Supporting Air Traffic Controllers During Sector Configuration Changes in Dynamic Air Space Configuration

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Abstract— **There is an increasing demand for a means of addressing growth in air traffic amount and complexity. One such means, dynamic airspace configuration (DAC) proposes moving from fixed, static airspace configurations to configurations that dynamically adapt to changes in traffic amount and patterns. Whiles several different DAC solutions have been proposed and evaluated, little is known about the acceptability of DAC approaches to their end users. The work reported in this paper focuses on Air Traffic Controllers' (ATCOs') acceptance of DAC. To address this, we developed a prototype controller working position (CWP) that supports ATCOs in understanding changes in airspace configurations and their effect. We conducted a study with ATCOs controlling the Milan Air Traffic Control Centre using this CWP. To our knowledge, this is the first time DAC has been implemented in a CWP and tested with ATCOs. We also investigated how different user interface mechanisms aided ATCOs. Findings presented here may be useful for further development of DAC and other work-intensive systems.**

Keywords *– Dynamic airspace configuration, controller working position, human-computer interaction, real-time simulation, 3D visualisation*

I. INTRODUCTION

En-route ATCOs are responsible for safety and effective guidance of aircrafts. They control flights in their assigned airspace volume, which is known as a sector. Airspace is divided in several non-overlapping sectors each controlled by an ATCO. Such a division is called a sector configuration. Traditionally, the sector configurations of an airspace in the en-route phase are fixed. This is denoted here as a static airspace configuration (SAC). In this approach, both the horizontal shape and vertical extent of the sectors are predefined. In some airspaces, sector configuration is always fixed, while in others, there may be different configurations based on the time of day, traffic and so on, usually based on the merging or splitting of existing sectors. The number of different configurations is limited, and they are all predefined and known by ATCOs.

In the next 20 years, as traffic demand increases, airspace users will require a more efficient air traffic management system [1, 2]. Airspace users want to fly their preferred trajectory with a minimum of re-routing, delays and cancellations. This means that airspace capacity should be used better and much more flexibly than it is today without reducing safety. An important determinant of the capacity of a specific airspace is how controller workload (for example, the number of flights a controller must handle) is balanced between controllers over time. In an ideal air traffic management system, the workload balance between sectors is such that all flights can fly their preferred trajectories [3].

To enable flexible changes in sectorisation, dynamic airspace configuration (DAC) has been developed. In DAC, instead of using one or a limited number of predefined sectorisations, the airspace is divided into a much smaller airspace comprising building blocks from which new sectorisations are built dynamically based on the volume and complexity of air traffic. In addition to these building blocks, there are dynamic mobile areas like military training areas, which are available only in certain time intervals. With a DAC concept, both the horizontal shape and height of each sector may change dynamically.

Eurocontrol has developed a software tool, called Research Network Strategic Tool (R-NEST), that computes DAC solutions for a combination of areas and traffic samples [23]. ATCOs' acceptance of a DAC solution based on R-NEST has been investigated in the Single European Sky ATM Research (SESAR) project solutions PJ08-01 and PJ16-04. This includes operational procedures like the nature and frequency of changes, and notification schemes to use when sectorisation changes are to take place as described in OSED - Operational Service and Environment Definition [4].

For ATCOs who have worked in a certain airspace for some time, sectorisation within a traditional SAC solution may be considered tacit knowledge. However, DAC imposes two main challenges for ATCOs. First, awareness of sectorisation is no longer tacit knowledge, as ATCOs must exert mental effort to investigate and maintain a mental picture of it. Second, when sectorisation changes, some traffic will need to be handed over to a new sector. The first challenge primarily imposes additional issues for ATCOs' situational awareness, while the second adds to ATCOs' workload before and after sectorisation changes. To manage this, ATCOs have used new operational procedures.

Increased challenges for ATCOs' situational awareness and periodically increased workload are a means to balance workload between controllers. Thus, an important goal of the work reported in this paper was to investigate how additional challenges arising from the use of DAC balance with its overall benefits from the perspective of ATCOs. To achieve this, there is a need for specific support for DAC in the user interface (UI) of the CWP.

The rest of the paper has been organised as follows. Section II describes related work, and Section III presents the DAC CWP prototype we developed. Section IV describes our experimental design. Sections V and VI present and discuss our findings, while Section VII concludes the paper and proposes future work.

