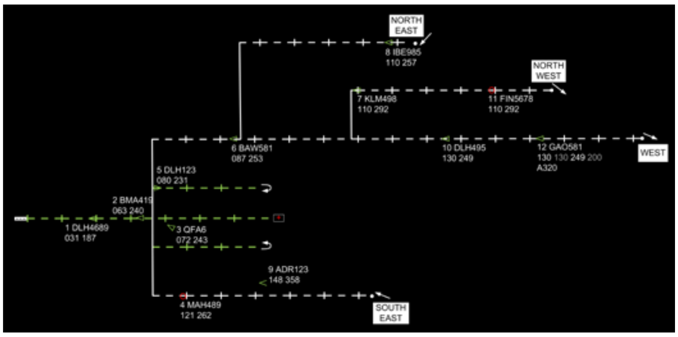

Figure 7. Unidirectional orthogonal monitoring display with the runway on the left side and downwind flights to be avoided (Display 9).

The enhanced orthogonal topography diagram was also modeled for different other airspace structures. Further actions to be implemented into this concept concern alternative route structures, runway structures, go-arounds and arrival procedures. Examples are circle structures of routes where arriving traffic in the north is guided onto a south route or alternative arrivals like fan, which demands for placeholders at final and trombone.

The strategy of getting from a current display to a future view deserves a clear aim at the beginning of the concept. One should then think of convenient transitions for the migration process with defining little steps as described or middle goals and further refinement between steps. The goal here was to reach an HMI visualization in which performance parameter, trajectories, times and distances can be handled in a safe and efficient way. The idea of a transition-roadmap was described as follows:

1) Marking of distances in nautical miles on every route.

2) Symbology for cardinal arrival directions.

3) Straightening of routes in the TMA outer area.

4) Homogenizing of route angles.

5) Rectification of routes.

6) Rotating of whole display until runway is horizontal.

7) Color and shape coding of aircraft icons.

8) Expanding merge points to merge lines.

9) Wrapping around all routes to one side of the runway.

IV. Design of Evaluation Study

The migration tolerant display revisions were evaluated during a study with n=10 controllers from the DFS. The trials took place at the DLR site in Braunschweig, Germany. Each study participant attended a training run and three simulation runs that lasted roughly 35 minutes each. The subject matter experts (age [years]: Ø: 41, SD: 9; professional experience [years]: Ø: 17, SD: 10; gender: 1 female, 9 male; working position: 55% ACC, 20% UAC, 25% TWR) were divided into two groups. Group G9 had to work with all ten display revisions experiencing nine transitions between them.

Group G2 only worked with basic display 0 (in run 1), intermediate revision 5 (in run 2), and last final display iteration 9 (in run 3) undergoing two transitions.

Group G9 worked with displays 0, 1, and 2 in run 1, with displays 3, 4, 5, and 6 in run 2, and with displays 7, 8, and 9 in run 3 (see Figure 8).

Assignment of Display Steps (D0-D9), Simulation Runs (R1, R2, R3) and Participant Groups (G2, G9)

Display Step	D0	D1	D2	D3	D4	D5	D6	D7	D8	D9
Group G2	R1					R2				R3
Group G9	R1			R2				R3		

Figure 8. Assignment of display steps, simulation runs, and participant groups.

All simulation runs that were conducted as a replay included forced deviations from standard routes, conflicts at merge points or on the centerline, as well as speed and altitude constraint violations. The controllers had to detect these situations and document it to an input mask. So there was no reaction on their input, but deterministic comparable reactions of each controller to always the same situation without simulation runs falling apart from each other. The display revision switched to the next one normally after one third of the scenario duration in group G9.

During all runs both groups also had to answer blocks of three online questions about the current air traffic situation. These questions concerned for example current aircraft status, relation of aircraft and projected relation of aircraft corresponding to the three levels perception, comprehension, and projection of situation awareness [35]. Also after one third of scenario length both groups had to answer offline questions where the screen was black and they had to remember the actual situation before black screen. In addition study participants had to rate their own workload with the instantaneous self-assessment method every five minutes.

Furthermore participants had to answer two questionnaires about system usability, and transitions after each of the three runs, and a concept questionnaire as a whole at the end of the day.

