INFORMATION SUPPORT FOR AIR TRAFFIC MANAGEMENT IN THE SUPERSECTOR:

COLOR SATURATION CODING OF AIRCRAFT EFFECTS ON AIR TRAFFIC CONTROLLER PERFORMANCE [1]

Ms. Liza Tam, Dr. Kevin M. Corker

San José State University, San José, CA.

Dr. Vu Duong

EUROCONTROL Experimental Centre

Abstract

The increasing demand on airspace capacity requires researchers to examine methods of accommodating a greater number of aircraft operations within a given volume of airspace without sacrificing safety or overburdening the air traffic controllers. We examined an ATM concept under development in the Innovative Research Area of the EUROCONTROL Experimental Centre (EEC) called supersector operations. The supersector is the first step towards the EEC's Sector-Less1 concept and includes operational procedures that redistribute controllers' roles and responsibilities. These include redistribution of effort between a tactical controller for short-term in-sector control and a planning controller for management of traffic flow and intersector operations. We undertook an investigation to enhance information delivery to the tactical controller in the supersector. Aircraft altitude information was indicated both in the datablock (alpha-numeric) and by color saturation of the aircraft on the radar display. We also compared the performance of controllers working in the supersector versus a current – day sector. The results fall into these two categories: first the results indicate that the supersector operational concept to be beneficial under high traffic density conditions, and second, the color-saturation coding of altitude alone did not yield statistically significant results but did provide a trend toward improvement under. Avenues for future research are proposed.

Introduction

Through the dual pressures of increased passenger operations increased reliance on air cargo the volume of continues to rise, air traffic over European skies is set to expand to unprecedented levels. Each year, the number of aircraft operations over Europe continues to rise [1], while aviation authorities search for workable technologies and procedures to support this growth [2-5].

Perhaps, the greatest challenge to accommodating more aircraft operations is the ability of the air traffic controller and flight crew to safely manage a growing number of aircraft in a finite airspace. Even though sophisticated communication, satellite and navigation technologies supply information to controllers and pilots, ultimately, it is the human operator must take this information and make safety-critical decisions in time-constrained situations. Air traffic management difficulty of handling traffic has been shown to depend on three factors: airspace complexity, air traffic density (including number and complexity of aircraft trajectories) and the information available to the controller manage that complexity .

[1] The work reported here was supported by a research grant from the Innovative Research Unit of the EEC to the San Jose State University Human Automation Integration Laboratory. Dr. Vu Duong and Mr. Gilles Gawinowski are the technical monitors of this grant.

Quantifying and comparing the complexity of air traffic is a complex task. Delahaye and Puechmorel [6] and Histon and Hansman [7] measured airspace complexity with physical factors, such as the type and number of aircraft in a sector, the shape of a sector, the array of trajectories, entries and exits and the structure of sectors. Alternatively, Pawlak, Bowles, Goel and Brinton,[8] and Morrow-Magyarits and Kopardekar [9] measured complexity by the cognitive and physical workloads imposed on controllers. Despite the lack of uniformity in measuring airspace complexity, it is generally agreed that traffic complexity is contributory to controller workload and therefore, efforts to reduce controller workload should logically focus on reducing traffic and airspace complexity.

In an effort to safely increase airspace capacity, many procedural changes and operating concepts have been proposed [4, 5, 10]. These concepts, through new technologies or operating procedures, aim to reduce or redistribute controller responsibilities. Along these lines, the Innovative Research unit at EUROCONTROL Experimental Center (EEC) proposed an operational concept, dubbed the *supersector*, that restructures both the operating procedures and architecture of the current airspace [11]. This concept is aimed at simplifying the array of airways and operating procedures needed to safely and efficiently manage air traffic.

The supersector concept

Current operations require communications between pilots and controllers as they enter and exit any sector. As the controllers' workload in a sector reaches capacity, the size of the sector is reduced and divided, to enable the workload to be shared. What results is a cyclical reduction of sector size due to an increasing workload. Eventually, the reduction in sector size reaches its physical limitations, making it impossible to reduce the size of a sector any further. As a result, the distribution of workload and sector design need to be carefully considered if the airspace is to safely and efficiently absorb more aircraft operations in the near future.