II. RELATED WORK

DAC has been developed in SESAR Solution PJ.08-01 [4] with the goal of dynamically adapting sectorisation to current traffic in terms of the number and shape of sectors. The main objectives of the DAC algorithm are to minimise the following: i) work overload for an individual sector, ii) workload imbalances between sectors, iii) the coordination of workload between sectors and iv) the transition cost of going from one configuration to another [5]. Different approaches to the development of DAC algorithms have been proposed [6, 7, 8, 9].

However, the successful implementation of DAC is not only an algorithmic problem but also a human–computer interaction problem. Both the process and the CWP interface need to be adapted to the DAC approach. Controllers should be notified of upcoming sectorisation changes. Further, they should maintain a high level of situation awareness when sectors are changed. Research in the area of attention guidance, such as [10, 11, 12, 13], provides a solid foundation for the design of the DAC-related functionality of our CWP. Further, the work of Endsley provided a design methodology focusing on situation awareness [14].

Sector configurations could change both horizontally and vertically. Therefore, 3D visualisation could be an obvious path to improve ATCOs' situational awareness of sector changes. 3D presentations of air traffic have been proposed as a means for reducing cognitive load and improving ATCOs' situation awareness [15, 16, 17]. Results of a study conducted by Dang et al. [18] indicated that 3D presentations can be beneficial for tasks with elements that move inside a limited area. Bourgois et al. [17] found that controllers performed better in terms of response time when identifying critical flight levels in a 3D condition compared to a 2D condition. Wittmann et al. [19] found a slightly higher judgment quality for a 3D than 2D reference system in a study asking controllers and laypeople to judge various potential conflicts involving two aircrafts.

III. DAC CWP PROTOTYPE

To conduct the experiment, we extended SINTEF's Multi-Agent Discrete Event Simulator Air Traffic Control (SIMADES ATC) prototype. This prototype consists of a real-time simulator and a CWP. The simulator manages airspace configuration and simulates traffic, taking into account changes to fight trajectories issued by pseudo pilots. For the experiment, the simulator was extended to support DAC [24]. DACs and opening schedules were calculated in a previous exercise within SESAR solution PJ08-01 using R-NEST and were based on the air traffic demand of a busy spring day at Milan AreaControl Centre (ACC). Configurations were validated up-front by ENAV and were used as input for this experiment. In principle, both horizontal and vertical sector borders may be skewed, but all sectors used in our study were flat, and each sector had the same shape and height.

The CWP provided standard strip-less ATCO functionality through a 2D radar screen, showing, among other airspace borders, sectorisation, flights, trajectories and speed vectors. It also filtered traffic based on flight level and the measurement of distances. For the experiment, the basic CWP was tailored to mimic the current CWP used by ATCOs at Milan ACC. Due to the design of the experiment (presented in Section IV), three variants of the CWP were created.

The first variant mimicked the current Milan ACC CWP, providing all functionality through a 2D radar screen. This CWP only supported static sector configurations, so we called it variant SAC-2D. The user interface of SAC-2D was a simplified variant of the 2D radar screen shown in Fig. 1. The second variant (shown in Fig. 1 and 2) also used a 2D radar screen as the main tool, but as it supported DAC, it included notification mechanisms to inform ATCOs of changes in sectorisation by blinking and showing sectors in different colours at given times ahead of a sector change. In addition, 15 minutes before a change, a small window was shown at the top left of the screen.