V. Evaluation Results of Study on Migration Tolerant Display Steps

An excerpt of the evaluation results is presented in this section. The recognition time needed to detect potential conflicts of two aircraft at two example merge points for each simulation run and both groups is shown as a boxplot in Figure 9. It visualizes minimum and maximum values (black horizontal line at the end of error indicators), the lower and upper quartile (quantile Q0.25 respectively Q0.75) as bottom and top end of the red-green area, the median (boundary between red and green area), and the arithmetic average (black plus, ø). Arithmetic average decreases from 227 s in run 1 to 222 s in run 2 and 178 s in run 3.

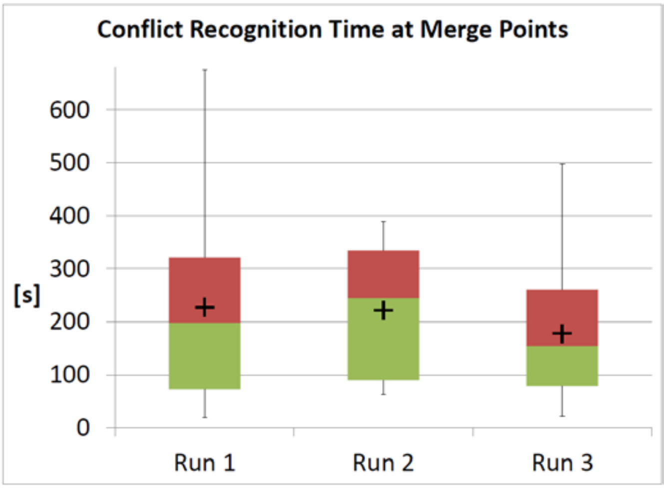

Figure 9. Time needed to recognize conflicts at merge points.

Figure 10 shows the portion of correctly answered online questions that were asked during each simulation run. The percentage in all runs was roughly 80% (run 1: 82%, run 2: 83%, run 3: 76%, with standard deviation below 12% visualized as black lines in the bar graph) and had no significant differences between groups or runs.

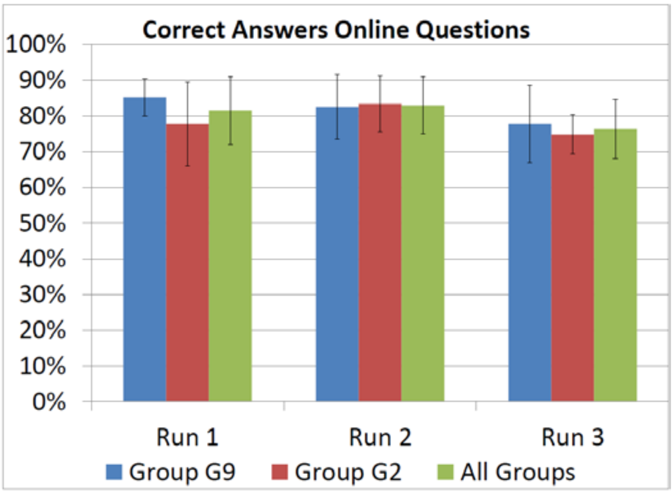

Figure 10. Percentage of correctly answered online questions.

Figure 11 shows three items of the transition questionnaire answered by group G9 for each display revision. The closer the rating is to the highest score 4, the better was the evaluation of controllers. Except of learnability in the last display step, all bars show values of 3 and above. Hence, it was clear to controllers how aircraft moved along STARs on the current display. Controllers were also able to quickly learn new display revisions. However, learnability was easier when only introducing symbology (step 2 and 7). Planning and delegation in the course of simulation task was possible.

Performing a one sample size t-test with significance level α=0.05 and 95% confidence interval at $n-1$ freedom degrees or even a Wilcoxon signed-rank test, almost all ratings lie significantly above the average rating scale value 2.

