Ergonomic Analysis of Different Computer Tools to Support the German Air Traffic Controllers

Muriel Didier, Margeritta von Wilamowitz-Moellendorff, and Ralph Bruder

Institute of Ergonomics, Darmstadt University of Technology,
Petersenstrasse 30, D-64287 Darmstadt, Germany
muriel.didier@iad.tu-darmstadt.de

Abstract. The Institute of Ergonomics of the Darmstadt University of Technology supported the German Air Traffic Control in analyzing how the implementation of new tools influences the work procedures of the air traffic controllers and if a modification of the work structures is necessary. New tools, such as “Data link” (contact with the pilot via an electronic connection), the Problem Display Window and the Main Data Window that replaces the former flight strips, were tested in simulations. The goals of the study were to select the most appropriate investigation method to be used, taking into account the specific features of the controllers’ work, to test different tools in a simulated environment and to analyze the impact of the new tools on the air traffic controllers.

Keywords: ergonomic analysis, air traffic controller, eye movements.

1 Introduction: The Air Traffic Controllers’ Activities

Eurocontrol estimated that the air traffic movements in the year 2015 will be twice as high as in the year 1999. The air traffic has in the last decades and will continue in the future to continuously increase, which has a large affect on Europe. The national organizations have to adapt to the evolutions of air traffic to ensure the high reliability of the air control activities. The German Air Traffic Control (DFS) continuously develops and optimizes the tools, the work structures and the work procedures of the air traffic controllers to cope with the changes in air traffic. One of the major issues when developing new tools or procedures is the understanding of the impact they will have on the activities of the air controllers and their mental processes and to evaluate if the expectations are going to be met.

In this context, the Institute of Ergonomics (IAD) of the Darmstadt University of Technology in Germany supported the DFS in analyzing how the implementation of the new tools influences the work procedures of the air traffic controllers and if a modification of the work structures is necessary.

Air traffic controller activities. Air traffic controllers currently work in a team, consisting of one “planner controller” and one “executive controller”, responsible for one sector. The role of the “planer controller” (also called “planer”) is to monitor the

air traffic in his sector as well as in the adjacent sectors to anticipate the airplane movements in order to avoid conflicts and choose the most adequate flight routes for each airplane. The “executive controller” (also just called “executive”) is responsible to inform the pilots about any route modification in his sector that the planer decided. One sector is not only defined horizontally as a certain part of airspace, but also vertically separating the sky into two slices of “high sectors” and “low sectors”.

To keep up with the increase in air traffic, new tools are regularly tested in simulations to evaluate their influence on the activities of the controllers. This paper will report on the impact of different tools that have been evaluated in the year 2008:

- The introduction of “Data Link” for 35% of the simulated air traffic, which is representative of the expected amount of airplanes using Data Link in the near future. Data link gives the possibility to inform the pilot on his route changes via an electronic connection instead a radio-voice connection. It decreases the number of verbal communication done by the Executive Controller.
- The introduction of a Problem Display Window (PDW). The PDW shows potential conflicts of airplane trajectories on a coordinates system that represents the distance between the airplanes and the time before entering in the predefined safe zone. The main goal of this display is to support the planer when monitoring the future air traffic.
- The use of a Main Data Window (MDW), where all the information about each flight is represented on a separate monitor, replacing the former paper flight strips.

2 Choice of the Investigation Method

The task of air traffic controlling is mainly related to mental activities. Air traffic controllers have to detect the airplanes, analyze their trajectory, plan the near future, make decisions and submit information to the pilots. The main objective is to permanently insure the safety distance between airplanes, but a second objective that receives more and more weight is to support the pilot to choose the optimal trajectory to reduce the consumption of fuels.

Several methods are available to analyze mental activities. Subjective measurements such as self-reports [1], [2], performance measurements [3], body posture/movements [4], objective measurements such as physiological indicators [5] are typical examples of methods often applied to analyze the mental activities. However, some of those approaches suffer partially from limitations in predictive power and general applicability [6].

Another possibility to analyze the mental activities is the recording of eye movements [7]. The eye is a sensory/perceptual organ for gathering information of our environment. Once processed, the collected information is used for further mental processes. The gaze pattern, based on the observation of fixations and saccades (jumps between the fixations), provides information on attention, interest, possible motivations, and intentions. This method, a non-verbal and non-invasive method, is often mentioned in the literature for the collection of information on the mental processes of a subject. Just and Carpenter [8] developed one of the first theories that clearly associated the gaze movements with the underlying cognitive processes.

Fig. 1. Eye tracking system (SMI)

The analysis of the gaze movements has been successfully used in different research fields (air planes, vehicles, usability etc.). The method does not interrupt the activities of the subject and lets the subject move freely. This is a big advantage in comparison to other evaluation methods of the mental processes and especially important for air traffic controllers. But the method also has some limitations, for example, it cannot be guaranteed that looking at an object is systematically followed by the mental processing of this object. However, in the case of the air traffic controllers, the study focuses on the comparison between different electronic tools and their impact on the work procedures and not on a deep understanding of the mental processes. In the case of gazes that are not followed by a processing of the information, we can then assume that they are coincidental and happened at random in all conditions. Additionally, the DFS recorded supplementary data: a simplified version of the NASA-TLX, some DFS specific situation awareness questionnaires, debriefing interviews, log files of the technical simulation parameters (such as number, type, and direction of airplanes).