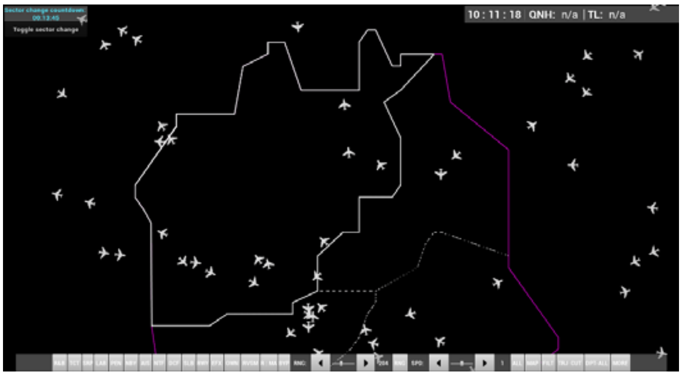


Figure 1. 2D radar screen using DAC before sector change

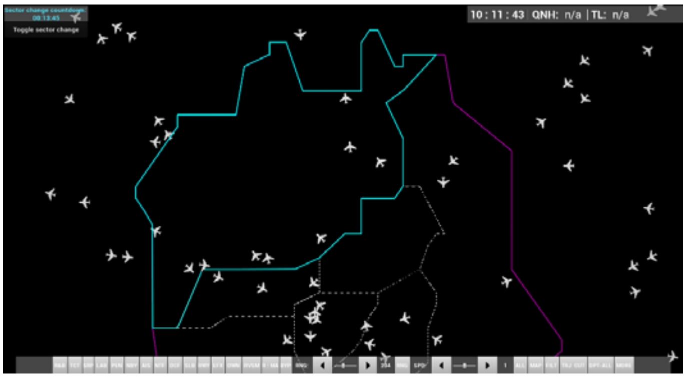


Figure 2. 2D radar screen using DAC after sector change

In addition to the 2D radar screen, this variant included an additional screen showing a side view of how the sector being controlled changed over time. It always showed the next 15 minutes, displaying lines to illustrate current and possible future vertical borders of the sector being controlled from the CWP. It supported DAC using 2D visualisations, so we called this variant DAC-2D.

The third variant provided an identical 2D radar screen to the DAC-2D variant. However, instead of the 2D side view of the current sector, it provided a 3D view of the whole airspace on an additional screen (shown in its context of use in Fig. 3). The sector being controlled was shown in an opaque colour, while other sectors had different transparent colours. This view could be controlled using multi touch gestures (MTIs). The 3D view did not have a time axis but provided similar notification mechanisms as the 2D radar view. As it supported DAC using 2D and 3D visualisations, we called this variant DAC-3D.

All variants of the prototype supported voice communication with pseudo pilots. In addition to the three main variants, a fourth variant was provided for pseudo pilots. This variant worked with any of the three main variants and was an extended version of the 2D radar view. It provided functionality for changing speed, height and heading for planes being managed by a pseudo pilot.

IV. EXPERIMENT DESIGN

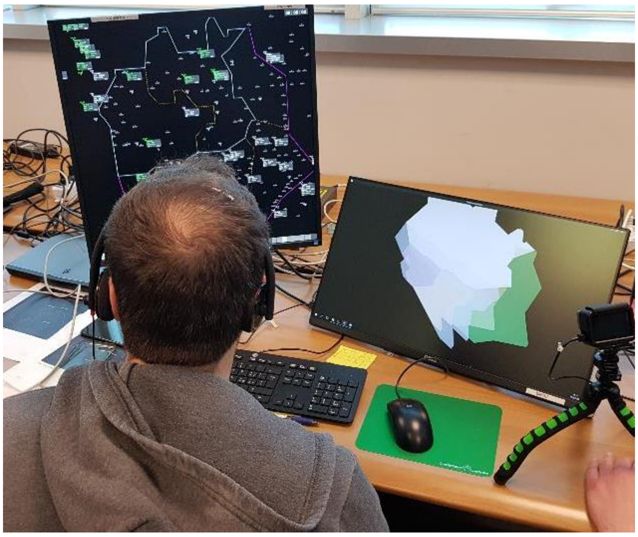
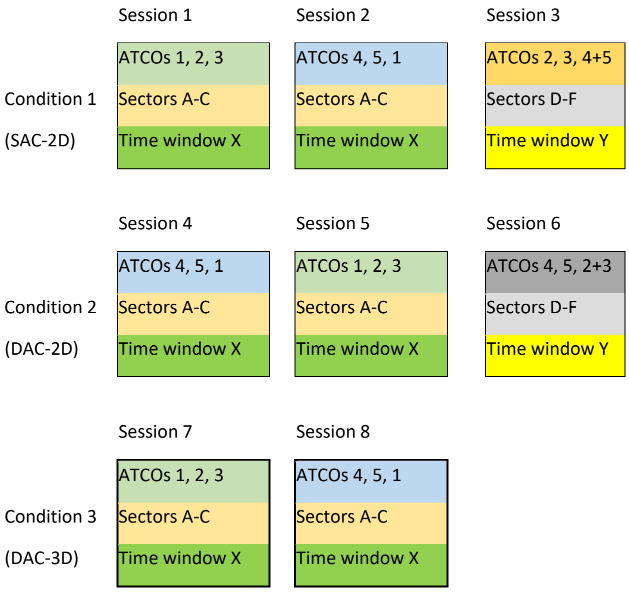


Figure 3. Setup of a CWP during the experiment

In addition to investigating ATCOs' acceptance of DAC, we wanted to find out whether UI styles and mechanisms influenced their performance and acceptance. Thus, the experiment consisted of two parts conducted in sequence with the same subjects, airspace configurations, traffic and data collection methods.

In the first part of the experiment, which we called the 2D Experiment, we investigated the effect of introducing DAC to ATCOs who were used to SAC. In the second part of the experiment, which we called the 3D Experiment, we investigated whether different user interface mechanisms (that is, 3D visualisation controlled using MTIs) influenced how DAC worked for ATCOs. Fig. 4 shows the overall design of the experiment.