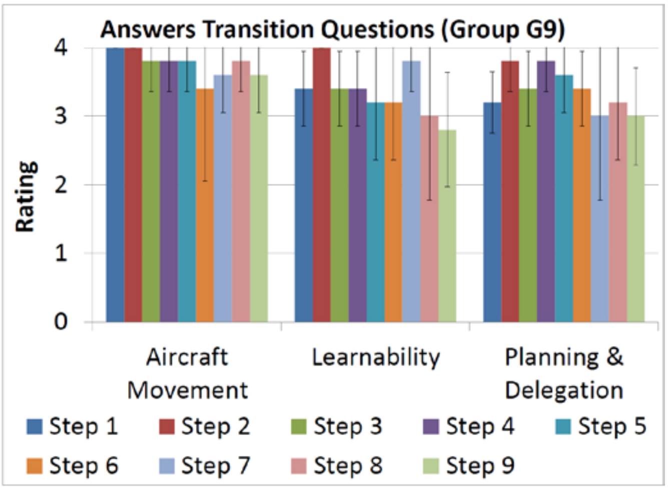

Figure 11. Group G9 participant ratings on transition questions (the higher the rating, the better).

Figure 12 presents three further questions comparing the current with the preceding display revision answered by the G9 participants. Only a few results of each item were significant due to the t-test. The degree of change to the last display revision perfectly fit except of too small steps 2, 7 (symbology introduction), and 9 (wrapping of routes). Recognition of conflicts got easier compared to each predecessing display revision. Controllers were in average better able to solve given tasks compared to last display revision.

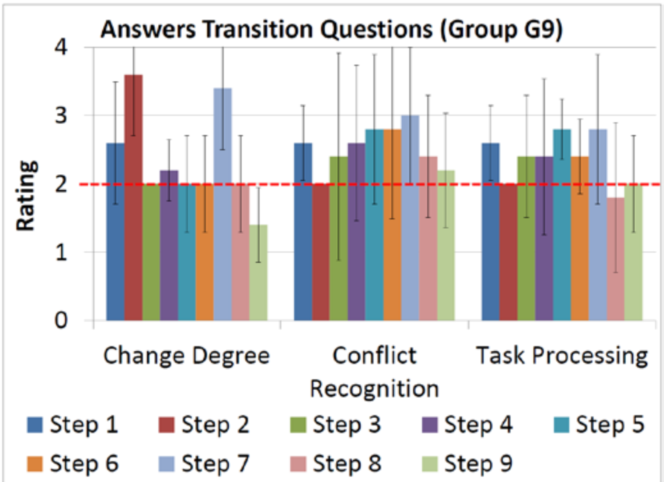

Figure 12. Group G9 participant ratings on transition questions (0: too big/worse/harder; 2: no change; 4: too small/better/easier).

Figure 13 compares controller group ratings at step 9 and shows big differences. Using the t-test for mean value differences between two independent samples, item 1 ($p<0.025$), 3, and 5 ($p<0.1$ each) showed significance. Group G9 that worked with all nine display revisions before, rated the last display revision roughly one point higher on a five-point-scale compared to group G2 that only experienced two transitions to the last display revision. These ratings include understanding of aircraft movement on screen, learnability, planning and delegation as well as easiness of system usability, and feeling of safety when using the system.

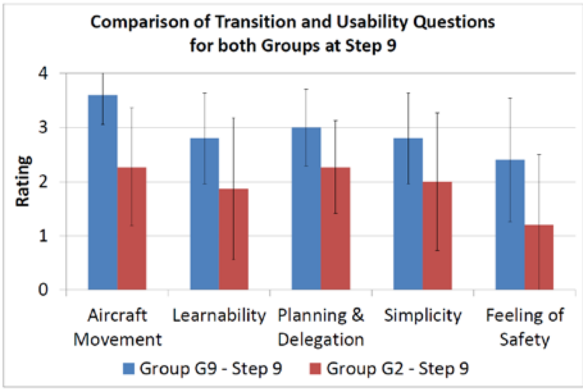

Figure 13. Comparison of participant ratings at ninth step between G9 and G2.

The self-assessed workload of controllers for group G9 and G2 in all three simulation runs is shown in Figure 14. Both groups started with the same display revision and self-assessed the same workload (Assessment Item 1). However, the red line for group G2, where the display changed only twice, afterwards lies predominantly above the blue line for group G9.

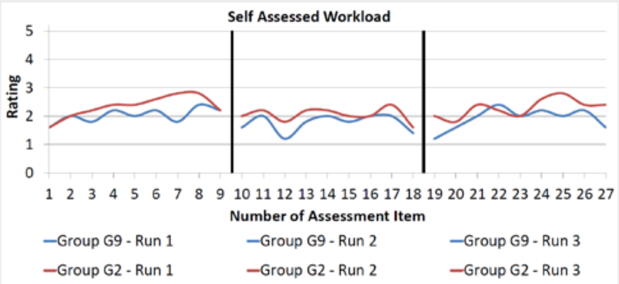

Figure 14. Comparison of self-assessed workload between group G9 and G2.