The supersector operates between flight levels 19 500 to 34 000 feet and focuses on the area over the north-west of France and integrates the airspace of six to eight current day sectors. Investigations into the viability of the supersector is part of an initial exploration of the EEC's SectorLess – 1 concept [11].

An innovation of the supersector is the redistribution of air traffic management (ATM) roles and responsibility. Under the supersector, ATM consists of two four – person air traffic control (ATC) teams who share responsibility for traffic management. One team manages the north and east bound traffic while the second team manages the south and west bound traffic. In each team, three members' roles are based on the expected arrival times of incoming aircraft; set at 15, 10 and 5 minutes out from the sector boundaries. The fourth team member, the tactical controller, manages the traffic within the supersector. The experiment described here focuses on the performance of the tactical controllers who manage the traffic within the supersector.

Converting from the current day operational procedures to an, as yet, unproven airspace concept, is potentially rife with unforeseen consequences. Research and testing of new operational concepts under different environmental and operating conditions are therefore essential.

Decision-support Technologies

To aid operators – both pilots and controllers – in coping with fluctuating workloads and decision-making responsibilities, the air traffic management is becoming increasingly reliant on automation and decision-support tools. However, despite the sophisticated technological capabilities, decision-support tools can have secondary, unintended, and potentially deleterious impact on operators' performance. The introduction of automation aiding and procedural changes in air traffic management impact not only the task at hand but also the information that is required to support the new tasks. The human-centered design process must consider both the changes to the process and the subsequent changes to the information requirements in the new tasks. We attempt to address both of those factors here.

A controllers' mental picture of the airspace is primarily based on the information on the radar display. For a controller, the text information that pertains to aircraft altitude is critical for maintaining legal separation since aircraft are displayed on the radar screen in a two-dimensional plan view. In today's control centers, controllers receive aircraft altitude information from the datablock. To decide on the likelihood of conflicts arising, perhaps from aircraft climbing through several flight levels or crossing traffic, controllers must first read the text information from at least two datablocks and then compare them. Additionally, the controller may also have to do mental arithmetic to ensure legal separation while scanning the radar screen for other possible incursions. Scanning, reading and then mentally calculating differences in aircraft altitude takes time as well as cognitive effort. More significantly, it leaves the controller vulnerable to errors when reading numbers or doing mental arithmetic. The color-saturation coding of altitude information is therefore proposed as a salient and immediate mode of delivering safety-critical information.

Color -saturation coding of aircraft altitude

Advancements in computer display technology provide an opportunity to increase the efficiency of information delivery to operators whose responsibilities demand both speed and accuracy. The greater availability of colors and the improved resolution of graphics allow display designers to exploit technological capabilities and deliver decision-support information more efficiently and effectively. However, the difficulty of designing appropriate and effective displays is compounded by the dynamic and complex nature of air traffic control. Therefore, efficiency in information delivery becomes an important criterion when working on a radar screen that has a tendency to display both information and clutter.

Two uses of color were manipulated in this study. First, color was used in the supersector operation to indicate the aircraft that were the particular responsibility of a given controller in the sector. This color coding manipulation was considered part of the examination of the supersector operational concept. Second, the use of color-saturation to compare the altitudes of aircraft was designed to increase the efficiency of controllers' visual searches. Conflict pairs would be quickly identified by finding targets displayed in the same color.

The perception of color is based on the interaction of light waves with chemicals in the visual system. Humans can identify roughly nine colors on an absolute basis and distinguish among twenty-four colors when properties such as saturation, luminescence and value are manipulated [12]. Hence, the wide range of perceptually distinguishable colors presents a strong medium for enhancing the efficiency of information delivery. In this experiment, color is used to code information in the supersector in two ways. First, different hues (green and blue) convey which controller is responsible of each aircraft. Secondly, the saturation of the hue is used to convey the aircraft altitude relative to another aircraft.

Saturation is the purity of a color relative to its brightness. In this experiment, coding is based on a system whereby saturation decreases (colors appear lighter) as an aircraft climbs to higher altitudes. Semantically, this coding system can be used to associate the darker saturation of colors (e.g., green aircraft to the dark green of foliage and landscapes. or dark blue reminiscent of the ocean). As altitude increases, the saturation of the color associated with an aircraft display that becomes lighter.