For the 2D Experiment, we compared Condition 1 (the SAC-2D variant of the prototype with fixed, static sectors throughout each session) with Condition 2 (the DAC-2D variant of the prototype with two sectorisation changes in each session). As seen from the setup in Fig. 4, the 2D Experiment consisted of six sessions (Sessions 1–3 for Condition 1 and Sessions 4–6 for Condition 2). Sessions 1 and 2 used the same sectors and traffic but were conducted by different ATCOs. Session 3 used different sectors and traffic and was conducted by the same ATCOs as Sessions 1 and 2 (one sector had both an executive and planner controller). For Condition 2, Sessions 4 and 5 used the same sectors and traffic but were conducted by different ATCOs. Session 6 used different sectors and traffic (the same as in Session 3) and was conducted by the same ATCOs as Sessions 4 and 5 (one sector had both an executive and planner controller). In this way, differences between ATCOs and sectorisation/traffic were reduced to some extent. The setup also allowed us to compare results from the same ATCOs working with the same sectors and traffic between the two conditions (by comparing Session 1 with Session 5 and Session 2 with Session 4).



	Session 1	Session 2	Session 3
Condition 1 (SAC-2D)	ATCOs 1, 2, 3 Sectors A-C Time window X	ATCOs 4, 5, 1 Sectors A-C Time window X	ATCOs 2, 3, 4+5 Sectors D-F Time window Y
	Session 4	Session 5	Session 6
Condition 2 (DAC-2D)	ATCOs 4, 5, 1 Sectors A-C Time window X	ATCOs 1, 2, 3 Sectors A-C Time window X	ATCOs 4, 5, 2+3 Sectors D-F Time window Y
	Session 7	Session 8	
Condition 3 (DAC-3D)	ATCOs 1, 2, 3 Sectors A-C Time window X	ATCOs 4, 5, 1 Sectors A-C Time window X	

Figure 4. Experimental design

For the 3D Experiment, Condition 2 (the DAC-2D variant of the prototype with two sectorisation changes in each session) was compared with Condition 3 (the DAC-3D variant of the prototype with two sectorisation changes in each session). The 3D Experiment consisted of four sessions (Sessions 4 and 5 for Condition 2 and Sessions 7 and 8 for Condition 3). Sessions 4 and 5 used the same sectors and traffic but were conducted by different ATCOs. For Condition 3, Sessions 7 and 8 used the same sectors and traffic but were conducted by different

ATCOs. In this way, differences between ATCOs were reduced to some extent. This setup also allowed us to compare results from the same ATCOs working with the same sectors and traffic between the two conditions (by comparing Session 5 with Session 6 and Session 4 with Session 8).

Each session lasted for 120 minutes. During the first 20 minutes, a combined master ATCO and pseudo pilot prepared traffic to let it build up in the airspace area as realistically as possible. This was followed by 60 minutes in which ATCOs and pseudo pilots controlled the traffic. In Conditions 2 and 3, ATCOs received a notification of sector change 5 minutes from the start. Then, 20 minutes from the start, sectors changed. A new change occurred 50 minutes from the start, and notification of this change occurred 35 minutes from the start. The last 40 minutes were used to fill out questionnaires, conduct interviews, perform backup and so on.

During all conditions and sessions, data was collected using manual observations of ATCOs, logging all activities from the simulator and the CWP part of the SIMADES ATC prototype, automatic capture of all screen activities by ATCOs (backed up with video recordings of all screens) and audio recording of communication between ATCOs and pseudo pilots. After each session, ATCOs filled in a questionnaire and were interviewed. The aim of data collection was to measure usability and acceptance and to obtain feedback on the CWP interface, procedures, workload, situation awareness, communication burden and safety (that is, the number of safety violations) [20, 21, 22].

V. FINDINGS

Controllers reported that the overall workload was acceptable and was the same or slightly reduced for DAC conditions. Few errors were reported. These were mostly due to simplifications of the protype's UI. Overall, participants' feedback on the proposed UI was very positive. It was described as 'good' and 'almost perfect', and 'it enabled them to easily maintain a picture of the traffic'. Proposed solutions for notifying and visualising both horizontal and vertical changes were useful. Some improvements were proposed. For example, extension of 3D visualisation functionality.

Controllers performed communication tasks successfully using DAC. Situation awareness was very good for DAC conditions. Further, our results showed the importance of presenting vertical changes in the DAC approach and a need for better alignment of the timing of and changes to ATCOs' workload. More details can be found in the validation report [25].

