Future of Aerodrome Traffic Control

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***Abstract*— The purpose of air traffic control as a process in the air traffic system is to provide safe, proper regulated and smooth management of air traffic. This includes paying due attention to the different requirements of those who use the air traffic system by establishing suitable procedures and rules, but also by providing technical equipment and services. Traditionally, air traffic control services for airspace are conducted by air traffic controllers located in air traffic control centres and those services for the control zone around and moving areas on airports by controllers located in air traffic control towers.**

During the past years, the number and scope of studies into the physical relocation of the air traffic control services providing by air traffic control towers has increased immensely. The following paper elucidates the motivation behind these studies. It will also describe and offer a qualitative assessment of the conceptual ideas on which the various studies have been based. Continuing and further developing on the previous work already conducted by Deutsche Flugsicherung GmbH (DFS), it will derive and describe principles for the design of an airport traffic control centre and summarise the initial results of the earlier projects.

***Index Terms*— remote operation, airport tower, cognitive modelling, human-machine system, airport traffic control centre, virtual tower, virtual reality, remotely atc**

1. INTRODUCTION

Technical progress made in the field of air traffic control has led over the past decades to considerable changes in human-machine interactions, even if the degree of automation can be classified as rather low [1]. If one compares the workplace of today's air traffic controllers with that of the 1950s, we see a significant change in the technical components in use (see Figure 1).

Today's workplace of the air traffic controllers in the centres and towers is more clearly laid out, coherent and compact. Information about the positions of the aeroplanes, the weather conditions, the peculiarities of the section of airspace being controlled and the instantaneous and expected traffic situation are presented electronically by various controller assistance systems, oriented to the specific workplace and role of the controller.

Figure 1: Air traffic controller workplace in a tower
(top: 1950s; bottom: 2002)

Air traffic controllers in the tower (see Figure 1) also make use of the visual information available to them by looking out through the windows of their tower (the 'outside view').

Due to their height, these control towers are among the most striking buildings of an airport. Air traffic controllers require this prominent position above the airfield in order to be able to carry out their air traffic control activities in the control zone and on the airport site ('airport control' for short). They primarily rely on visual information from the scene in front of them to enable them to perform their work [14].

The continuously growing volume of air traffic demanded appropriate upgrading of the air traffic control system. The development of new operator concepts during the past years, such as flexible use of airspace, traffic-dependent planning of staff shifts or standardisation of air traffic control procedures, has however only been able to partially reduce the existing asymmetry between the control philosophies for air and ground activities. Increasing the degree of automation in air traffic management has only recently become a topic as a potential key to achieving long-term growth in capacity, efficiency, productivity and safety [17].

Moreover, research in recent years has turned to the question whether an airport control room could not basically be physically located at a separate site away from an airport, in a technical environment comparable with that of today's air traffic control centres. The following aspects can be seen as driving forces behind this development aimed at physically relocating and concentrating airport control rooms in a centralised facility:

1.1 Regionalization of air traffic

Contrary to the tendency followed over many years towards concentrating air traffic on a small number of airports, we have in recent years seen more and more signs of a trend reversal.

Whereas the two hubs of Frankfurt and Munich together handle almost the same volume of air traffic as all of Germany's other commercial airports with control zone put together [2], the growing demand for mobility and the demarcation of the newcomer airlines in the air-shuttle segment (also known as the "low cost segment") is at the same time leading to a shift away from traditional charter and scheduled carriers to regional markets.

In the last three years, Germany alone has seen four new regional airports with control zones join the list of established airports. But the high infrastructure and personnel costs have also brought about considerable economic challenges. Cost pressures on air traffic control services are growing. The requests from airports and the users of the air traffic system for new concepts aimed at offering air traffic control at variable costs are consequently increasing.

1.2 Innovation bottleneck

The demand for uniformity in the air traffic control system from the air to the ground is inherent to the system. As the demand in air traffic increases, the capacity of the air traffic control system will always depend on optimum interaction between the air-related and ground-related processes.

Viewed at the speed and the possibilities for introducing innovations, airport control rooms are at a disadvantage compared with air traffic control centres purely due to the relatively high number of them. A change to a technical system, for instance, today in Germany only has to be carried out at five control centres. The task of standardizing control procedures or the introduction of technical upgrades system-wide is made far more labour-, time- and cost-intensive by a system with large numbers of airport control rooms, resulting in delays in their introduction.

1.3 Flexible use of ATC staff

Quantitative fluctuations in air traffic demand have led to the development of adaptive shift management in the air traffic control. The greater the volume of traffic to be expected, the smaller the area for which each individual controller is responsible, obviously in order not to overload them.