Redundant color-coding in the aviation domain is a well-documented area of research, although much of this work has focused on its application in the design of cockpits displays [13-15].

The following hypotheses were tested with a human-in-the-loop simulation:

1. Color-saturation coding of altitude results in earlier conflict resolution, fewer conflicts and a reduction in controller workload than if altitude information were only presented as alphanumeric text in a data block.

2. Operations under a supersector will reduce controller mental workload, yield earlier conflict resolution and fewer potential conflicts when compared to the current - day sectored airspace.

Method

Participants

Ten participants were recruited for simulations that lasted one day. Seven participants were active working as air traffic controllers while three participants were retired. None of the participants had color vision problems. All participants had at least 2 years working experience as an en route controller in the radar capacity. All the participants were paid for their participation.

Simulation

A computer simulation displayed aircraft in a plan display airspace. We performed an experiment testing performance under two types of airspace (the supersector and a current-day sector with current operating procedures called the Uniform Juliet (UJ) sector), two levels of traffic intensity (medium and high) with and without the presence of color-coded altitude, yielding a 2x2x2 fully crossed analytic design.

The computer program was written so that every 7 seconds, the computer scanned for potentially conflicting aircraft pairs up to 5 minutes into the future. These were conflict pairs were logged and used for data analysis.

Two participants simultaneously controlled the traffic in the simulation. Each controller was linked to a pseudo pilot through microphones and headphones so that controllers and pseudo pilots observed the same traffic in real time. When operating under supersector procedures, the participants shared management of the traffic. Alternatively, when managing traffic in the UJ airspace, participants managed all the traffic traversing through their airspace.

Display

Aircraft were represented on the screen by solid colored triangles equal to 40 minutes of visual arc when the participant was seated 50cm away from the screen. The screen display of each aircraft was called a *target.*

The Red-Blue-Green (RGB) values of the colors were selected from the Munsell color system [16] so that all colors were psycho – perceptually spaced one step apart. With color-saturation coding, aircraft in the blue hue had five values while the aircraft displayed in the green hue had six values.

Without color-saturation coding, the participants identified the aircraft under their responsibility by the hue of the targets. That is, the saturation levels of the blue and green were absent but the hue of each traffic set remained. However, in the UJ airspace, all the aircraft were displayed in green. Thus when color-saturation coding was present in the UJ airspace, six levels of green were used to code altitude. Datablocks were always displayed with white text and linked to all targets by a thin, white leader line.

Procedure

Controllers were given as much latitude as possible so to simulate a realistic operation. The participants were told that they could reroute aircraft, by giving pilots 'fly-direct' instructions and could ask pilots to temporarily vector for traffic. The participants could also direct the pseudo pilots to change the altitude of an aircraft and adjust aircraft speeds.

In the supersector scenarios, the participants were required to share responsibility for the traffic in the sector, as described in the EEC's operational concept document [11]. When the controllers managed traffic in the UJ airspace, they operated independently of one another since they were managing the same traffic and airspace scenarios simultaneously; this could be likened to two controllers managing the same traffic in a 'parallel universe' situation.

Participants were briefed and given 45 minutes of practice on each type of airspace. In both practice scenarios, the color-coding condition was turned on. The data-collection scenarios were run in a random order so to avoid order effects. Each data collection scenario lasted for 30 minutes.

Dependent Variables

Subjective workload ratings

Individual subjective estimates were provided during the simulation using a small box appeared on the top right hand corner of the screen every three minutes during each scenario. Participants were given 20 seconds to with a workload rating between 1 (*low*) and 9 (*high*). A rating of 10 could not be manually entered since this implied the participants were at their maximum working capacity. Without any response, the computer entered 10 as a default score.

Time before conflict

The computer detected aircraft pairs in potential conflict paths and timed how long the participant had until a conflict; defined as an incursion of legal separation. It counted down until either the potential conflict was averted, or a violation of legal separation occurred.

Number of Actual and Potential conflicts

The algorithm that counted down toward a conflict also allowed us to count how many potential conflicts and actual conflicts occurred.