A. *Workload*

Subjective and objective measures of controllers' workload per position and workload distribution were taken. Subjective experience of workload was assessed during and at the end of the experiment. At the end of the experiment, controllers were asked to fill in post-run questionnaires. Further, in interviews following the sessions, controllers were asked to elaborate on their workload during the experiment. We also asked controllers to report their workload in a questionnaire at several points during the experiment. Overall, workload was considered acceptable and was the same or slightly reduced in DAC conditions in comparison to the SAC condition. Controllers suggested that the timing of the changes and their notifications should be better synchronised with their workload.

In the post-run questionnaire, controllers reported their peak and average workload during sessions on a scale of 1 to 10, where 1 represented an insignificant workload, and 10 represented an unsustainable workload. Results have been shown in the tables below. Median peak workload and the median of the average workload reported by ATCOs was the same for all conditions. Their peak workload (7) was high, and their average workload (5) was moderate. One of the motivations behind DAC is a better distribution of workload, so we wanted to check if the total workload of the team (sum of the workload for all sectors) changed as a result of using a DAC approach. Analysis of workload for directly comparable sessions (Sessions 1 and 5/Sessions 2 and 4) showed that total workload was slightly lower for the DAC condition at almost all times (Fig. 5 and 6). In the figures, red lines show sector changes (20 and 50 minutes), and purple lines show the first notification of a change (3 and 35 minutes).

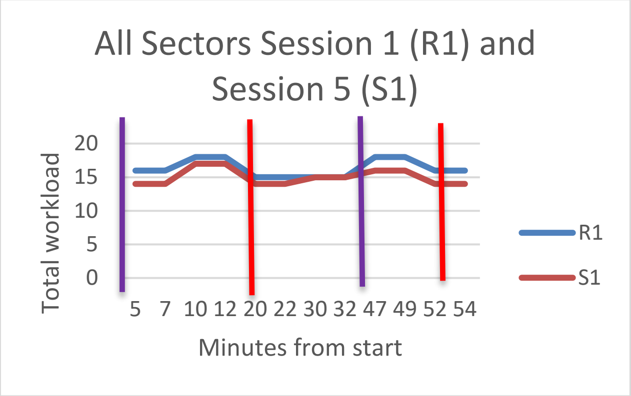


Figure 5. Total workload for all sectors in Sessions 1 and 5

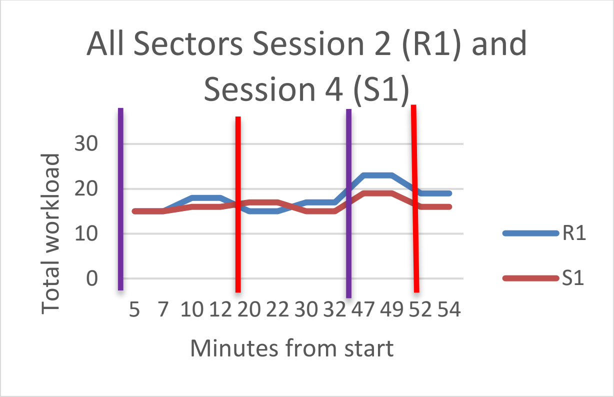


Figure 6. Total workload for all sectors in Sessions 2 and 4

Similarly, a comparison of total workload between DAC-2D and DAC-3D sessions (Fig. 7 and 8) showed that total workload for directly comparable sessions (Sessions 4 and 8/Sessions 5 and 7) was at the same level (slightly higher for DAC-3D than DAC-2D for Session 8 compared to Session 4 and exactly the same for the other two sessions). Differences over time did not correlate with sector change times, indicating that the 2D and 3D conditions did not affect workload during sector changes.