VI. Discussion of Results and Controller Remarks

Group G9 did not have great problems learning to use iterative display revisions. Small changes and logical consecutive steps eased learnability. Only the last display steps with more turning away from current air traffic situation displays forced slightly longer habituation times. One controller praised the general view in step 8 as excellent. Some participants of group G2 also attested better learnability. However, especially the step from display revision 5 to 9 was too great for them. But there were also controllers that were not bothered due to the missing geographic resolution on display. Some declared the view as good to use for a monitoring controller. Others liked early recognition of aircraft sequences as well as earlier and easier conflict detection. Nevertheless, such systems should not generate bonsai controllers that will follow a machine without thinking and with only minor tasks. An operational integration of small updates would be reasonable and thinkable due to the controllers' opinions. Nevertheless, questions on training, safety assessment, and costs have to be clarified beforehand.

The ten transition steps were understandable for group G9 at all times. As a trend, step 2 and 7 were too small, whereas step 9 was slightly too large. The questionnaire item on reducing complexity revealed different results.

Two controllers of group G9 affirmed although this was not true for every single transition. Two others partly agreed, but mentioned that the complexity was not reduced in the last steps. One controller of group G2 was able to understand the display steps even after the initial presentation and could therefore think of a faster transition. Three others denied an HMI complexity reduction particularly in the transition from display revision 5 to 9.

Figure 9 and Figure 10 show without statistical significance that migratory displays do not deliver worse user results compared to current controller displays. Figure 11 and Figure 12 illustrate that important characteristics of displays do not suffer from being migrated. If anything, those characteristics are improved from revision 0 to 9. The time needed to recognize potential conflicts at merge points slightly decreased with further display revisions. Figure 13 and Figure 14 demonstrate in a pairwise comparison of group G9 and G2 results that learnability and use of new display steps is easier and quicker with small transition steps. The ratings of group G2 were much lower than of G9 for the same display revision but with different transitions on the way towards it. Thus, consecutive implementation steps also improve user acceptance. Workload was rated higher if display revisions went on in two great instead of nine small steps as well. However, large error bars in most of the result diagrams show heterogeneity of controller characteristics regarding different requirements at their working positions and locations.

The evaluation study for the controller displays revealed two results. First, there could not be stated a decrease in performance of current controller tasks compared to today analyzing conflict detection or lower situation awareness derived from the percentage of correct online simulation run questions. Second, user acceptance can be increased when introducing new functionalities with a row of iterative transition steps instead of few great steps.

VII. Summary and Outlook

A new method of airspace surveillance and new controller HMIs respectively roles were developed. Possible transition steps with iterative displays on the way towards this new controller environment were designed and implemented. The evaluation study showed that the degree of layout modification between most display steps is suitable and comprehensible. Furthermore, using a monitoring display to supervise air traffic is basically thinkable. Adapting controller displays in several small steps was beneficial against one great step.

Further adaptations need to be integrated so that a proof of concept verification can be completed. In addition, a more intensive validation study is necessary to get a broader feedback also including teamwork of new controller roles with new HMIs and to prove hypotheses derivable from described partly significant results.

The SESAR ATM master plan published in December 2015 also demands transitions in the course of an evolutionary concept implementation. Migratory implementation steps shall serve as an approach for change management [36]: „Provisions: These will be made for the training needs that enable effective and optimal change management.

This will support a transition path that considers the influence of successive migratory implementation steps towards the agreed concept evolution and minimizes the extent to which the human system relies on phenomena such as mode switching.“ This quotation with actual high level requirements of the ATM industry demonstrates necessity of solutions for migration tolerant introduction of new functionalities. The need for smooth transitions has already been anticipated and led to the migration tolerant display steps of this paper. With their implementation and a first proof of basic operability, a future practical use may be looked forward to.

REFERENCES

[1] E. Kesseler and E. Knapen, Designing future advanced controller displays, NLR, Amsterdam, 2004 (NLR-TP-2004-307).