Number of actions taken in each scenario

We recorded the number of actions taken by each controller as an objective measure of workload. This included the number of mouse clicks, the number of times datablocks had to be dragged, the frequency of checking aircraft routes and vectors, zooming and panning over the map as well as amending the aircraft datablocks

Independent Variables

Participants' performances were manipulated using three independent variables, each at two levels.

First, participants handled aircraft in two types of airspace operations, the supersector and the current day procedures of the UJ airspace. In the supersector, the participants shared one large sector and divided responsibility based on aircraft trajectory. Each controller handled the traffic heading in one direction.

The second type of airspace was that of a current sector and was based on the Uniform Juliet (UJ) sector located in south-east France. The UJ sector was approximately one-sixth of the size of the supersector and each controller managed all of the traffic traversing the sector.

We compared performance with and without the color-saturation coding of aircraft altitude. Aircraft were designated altitudes depending on their heading.

The second independent variable was traffic load. Two levels of traffic intensity, high and medium, were used to assess the sensitivity of changes in performance based on traffic density conditions. The levels of traffic were based on current mid European traffic densities associated with the Uniform Juliet and surrounding sectors. Traffic complexity is a function not only of the number of aircraft in a sector but also on the trajectory patterns and interactions of those aircraft, and since the super sector operation by design increased the size and traffic load in an area the absolute number of aircraft in a sector is not a good metric for complexity. Two other methods, one computational and one based on subject matter expert opinion, were used to calibrate the sector load levels. However, for reference to current sector operations, the "medium" traffic involved approximately 20-25 aircraft in the current operations mode and 40-45 aircraft in the supersector mode. The "high" density mode consisted of approximately 35 aircraft in current operations and 65 aircraft in supersector operations.

Results

Actual Conflicts

There were no conflicts in during supersector operations under all conditions. The scenarios in the UJ sector, resulted in several conflicts with the number of these increasing as a function of increased traffic load. Color-saturation coding had no significant effect, $F(1,9) = 2.561$, _ = 0.144, on the number of conflicts across all conditions. Under medium traffic, the supersector yielded significantly ($F(1,9) = 18.00$, _ = 0.002) fewer conflicts than in the UJ airspace. This difference was amplified in the high traffic condition,; the supersector yielded significantly fewer conflicts, $F(1,9) = 44.655$, _ < 0.001. (see figure 1).

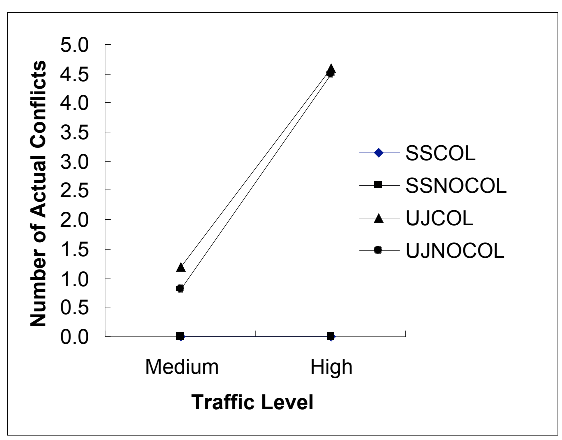

Figure 1. Mean Number of Actual Conflicts

Potential Conflicts

Potential conflicts were defined as aircraft pairs that were within 5 minutes (based on current trajectories) of breaking minimum separation standards.

Operations in the supersector resulted in a significantly fewer number of potential conflicts, F(1,9) = 252.203, _ < 0.001. as compared to UJ sector operations. There was also a significant (F(1,9) = 102.402, _ < 0.001) two-way interaction between airspace and traffic levels. (See figure 2). Suggesting that the increase of traffic load had a differential and significantly larger impact on current than on supersector operations.