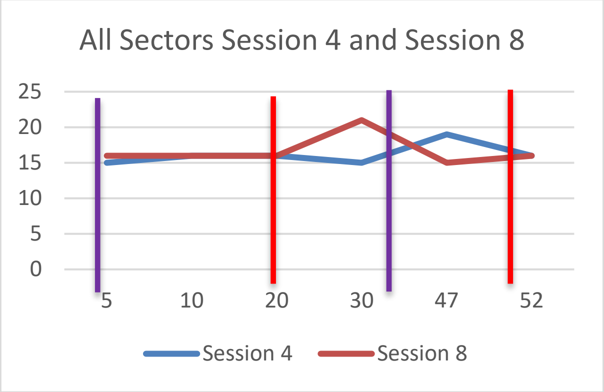


Figure 7. Total workload for all sectors in Sessions 4 and 8

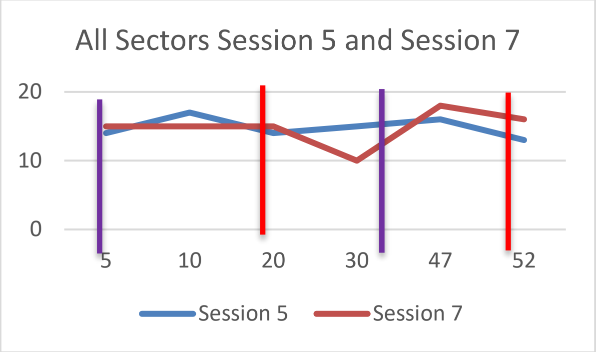


Figure 8. Total workload for all sectors in Sessions 5 and 7

We also measured the number of clicks per hour (ClickpH) using SIMADES ATC UI log files. Overall, ClickpH was lower in DAC conditions (2905) than in static conditions (3187), which supported workload findings reported by controllers. However, ClickpH may be influenced by UI and problems that have occurred. In the post experiment questionnaire, controllers were asked to describe the mental effort related to different tasks, such as multitasking, planning, decision making and building and maintaining situation awareness on a scale from 1 (easy) to 10 (difficult). Median values (MED) for all conditions were around 5 In the interviews, we asked controllers to elaborate on their workload during the experiment. There were no differences between workloads reported in the questionnaires and in the interviews. Participants reported that their workload was the same as during a normal day at work. We also asked them to describe situations when workload peaks occurred. For the static condition, workload peaks were related to high traffic and coordination.

Controllers reported that coordination/handover was sometimes postponed if workload was high before a sector change (DAC conditions). Further, they reported that if workload was high, the visualisation presenting the coming change repeatedly could be a distraction. Controllers suggested that changes should be made when workload was low. They said that the chances of making mistakes in coordination are higher if changes take place when workload is high. One controller said that workload was more balanced during the DAC session but was not sure if this was due to DAC or because he felt more confident during the experiment. One controller reported periods of low workload, as the sector area was small, and traffic was well separated.

B. *Human error*

In interviews, participants were asked about errors they made while controlling traffic. Reported errors were mostly (four of five) due to the simplification of the prototype's UI or due to fatigue. One controller reported an error related to the DAC UI. He reported sending one flight to the wrong controller. The controller missed part of the new sector because of an earlier zoom and only realised this when workload decreased. He suggested having an automatic zoom after a sector change if some parts of the new sector are outside the visible area.

C. *User interface acceptability*

Participants gave the following the feedback on DAC-2D and DAC-3D:

- The presentation of sector changes was good. The colours were clear and easy to differentiate. A legend would help. Participants were always aware of the borders of their sector. Both horizontal and vertical changes were well presented.
- Presenting new sectors with a solid line was good. It was easy to visualise new sectors. One controller proposed that all sector borders on the same level band should have solid borders, while the others have dashed, and the current sector should have a different colour.
- It was good to have different colours for old and new sectors.
- The toggle button was useful and used frequently. Participants could toggle to see the new sector when workload was low.
- Reminding controllers about changes (10, 5 and 2 minutes before the change) was useful but could be distracting.
- Controllers said that a 15 minute notification of sector changes was ok for planners and supervisors, but some controllers said that it might be too long for executive ATCOs. It was enough time to be familiar with the new sector.
- Generally, participants were positive about using a second screen to view vertical changes in DAC-2D. Presenting which flight levels (FLs) were within a controller's sector was useful. Some suggested that the screen should be smaller, and some suggested that vertical changes should be presented on the radar screen with the possibility of turning them off. In DAC-3D, reception of the 3D visualisation was mixed, and in general, it was only used occasionally, mostly during periods of low workload. Most ATCOs suggested possible enhancements to both 2D and

3D variants, for example, they proposed that the 2D side view should be shown with the 3D visualisation.
- Understanding the sectors of other controllers, including flight levels, after changes was poorly supported. Controllers could not see the whole picture and solved this by looking at each other's screens.

D. *Communication burden*

Results showed ATCOs' ability to perform communication tasks using DAC. Communication burden was measured by the number of messages per hour (MesspH). First, audio files were transcribed by a professional. The number of messages (NMess) was counted automatically using the 'find' function in Microsoft Word. In total, the number of messages per hour was smaller in the DAC-2D condition than in the static condition (1274 messages for Sessions 1, 2 and 3 versus 1227 messages for Sessions 4, 5 and 6).