The eye tracking system. A head mounted eye tracker (from SMI) was chosen, due to the numerous body and head movements of the controllers during their work. The selected system is a helmet equipped with an eye tracking system Figure 1 based on the cornea reflex method.

The output of the eye-tracker is an mpeg video of the regarded scene on which the fixations are superimposed in form of a colored circle.

3 Experimental Set Up

Simulation of air traffic situations. The study took place in the air traffic simulator of the DFS. The room is very similar to a normal control room and the whole electronic equipment is identical to the real workstations. A simulation session lasts between 5 and 10 days, each day between 2 and 3 scenarios, named “runs” (one-hour long simulation scenario), are evaluated. Several runs are used as training runs to insure that the functions and the manipulation of the new tools are correctly understood.

The results presented in this paper are based on one simulation session of 10 days that took place in 2008. During this simulation 20 runs were conducted, 7 of them were training-runs. The main objective of the Institute of Ergonomics of Darmstadt during this simulation session was to analyze the influence of three different tools on the activities of the controllers: Data-Link, Main Display Window (MDW) and Problem Display Window (PDW).

To analyze the use of those tools, two head mounted eye-tracking systems have been set up. This configuration allowed the simultaneous collection of the eye-movement patterns of a working team (“executive controller” and “planer controller”), which increases the reliability and the quality of the analyses. Two test supervisors attended the runs and monitored the eye trackers.

3 Collection and Preparation of the Data

The first step of the analysis consisted in manually encoding the videos with the help of the software “Interact” (from Mangold). The second step of the analysis was performed with a statistical program “Statistical Package for Social Science” (SPSS).

First step: Encoding. The encoding of videos delivers information about the duration, the frequency and the sequence of some pre-defined events. The quality of the analysis is highly dependent on the choice of the event and on the precision of the encoding. Based on the previous experiment and on the specific question of this simulation session the following fixation areas were defined as follows: Radar, PDW, MDW, radar (partner), MDW (partner), Partner, Displays (other controllers), other controllers, radio, phone, notes, NASA-TLX, Miscellaneous Figure 2.

Moreover, some events related to the type of activities were defined: tasks related to control activities or planning activities, and whether they were related to actual or future traffic.

Fig. 2. Work place of an air traffic controller with pre-defined fixation areas for the encoding

Second step: Statistical analysis. In such simulation sessions, the number of subjects (between 8 and 14) as well as the number of trials (between 20 and 60) is greatly reduced, due to the availability of the simulation infrastructure and personnel. Moreover, a controller is qualified only for a group of sectors, which reduces the number of potential subjects. These limitations explain why only descriptive statistics were performed for the analysis and some results need to be confirmed in further investigations. However, past experience has shown that analysis performed in such simulation sessions is very valuable in the development and improvements of the working place of air traffic controllers.

4 Results

Before presenting the results some explanations on the meaning of some analyzed variables are needed.

It is necessary to distinguish the control activities and the planning activities during the use of the Air Situation Window (ASW or radar). Control activities are tasks that modify the course, the altitude and the speed of an airplane (e.g. activation of labels menu). The controller actively modifies the airspace configuration. The planning activities consist of the tasks that serve the generation of information and the development of alternative solutions. The controllers take information on the state of an airplane or many airplanes without modifying any parameters (e.g. distance between one airplane and another airplane).

With control and planning activities a further distinction can be made between the activities that are oriented on the actual or on the future air traffic. The actual traffic is defined as airplanes that are directly under the responsibility of the controller because they are in his sector. The future traffic is defined as airplanes, on which an activity is accomplished although they are outside of the actually controlled sector.

Another variable that needs to be clarified is the already mentioned difference between a high level sector and a low level sector. In a high level sector, in contrast to a low level sector, the airways are no longer predefined with routes and nodes, rather the pilots are free to choose the shortest way to reach their objectives. This is called the “direct-routing-structure”. Thus, the air traffic in a high level sector is distributed over the complete airspace. The airplanes do not have to cross over certain predefined nodes which should reduce the number of conflicts that the controller has to handle. This decrease should also be reflected in the number of control activities of the controller: the controllers do not need to modify the course, altitude or speed of the airplanes.

Hypothesis flight level and control activities: In the high level sector, the number of control activities will be lower than in the low level sector.

As expected, the average number as well as the average duration of control activities are lower for the high level sector than for the low level sector Figure 3. It shows that a direct-routing structure requires less active intervention of the controller in the airspace configuration.

Fig. 3. Average number (left) and average duration (right) of control activities related to flight level

A further question was to see if this effect could be observed for the future as well as for the actual traffic or if there are any differences. The results show that there is a similar decrease to the one observed for the control activities in the high level sector for actual traffic, whereas future traffic displays no major difference between the flight levels.