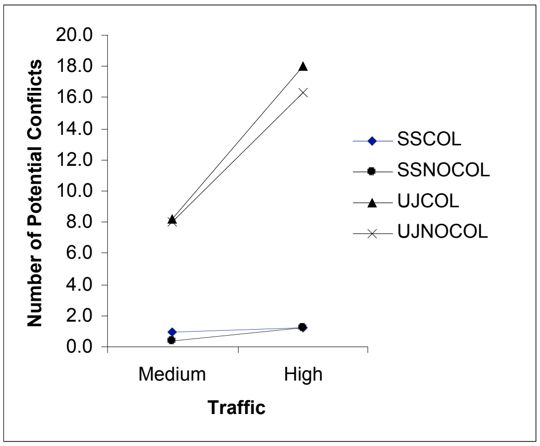

Figure 2. Mean Number of Potential Conflicts

Conflict Resolution Performance

Overall, potential conflicts were resolved significantly (F(1,9) = 7.224, _ = 0.025) earlier in the supersector airspace than in the UJ sector. (See figure 3). The calculation of time-to-conflict is a measure of how long before a potential conflict, that a situation was safely resolved. Hence, an earlier or longer time-to-conflicts could be construed as more desirable when controlling traffic.

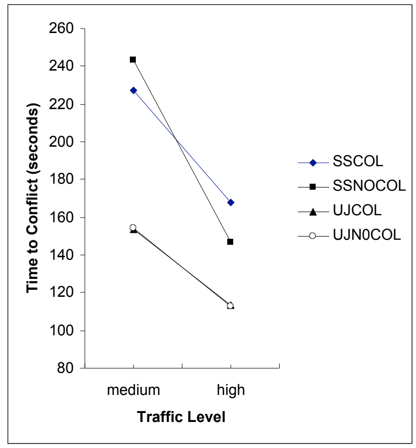

Figure 3. Mean time before conflict that a situation was resolved.

Under medium traffic, the supersector provided significantly better performance (F(1,9) = 15.601, _ = 0.003) but under high traffic, the type of airspace did not have any significant impact on conflict resolution time (F(1,9) = 1.588, _ = 0.239). This lack of statistical significance was due to the high standard error in the data collected.

Without color-saturation coding, the type of airspace control only moderately affected performance, F(1,9) = 4.889, _ = 0.054. However, with color-saturation coding, the type of airspace and traffic level each had a significant impact on performance. The supersector with saturation coding produced significantly better performance, F(1,9) = 6.203, _ = 0.034, than saturation coding in the UJ airspace.

Number of Actions Taken

Analysis of the number of actions taken found no significant main effects across conditions. However, a significant three-way interaction surfaced, F(1,9) = 5.445, _ = 0.044.

An analysis of simple main effects suggests that under high traffic conditions, participants used significantly fewer actions when working in the supersector, F(1,9) = 27.995, _ < 0.001 and that effect was amplified by the availability or color-saturation coding However, under medium traffic conditions, there was no significant difference in performance based on either the traffic conditions or the color-saturation coding condition.

Subjective Workload Ratings

Operations in the supersector across conditions yielded a significantly lower subjective workload rating, F(1,9) = 19.136, _ = 0.002 when compared with UJ sector operations. As would be expected medium traffic resulted in a significantly lower workload rating, F(1,9) = 27.692, _ = 0.001, than operations under a high traffic condition across conditions. A two-way interaction between airspace and traffic level was also found to be significant, F(1,9) = 12.193, _ = 0.007 indicating that workload impact of traffic density was different across operating conditions.

Discussion

Although investigations to explore the viability of the supersector procedures are in a preliminary stage, the experimental results here point to the strong potential of this operational concept. The most striking and consistent finding was the marked and significant improvement in performance in the supersector compared to performance in the current – day airspace across traffic conditions. In contrast, the color-saturation coding of aircraft altitude did not produce any significant main effects. Although the three-way interaction of traffic levels, type of airspace and color-saturation coding on the number of actions taken strongly suggests that color-coding of aircraft altitude deserves further attention.

Actual & Potential Conflicts

The absence of actual conflicts in the supersector airspace condition is a positive indication that the division of responsibility for traffic in a larger airspace could provide controllers with a concept capable of absorbing the growth of air traffic. By dividing the traffic management responsibilities into two hues, participants reported that it was easy to quickly identify 'my own' aircraft. Additionally, the single direction of the airways meant that only one controller managed each airway and the only time to negotiate with the other controller was at crossing points and times when a controller wanted to use an altitude assigned to traffic moving in the opposite direction.