In interviews, controllers reported that communication with pseudo-pilots and other controllers was fine. Communication was clear with no problems, and everybody knew what was happening. All but one controller said that the communication burden was the same for all conditions. The controller explained that there was more communication during sessions with the dynamic approach and that the lack of phone communication with other controllers made it more complicated.

E. *Situation awareness*

Results showed ATCOs' ability to maintain good situation awareness when working with DAC. Participants were asked to report their situation awareness on a scale from 1 (not acceptable) to 10 (very good). The median (MED) situation awareness was the same for directly comparable sessions. It was very good (9) in Sessions 1 and 5, good (8) in Sessions 2 and 4 and good (8) in Sessions 3 and 6. The MED was 8 in both DAC-3D sessions. The MED and minimum (MIN) for SA (good/8 and reduced/5, respectively) were the same for SAC-2D and DAC-2D, while the MED and MIN were both 8 for DAC-3D. Maximum (MAX) SA was higher for the static condition than for the dynamic one (10 for SAC, 9 for DAC).

F. *Acceptability of the DAC approach*

Results showed good ATCOs acceptance of the approach. Acceptability was assessed using a post-run questionnaire. Participants were asked to answer two questions about the system as a whole on a scale from 1 (completely disagree) to 10 (completely agree). The first question was about the suitability of the tools, functions and information presented by the system for tasks ATCOs should perform. The second was about their overall confidence in the system as a whole. Acceptability was good (6) for all conditions. Overall confidence in the system was at the same level (6 or 6.5) for all conditions.

Findings were confirmed by interviews. Participants were asked open questions about working with the proposed system and the dynamic approach. All participants said that the approach, proposed procedures and the way information was presented were suitable for their work and potentially beneficial. They said that the DAC approach could be useful for achieving a better distribution of workload among ATCOs (splitting a sector with lots of traffic, for example) and would help supervisors and planners with their jobs. They also emphasised the importance of good training and clear working procedures. We asked controllers what they thought about sectors used during the experiment in the DAC approach. Although they were satisfied with the changes overall, they said that in some cases, the layout of the new sectors was not optimal. Some planes crossed into another sector for a very short period of time, which caused unnecessary work.

VI. DISCUSSION

As outlined in the introduction, the use of DAC for ATCOs may add to their workload and introduce an additional burden on ATCOs' situational awareness. However, an important goal of using DAC is to balance workload between ATCOs and level it for each ATCO over time. Results from both parts of the experiment showed small differences between conditions regarding workload, situational awareness and performance. Furthermore, additional burden on ATCOs' situational awareness was present, but this was acceptable or was compensated by having a more balanced workload. The experiment identified two critical factors for the success of DAC: how sector changes are executed and an understanding of the implications of sector changes for traffic. Both of these factors underlined the need for good procedures, which may need to be changed when DAC is introduced.

A. *Execution of sector changes*

Regarding how sector changes are executed, the experiment showed that timing is essential. Having sector changes as often as every 30 minutes worked fine, and the notification scheme seemed appropriate with some adjustments. However, more effort is needed regarding when sector changes are performed. For some sectors, some changes occurred in periods of high workload. Ideally, re-sectorisation should happen when workload is low, but this is difficult to achieve for all sectors, as the main reason for re-sectorisation is to balance workload. However, it should be avoided during periods of high workload, and to succeed in this, the DAC algorithm should take into account and align with the forecasted workload of controllers at the moment of change. Having a fixed interval between sector changes was less important than fine tuning the timing to periods when no ATCOs were experiencing a high workload.

User interface mechanisms in both parts of the experiment were successful in helping ATCOs understand the existing and new layouts of the sectors they controlled. Most ATCOs experienced challenges in understanding the layout of the rest of the sectors after a change. Such understanding is particularly important for neighbouring sectors. To some extent, the 2D view made it possible to understand horizontal changes for neighbouring sectors, but understanding vertical changes was also important. The 3D visualisation of airspace was meant to aid this understanding, but to succeed in this, the 3D visualisation needed additional information and functionality not available in the prototype. Furthermore, some ATCOs did not use the 3D visualisation very much. As this visualisation was quite different from the tools ATCOs used in their daily work, it is possible that training needs for this part of the prototype were underestimated. As such, with more training, this part may have enhanced ATCOs' understanding of neighbouring sectors. In addition, some participants suggested showing the 2D side view of the airspace and the 3D visualisation simultaneously.