Discussion: the results confirm that the implementation of a direct-routing-structure reduces the proportion of control activities. With this structure the number of interventions and modifications of the airspace configuration is reduced. This is not the case for the future traffic because the main control activity concerning the future traffic is the activation of a label to “accept” the control of an airplane. This activity is not influenced by a change of the routing-structure: all airplanes have to be “accepted” in the controlled sector independently from the route-structure.

Hypothesis flight level and planning activities: In the high level sector, the number of planning activities will be higher as in the low level sector.

Due to the fact that the pilots of airplanes in high level sectors decide on their own route, it is more difficult for the air traffic controller to foresee the course of an airplane although he is still responsible in regulating the traffic such that no airplane enters a conflict zone (defined over the time gap or the distance between two airplanes). To complete their tasks, the controllers have to modify the way they normally work to perform the planning activities.

The results in Figure 4 confirms the hypothesis that in the high level sector the controllers perform more planning activities and that their duration is longer than in the low level sector.

Fig. 4. Average number (left) and average duration (right) of planning activities related to flight level

Fig. 5. Average number (left) and average duration (right) of planning activities related to flight level and actual/future air traffic

The analysis of the actual and future traffic confirms that there is an increase of activities in the high level sector but only for the future traffic Figure 5. For the actual traffic they are similar, with slightly lower scores in the high level sector.

Fig. 6. Average number (left) and average duration (right) of control activities related to Data Link

Discussion: with a direct-flight-structure the list of nodes over which the airplanes have to fly is disappearing, such that the controller cannot foresee, as precisely as needed, where the airplanes are going to enter the controlled sector. They have to acquire more information on the route of airplanes that are outside their own sector before they can accept them. For the planning activities in high level sectors the controllers have to collect more information on the route to insure that the minimum time gap and distance limits between airplanes will not be exceeded.

Another focus of the study was the influence of the use of Data Link (digital connection to the pilot) as a communication medium between the air traffic controllers and the pilots compared to radio-voice communication.

Hypothesis Data Link and control activities: The number and duration of control activities will be increased with the introduction of Data Link.

The results show that there is an increase (about 17%) of control activities when about 35% of the airplanes are equipped with Data Link Figure 6. Even though the main control activities are not controller-pilot communications, it is possible to conclude that there is a link between the introduction of Data Link and the increase of control activities although the increase is not as high as expected.

Another effect of the introduction of Data Link was observed when considering the number and duration of direct verbal communication with controllers outside their team. The controllers communicate within the team as well as with teams from neighboring sectors (when the distance allows it) to agree upon or confirm some decisions and to prevent or support when conflicts arise. The results show a clear decrease in this communication when 35% of the airplanes are equipped with Data Link (Figure 7). It seems that the transfer of information to the pilot over an electronic

Fig. 7. Average number (left) and average duration (right) of direct verbal communication with controllers from the neighboring sectors related to Data Link

medium offers the controllers of neighboring sectors the possibility to directly collect information on the status of some changes (open, confirmed, refused) or on approaching, potential conflicts that could need support.

To support the controllers in preventing conflicts from arising, a “Problem Display Window”, a small window within the ASW (radar) on which the time or distance critical parameters of two airplanes are displayed, was introduced.

The use of the PDW was on average about 10 times per run. With such a low frequency, it is difficult to make comparisons with the whole number of activities. The second difficulty resides in the very large differences observed between the runs: from 0 glances to more than 40 in a run. No link could be found between the type of run or the number of critical situations. The individual differences in the control strategy or in the learning phase could explain these differences, although it was not possible to discover, in particular due to the small number of glances, what factors (e.g. controller/planner, actual/future air traffic, high level/low level sector, years of experience of the controllers...) influenced these results. Further investigations are needed to understand why such large differences can be observed.

5 Conclusion

Three major results are presented in this paper and based on the eye-tracking data it could be demonstrated that:

- There are links between the patterns of eye-movements and the type of air traffic structure: in the “high level sector”, in which the airplane can choose its own route based on a direct-flight-structure, there is a transfer of the controllers’ activities.

There are less control activities but more planning activities due to the necessity to more frequently collect information about the route of the airplanes that are going to enter the controlled sectors.

- The use of "Data Link" by 35% of the controlled airplanes slightly increases the number and the duration of control activities compared to the use of the formerly used "radio contact". However, at the same time, it reduces the number and duration of direct verbal communications with teams from neighboring sectors. Further investigations with a prevalent used of Data Link that analyses all types of verbal communications in detail should be performed.
- Related to the use of PDW, it is not possible to establish a link with some factors that could influence the observed results. The use of the PDW seems to be dependent on some individual control strategies which could be interpreted as a weakness in its design: if only a few controllers are using it, it is probably due to the fact that it does not provide the right information at the right time.

The analyses confirmed some expected results, but showed some unexpected findings as well, which should lead to a further improvement of the future tools for the air traffic controllers. Additional investigations have to be conducted to insure that the results are not coincidental, due to the small number of subjects, and that the improvements have a positive impact on the working structure.

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