The contrast in performance can be explained by the differences in the structure and physical characteristics of the two airspace as well as the redistribution of responsibilities. Firstly the greater area of the supersector enabled the participants to vector and reroute aircraft direct to waypoints and reduce the traffic volume in the congested areas of the airspace. It also enabled the controllers to have more alternatives when looking for strategies to manage traffic. Secondly, the greater area also resulted in a longer look – ahead time in which to detect and resolve conflicts. This, compounded with the larger area enabled the participants to better strategize and prioritize tasks.

Interestingly, the ability to detect and resolve conflicts evolved differently as a function of airspace type and traffic intensity. Although the number of potential conflicts in the supersector rose statistically significantly with higher traffic intensity, the actual mean number of conflicts represented by this rise was not large (from .5 o 2). This demonstrated that despite a significant rise in the intensity of traffic the supersector could well absorb a significantly greater number of aircraft without the expected rise in conflict pairs.

Although color-coding did not have a statistically significant positive main effect on performance, it did result in observably poorer conflict detection performance under medium traffic intensity. These results under the medium traffic condition support the findings of Stager and Hameluck, [17] and Stager, Hameluck and Jubis, [18] whereby the number of operational errors tend to increase under low to moderate workload. The redundant color coding may have offered a false sense of security that amplified the tendency to be less vigilant under moderate workload conditions. This possibility warrants further investigation.

Time to Conflict

The supersector airspace produced significantly earlier conflict detection compared to the UJ airspace. However, under high traffic intensity, the supersector did not produce significantly better performance. This was probably due to the large standard error under the supersector condition. Nonetheless, the results reflected a consistently earlier conflict resolution time in the supersector condition during high traffic.

We speculate that the lack of difference between the color conditions in the UJ airspace suggests that the small size and short look-ahead time of this airspace leaves the controller in a time-critical decision making state; such that the introduction of any decision-support aid is unlikely to yield much improvement in performance.

Modes of Control: Theoretical Framework

In Hollnagels' model of supervisory control [19], the situation where a supervisor is unable to strategize in a medium or long-term context and where each action is decided by the current situation, is called *opportunistic control*. Under opportunistic control, information and decisions are drawn from salient current information rather than planned goals. With increasing workload, reduced availability of information and time demands, the level of control is reduced.

Hollnagel argued that control happens on four levels. The most efficient and desirable level of control, called *strategic control* is one where the operator is able to draw information from a broad range of sources with a wide event horizon. This type of control allows the supervisor to prioritize tasks and plan actions well ahead of time.

Tactical control is control with a moderate amount of planning, with a reduced look-ahead time and the experience of the operator guides expectations and decision-making performance.

The next level of control is called *opportunistic control,* while the most frenzied and unpredictable type of control is called *scrambled control*. This refers to situations where controllers' behaviors and order of events are stochastic.

In the UJ sector, we saw that heightened traffic density resulted in the marked increase in actual conflicts. Additionally, the narrow event horizon and the lack of time to formulate any strategy, lead us to describe operations in the UJ sector as being opportunistic control. In contrast, operations in the supersector resulted in only a small rise in potential conflicts and no actual conflicts were observed. The earlier conflict resolution in the supersector and the long look-ahead time meant the controllers had the time and adequate information to formulate a series of conflict resolution and task prioritization plans and engage in strategic control.

This marked difference in the levels of control is of significant importance for formulating and assessing operational concepts. To enable controllers to engage in strategic control has numerous advantages, some of which include the ability to delegate tasks well ahead of time, the ability to better organize traffic patterns, workloads, responsibilities and aircraft movements. Additionally, strategic control of airspace allows both pilots and controllers to work more efficiently. Based on the modes of control, the supersector seems to provide a level of strategic control that is two 'steps' ahead of the current sector design. However, these claims have to be qualified by further investigations of the concept and the integration of the other controllers' roles in the working of the supersector. The experiment here only tested the performance of the tactical controller in the supersector.