[2] U. Metzger and R. Parasuraman, Automation in Future Air Traffic Management: Effects of Decision Aid Reliability on Controller Performance and Mental Workload, in: Human Factors: The Journal of the Human Factors and Ergonomics Society 47, 2005, No. 1, pp. 35–49.

[3] A. Neal, J. Flach, M. Mooij, S. Lehmann, S. Stankovic, and S. Hasenbosch, Envisaging the Future Air Traffic Management System, in: The International Journal of Aviation Psychology 21, 2011, No. 1, pp. 16–34.

[4] P. Brooker, Air Traffic Control Separation Minima: Part 1 - The Current Stasis, in: Journal of navigation (Online) 64, 2011, pp. 449–465.

[5] P. Brooker, Air Traffic Control Separation Minima: Part 2 - Transition to a Trajectory-based System, in: Journal of navigation (Online) 64, 2011, pp. 673–693.

[6] SESAR: European ATM Master Plan: The Roadmap for Sustainable Air Traffic Management, Brussels, 2012.

[7] SESAR, Modernising the European Sky, SESAR, Brussels, 2014.

[8] Federal Aviation Administration, NextGen - Implementation Plan, NextGen Integration and Implementation Office, Washington, 2014.

[9] O. Ohneiser, Migration Tolerant Human Machine Interfaces – Are we ready for the Future?, original German title: Migrationstolerante Mensch-Maschine-Schnittstelle für Lotsenarbeitsplätze – Sind wir auf die Zukunft vorbereitet?, in: Future Visualization Systems for Vehicle- and Process Guidance (DGLR-Report 2012-01), original German booktitle: Fortschrittliche Anzeigesysteme für die Fahrzeug- und Prozessführung, M. Grandt, S. Schmerwitz, eds., German Society of Aerospace, Bonn, 2012, pp. 283–286.

[10] ICAO, ATM (Air Traffic Management): Procedures for Air Navigation Services, International Civil Aviation Organization (ICAO), Montréal, 2007 (DOC 4444 ATM/501).

[11] T. Hauf, H. Leykauf, and U. Schumann, Air Traffic and Weather: State paper June 2004, original German title: Luftverkehr und Wetter: Statuspapier Juni 2004, Arbeitskreis Luftverkehr und Wetter, Hanover, 2004.

[12] T. Gerz, F. Holzäpfel, and D. Darracq, Commercial aircraft wake vortices, in: Progress in Aerospace Sciences 38, 2002, No. 3, pp. 181–208.

[13] SESAR, SESAR Solution - Time Based Separation: Contextual note, SESAR, Brussels, n.d.

[14] Air Traffic Management Requirements and Performance Panel (ATMRPP), Proposal for the development of TBO concept: Managing unpredictable evolution in trajectory based operations, ICAO, Toulouse, 2014 (ATMRPP WG/25-WP/601).

[15] A. Kuenz and B. Korn, Enabling Green Profiles for Today’s Traffic Mixture in High Density, in: Proceedings of the 2009 Integrated Communications, Navigation and Surveillance Conference, IEEE, 2009, pp. 15–24.

[16] H. Helmke, Time-based arrival management: New controller support tools are necessary to ensure best-possible use of the available airspace, Air Traffic Technology International 2011, 2011.

[17] H. Erzberger, The Automated Airspace Concept, NASA Ames Research Center, Santa Fe, 2001 (Fourth USA/Europe Air Traffic Management Research and Development Seminar (ATM2001)).

[18] M. Endsley, R. L. Sollenberger, A. Nakata, and E. S. Stein, Situation Awareness in Air Traffic Control: Enhanced Displays for Advanced Operations, Federal Aviation Administration, Atlantic City, 2000 (DOT/FAA/CT-TN00/01).

[19] V. Duong, G. Gawinowski, J.-P. Nicolaon, and D. Smith, Sector-Less Air Traffic Management, EUROCONTROL, Santa Fe, 2001 (Fourth USA/Europe Air Traffic Management Research and Development Seminar (ATM2001)).