B. *Implications of sector changes for traffic*

When sectorisation changes, some traffic must be handed over to a new sector. Domain experts at Milan ACC made detailed procedures for how these flights were to be handled in different conditions, and these procedures were an important part of the training material for ATCOs participating in the experiment. During the experiments, ATCOs were able to manage traffic when sectorisation changed, and security was maintained. Despite this, during interviews, ATCOs said that they needed to make more effort to maintain an understanding of the traffic they controlled than in normal operations.

This problem had at least two causes. First, needing to hand over a number of flights at the same time as trying to understand how sectors have changed increased mental strain for the ATCOs. Second, as the shapes of new sectors were unknown, ATCOs were not able to determine whether a flight was in or would soon enter their sector as easily as in normal operations. The main challenges related to this were related to the vertical size of sectors.

This raised more general issues regarding the use of a research prototype for such an experiment. To make the implementation of the prototype manageable, functionalities to include were prioritised by domain experts at Milan ACC. Some functionalities were excluded, such as a sector flight list and having a special colour for flights anticipated to enter a sector. The exclusion of these functionalities was based on ATCOs' tacit knowledge about sectorisation, which means they can easily identify flights anticipated in their sectors. These functionalities, therefore, were not critical in daily operations. During the experiment, when sectorisation was dynamic, ATCOs were no longer able to do this as easily, so they missed this functionality.

C. *Possible enhancements for managing DAC*

In the discussion above, we identified different means for providing better support for DAC, including enhancing 2D and 3D visualisation and functionality, combining the 2D side view and the 3D view of airspace and providing better support for identifying current and anticipated traffic when sectorisation changes. In addition, a more radical approach may be used to support DAC operations. Dynamic changes cause additional burden on ATCOs' situational awareness, which may require tools to relieve their workload and situation awareness needs. Increasing the level of automation and providing better tools for conflict detection and management are two approaches for this. Furthermore, the quality of the DAC algorithm is important in this context. More clever sector changes may reduce the demands of handover, both in general and by reducing the number of flights that need to be handed over when sectorisation changes. In addition, an important criterion for future DAC algorithms is that they can produce sector layouts that are visualisation friendly, and through this, are 'natural' and easy to understand for ATCOs.

One may speculate on how dynamic DAC will be in the future, when it has been in operational use for some time. As traffic has certain patterns, and these patterns occur regularly over days, weeks and seasons, over time, a DAC algorithm may reproduce more or less the same sectorisations. For ATCOs, this will mean that sectors will not change into completely unknown configurations. Rather, they will change into one of a limited number of sector configurations. If this happens, then ATCOs will build tacit knowledge about different sector configurations, and as a result, the needs for special support in the CWP for sector changes will decrease.

VII. CONCLUSIONS AND FUTURE RESEARCH

We have conducted the first experiment in which DAC was tested with ATCOs. The main goal of the experiment was to assess the overall acceptability of DAC. In addition, we investigated how different user interface mechanisms aided ATCOs. To conduct the experiment, we extended and enhanced SINTEF's SIMADES ATC prototype to support DAC. To assess the acceptability of DAC and the effect of different user interface mechanisms, the experiment was split into two sections with three conditions, all tested with executive controllers from Milan ACC.

The main finding of this experiment was that DAC was acceptable to ATCOs, both subjectively and based on measures of human performance, operational feasibility and security. ATCOs reacted positively to using the DAC solution and to the proposed UIs, which they provided suggestions for improving. When comparing SAC-2D and DAC-2D conditions, there were no significant changes in workload, situational awareness or performance. This was also the case when comparing DAC-2D and DAC-3D conditions, even though the 3D part had a mixed reception and was used less than the 2D parts of the system. Despite the positive reception of DAC, certain challenges were reported and observed during the experiment.

In future work on DAC and its supporting UIs, it will be important to address ATCOs' understanding of vertical changes and the layout of neighbouring sectors. This should be done by making sectorisation easily understandable and using enhanced 2D and 3D visualisations. Related to this, the timing of sector changes must be coordinated with ATCO workload to avoid sector changes when workload is high. The experiment also indicated that functionality and timing should be different for executive controllers than they are for other roles, such as planners and supervisors.

The experiment also emphasised that during the introduction of DAC, ATCOs need tools to help them understand anticipated traffic and how it changes when sectorisation changes. This may partly be supported not only by clever UI solutions but also through the DAC algorithm itself by making sector changes that minimise traffic changes for each sector. In our future research on DAC, we plan to improve DAC solutions by proposing new algorithms with more flexible timing and enhanced sectorisation and by making enhancements to the UI of the CWP. In addition to enhance 2D and 3D visualisations and functionality, we plan to extend the CWP with automatic speech recognition.

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