Workload

The subjective workload measures indicated a two-way interaction between the type of airspace and traffic levels. As traffic intensity grew, subjective workload in the supersector airspace moderately increased while under the UJ airspace, subjective workload ratings escalated sharply. Hence, differences between operational concepts and their effects on controllers' subjective workload do not become apparent until the traffic intensity heightens.

With color – saturation coding, there was also a two-way interaction between the type of airspace and traffic levels. As expected, in the UJ airspace, the transition from a medium to high traffic intensity resulted in a sharp rise in the number of actions taken (as an indicator or workload). However, the reverse happened in the supersector airspace; there was a noticeable drop in the number of actions when traffic intensity increased. This was a surprising result considering that there were more planes in the airspace and more conflicts to resolve.

Since the area of the supersector is six to eight times greater than the UJ airspace, there were markedly more targets and datablocks to monitor. Additionally, the controllers could not afford to zoom in closer or they would lose the displays of aircraft on the edge of the sector. The only aid they had for detecting potential conflicts was the saturation coding. As such, it is possible that visual search, rather than physical actions, became the new strategy for managing traffic.

We suggest that the marked increase in the number of actions in the UJ airspace underscores the transition toward opportunistic control as traffic intensity rose. The number of actions rose with an increasing number of targets since the datablocks needed to be kept uncluttered while information was being sourced and amended. Hence, the increasing need to react to the most salient and immediately available information was reflected by the escalation in actions with increasing traffic.

One of the experimental hypotheses was that operations under a supersector would reduce controller mental workload, result in fewer potential conflicts and yield earlier conflict resolution when compared to the current - day sectored airspace. The supersector not only reduced the number of potential conflicts but also yielded zero actual conflicts. Hence, we take this hypothesis to be proven correct.

Color-saturation Coding

Since the participants were all experienced air traffic controllers, with an average of 15.5 years of experience, searching for altitude information from the datablocks was an automatic reaction. Despite being given two hours of training and practice at the beginning of experimental trials with the color – saturation coding and encouraged to increase their awareness of the color- saturation coding, the tendency to look for altitude information from the data blocks remained entrenched. Since the majority of the participants were active controllers, we had no intention of diverting them from their usual and trained reactions. The best result we could have expected was to have the participants make a conscious effort to use this new display concept.

The participants did report that as the experiment carried on, they started to use the colors to ascertain the proximity of one aircraft's altitude to any nearby plane. However, confidence in the saturation coding system waned as aircraft approached higher altitudes. This was due to difficulties in seeing differentiating between colors bearing little saturation; the targets with higher altitudes started to blend into a near white color.

Debriefings with the participants indicated there was interest in the color-saturation coding display, but controllers agreed that years of training and experience had biased their reactions to the altitude information and all found themselves immediately looking for altitude information from the datablocks. Under high traffic intensity, the participants reported they mainly used color for identifying which aircraft were under their control.

More salient color differentiation and a participant pool that is less inclined to source altitude information from datablocks may prove color-saturation coding useful.

Airspace

Participants generally regarded the division of responsibility in the supersector airspace with a positive attitude and the problems found in each scenario were regarded as being realistic. The airways provided predictability and made risky areas, such as airway crossing points, more salient than in the UJ airspace. Additionally, the look-ahead time and the controllers' ability to identify 'my own aircraft' based on route and target color elicited positive results for the supersector concept. Although the traffic flow in the UJ airspace did follow a set of routes, the strikingly smaller area and short sector transition time prevented planning and strategic methods of avoiding conflict situations.

Conclusion

Overall, the most noticeable differences in performance were in the scenarios where the supersector was crossed with high traffic. It is in these scenarios that we tested the controllers' ability to manage a higher traffic load with the redistribution of roles and responsibilities. Performance was measured over several dimensions so that analysis of the supersector was based not only on reducing airspace complexity, but also on its impact on airspace safety and efficiency. We postulate that the airspace design and procedural organization enabled the controllers to be more efficient in prioritizing workloads due to the longer event horizon and larger airspace.