[20] O. Ohneiser, Flight Guidance Support to Integrate Conventional Equipped Aircraft into a time based Arrival Flow, original German title: Führungsunterstützung zur Integration konventionell ausgerüsteter Luftfahrzeuge in einen zeitbasierten Anflugstrom, in: Future Visualization Systems for Vehicle- and Process Guidance (DGLR-Report 2012-01), original German booktitle: Fortschrittliche Anzeigesysteme für die Fahrzeug- und Prozessführung, M. Grandt, S. Schmerwitz, eds., German Society of Aerospace, Bonn, 2012, pp. 175–192.

[21] O. Ohneiser, M.-M. Temme and J. Rataj, Trawl-Net Technology for Timely Precise Air Traffic Controller Turn-To-Base Commands, Lisbon, 2015 (Eleventh USA/Europe Air Traffic Management Research and Development Seminar (ATM2015)).

[22] R. Benhacène, M. Anthony, and M.-P. Rousselle, As rapid as paper strips? Evaluation of Vertidigi a new control tool for terminal sectors, Baltimore, 2005 (Sixth USA/Europe Air Traffic Management Research and Development Seminar (ATM2005)).

[23] A. M. P. de Leege, M. M. van Paassen, A. in’t Veld, and M. Mulder, Time–Space Diagram as Controller Support Tool for Closed-Path Continuous-Descent Operations, in: Journal of Aircraft 50, 2013, No. 5, pp. 1394–1408.

[24] V. Kapp and M. Hripane, Improving TMA sequencing process: Innovative integration of AMAN constraints in controllers environment, in: 2008 IEEE/AIAA 27th Digital Avionics Systems Conference, IEEE, 2008, pp. 3.D.1-1–3.D.1-9.

[25] C. König, T. Hofmann, and R. Bruder, Application of the user-centred design process according ISO 9241-210 in air traffic control, in: Work: A Journal of Prevention, Assessment and Rehabilitation 41, 2012, No. 1, pp. 167–174.

[26] INDRA, DFS UAC Centre Karlsruhe Operational since Dec 2010 delivered by Indra, INDRA, DFS Deutsche Flugsicherung GmbH, Madrid, n.d.

[27] P. Axt and M. Axt-Gadermann, From the fortune of small steps, original German title: Vom Glück der kleinen Schritte: Step by step - das Gewohnheitstier in uns überlisten - Das 52-Wochen-Gesundheitsprogramm. Munich, Herbig, 2008.

[28] O. Ohneiser, M. Heesen, F. Flemisch and J. Rataj, Migration Tolerant Human Machine Interface Concepts in the Domain of Air Traffic Management and Automotive, 63rd German Aerospace Congress, 2014, Augsburg, German Society of Aerospace.

[29] O. Ohneiser, Migration tolerant transitions of incremental display steps for air traffic controllers, original German title: Migrationstolerante Transitionen von inkrementellen Displaystufen für Fluglotsen, Dissertation Technische Universität Braunschweig, 2016, Braunschweig, to be published.

[30] M. Rauterberg, Usability Engineering Methods and Tools: User Centered Design, Technical University Eindhoven, Eindhoven, 1998.

[31] E. M. Palmer, T. C. Clausner, and P. J. Kellman, Enhancing air traffic displays via perceptual cues, in: ACM Transactions on Applied Perception 5, 2008, No. 1, pp. 1–22.

[32] S. Malakis, T. Kontogiannis, and B. Kirwan, Managing emergencies and abnormal situations in air traffic control (part I): Taskwork strategies, in: Applied Ergonomics 41, 2010, No. 4, pp. 620–627.

[33] S. Malakis, T. Kontogiannis, and B. Kirwan, Managing emergencies and abnormal situations in air traffic control (part II): Taskwork strategies, in: Applied Ergonomics 41, 2010, No. 4, pp. 628–635.

[34] O. Ohneiser and S. Beddig, Air Traffic Controller Support for Conformance Monitoring and Active Guidance of Air Traffic, original German title: Fluglotsen-Unterstützung für die Konformitäts-überwachung und aktive Führung des Luftverkehrs, 62nd German Aerospace Congress, 2013, Stuttgart, German Society of Aerospace.

[35] M. R. Endsley, Situation Awareness Global Assessment Technique (SAGAT), in: Proceedings of the IEEE 1988 National Aerospace and Electronics Conference: NAECON 1988, 1988.

[36] SESAR, The roadmap for delivering high performing aviation for Europe – European ATM Master Plan, Brussels, 2015.