References

1. EUROCONTROL, *Air Traffic Statistics & Forecasts (STATFOR): Medium-Term Forecasts of Annual Number of IFR Flights (2002-2009). Volume 2*. 2002, STATFOR: Brussels.
2. Johnson, W., V. Battiste, and S. Belcher. (1998). *Analysis of CDTI Requirements for Free Flight Self-Separation*. Moffett Field, CA: NASA Ames.
3. Boeing. (2002). *Air Traffic Management Working Together Team Phase 1: System Performance Requirements Document* (D780-10010-1).
4. Duong, V., E. Hoffman, and J.P. Nicolaon. *Initial Results of Investigation into Autonomous Aircraft Concept (FREER-1)*. in *1st USA/Europe Air Traffic Management R&D Seminar*. 1997. Saclay, France.
5. Hoekstra, J.M., R.C.J. Ruigrok, and R.N.H.W. Van Gent. *Free Flight in a Crowded Airspace?* in *3rd USA/Europe ATM R&D Seminar*. 2000. Napoli, Italy.
6. Delahaye, D.L.C. and S.E. Puechmorel. *Air Traffic Complexity: Towards Intrinsic Metrics*. in *3rd USA/Europe Air Traffic Management R&D Seminar*. 2000. Napoli, Italy.
7. Histon, J. and R.J. Hansman. *Introducing Structural Considerations into ATC Complexity Metrics*. in *Joint University Program (JUP) for Air Transportation Research Meeting*. 2001. Boston, MA.
8. Pawlak, W.S., A. Bowles, V. Goel, and C.R. Brinton. (1997). *Initial Evaluation of the Dynamic Resectorization and Coordination (DIRECT) System Concept. Final Report for NASA*. (Contract # NAS2-97057). Boulder, CO: Wyndemere Incorporated.
9. Morrow-Magyarits, S. and P. Kopardekar. (2000). *Dynamic Density: The Measure of Air Traffic Control Sector Complexity: Phase I* (Draft Report for the FAA Report No. ASD-130, ATP-400): FAA and NASA Ames Research Center.
10. Van Gent, R.N.H.W., J.M. Hoekstra, and R.C.J. Ruigrok. *Free Flight with Airborne Separation Assurance*. in *HCI Aero*. 1998. Montreal, Canada.
11. EEC. (2002). *Supersector (SectorLess-1) Operational Concept Document* (Document 0.1). Bretigny-sur-Orge: EUROCONTROL Innovative Research.
12. Stokes, A., C. Wickens, and K. Kite, *Display Technology*. 1990, Warrendale, PA: Society of Automotive Engineers Inc.
13. Beringer, D.B., R. Allen, K.A. Kozak, and G. Young. *Responses of Pilots and non-pilots to Color-coded Altitude Information in a Cockpit Display of Traffic Information*. in *Human Factors and Ergonomics Society 37th Annual Meeting*. 1993. Santa Monica.
14. Reising, J.M. and A.J. Aretz, *Color Computer Graphics in Military Cockpits*, in *Color and the Computer*, H.J. Durrett, Editor. 1989, Academic Press, Inc.: Boston, MA. p. 151 - 169.
15. Luder, C., *Redundant Color Coding on Airborne CRT Displays*. Human Factors, 1984. **26**(1): p. 19 - 32.
16. Macbeth, G., *Munsell Conversion Program*. 2001.
17. Stager, P. and D. Hameluck, *Ergonomics in Air Traffic Control.* Ergonomics, 1990. **33**: p. 493-499.
18. Stager, P., D. Hameluck, and R. Jubis. *Underlying factors in Air Traffic Control Incidents*. in *33rd Annual Meeting of the Human Factors Society*. 1989. Santa Monica, CA: Human Factors Society.
19. Hollnagel, E., *Human Reliability Analysis: Context and Control*. 1993, London: Academic Press.

Biography

Liza Tam received her Masters Degree from the San Jose State University. She has a B.A. in Fine Arts from the University of Sydney, Australia and a Bachelor of Industrial Design from the University of New South Wales, Australia. Her research interests are in human-computer interaction in the aviation domain.

Kevin Corker is Professor in the Industrial and Systems Engineering Department, San Jose State University. Dr. Corker's research interests are human-system integration, aero transportation systems and computational representation of human-system performance

Dr. Vu Duong id the Director of the Innovative Research Area of the EUROCONTROL Experimental Centre, Bretigny , France.