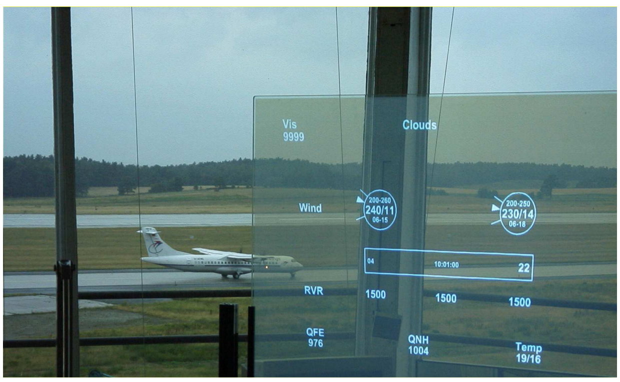
Air traffic controllers operate in assigned areas of responsibility. In control centres these are airspace sectors, while in towers they are the control zone and sections of the airport's movement areas. Areas of responsibility can be split or merged dynamically depending on the volume of traffic. In this way, the number of staff deployed at any one time is adjusted to match the traffic volume, with a necessary lead-in and rundown period. What is known as "rating and unit endorsements groups" can be formed to achieve this flexibility in personnel deployment. This means that an air traffic controller can be deployed in several areas of responsibility. Prerequisite for this is the systematic standardisation of the workplaces and processes that have already been created in the control centres during the last years.

In airport control rooms, too, one or more air traffic controllers are deployed depending on the traffic demand. The lowest number of staff that can be deployed at any one time, however, is one controller per control zone due to the limits of today's system. If, for example, there is no traffic demand in several control zones at one and the same time, these control zones are currently not allowed to be controlled by just one controller. The current organisational system of airport control rooms prevents comparable personnel deployment concepts from being introduced.

2. PREVIOUS INVESTIGATIONS

The modern airport control room is a typical human-machine system [10]. One important finding from the behavioural analyses of tower controller activity conducted by Pinska [14] is that of the direct dependence of an airport controller's perception of his activity on the information gained from the immediate outside view, where the term "outside view" refers to the controller's field of vision from the tower.

Based on this finding, almost all of the work conducted until now has been aimed at generating the controller's outside view using camera images. That means, the pieces of information acquired visually in the control zone and on the movement areas of the airport must without doubt be viewed in differentiated manner due to their different spatial dimensions. Recognizing objects at a distance of 4 to 10 km



still requires considerable effort even when using state-of-the-art camera technology.

Figure 2: Use of a transparent projection in the tower at Dresden (Photo: DLR)

The DLR Institut für Flugführung (Institute of Flight Guidance), in Braunschweig (Brunswick), Germany conducted a series of experiments between 2002 and 2004 to examine the potentials of a possible use of Virtual Reality (VR) or Augmented Vision (AV) technologies.

For example, experiments were conducted in Dresden Airport's tower into the use of a transparent (holographic) projection (see Figure 2) with the goals of improving visibility under low visibility conditions (LVC) and reducing "head-down times" [7].

Further studies are based on the use of high-resolution cameras. To visualise the view in the area of responsibility in bad weather (e.g. fog), the information acquired with these cameras is supplemented by additional installed infrared cameras . The view reproduced for the controller on the basis of a digitised video signal is also superimposed with data from yet more systems, such as the ground situation monitor, the weather display and the flight data processor. The view of the physically distant area of responsibility generated for the controller in this way using data fusion has already reached a remarkable quality in these studies [8].

The separation between visual information and supplementary data on electronic displays is supposed to be overcome by the vision of an integrative, ad hoc information desk. Considering the fact that the activities currently conducted by a controller in an area of responsibility at an airport are based substantially based on the information acquired by looking out through the tower windows at the outside view, one could assume that the route taken promises success.

2.1 Classification of the familiar conceptual approaches

The objective of the studies in the experimental environment presented below is to develop a future workplace design for airport control of a physically distant control zone as a first, comparably in near time to implement intermediate step on the route to the "Virtual Tower".

2.1.1 Workplaces in a future tower with video panorama

In this concept, the workplace for the distant control zone is to be integrated in an existing tower, so that this tower is equally responsible both for its own (local) control zone as well as the distant control zone.

The studies describe an air traffic controller's workplace that has been set up in an experimental environment. The outside view is generated for the controller by means of Augmented Vision Video Panorama HMI [8]. Various cameras, positioned at what is eye level for the controllers in the real tower, supply a digital video image. The individual video channels are combined to create a continuous video panorama. The quality of the outside view generated in this way depends completely on the technical parameters of the recording and display equipment and on the bandwidth of the data transmission system.

So far, the quality of reconstruction of the outside view of the control zone and movement areas has not been comparable with the actual outside view the controllers enjoy from the tower. The reason is the restricted technical possibilities. Due to priority being given to assembly of the outside view, the current status of the workplace design still does not incorporate a large number of standard system components. These are to be integrated in the course of the next phase.

Until used for the first time in the simulated environment, it remains to be seen whether a practical, ergonomic workplace design that functions and can also be integrated in existing towers can be found. The restriction to just one physically distant control zone, the necessity of having to find an adequate amount of space in an existing tower and, not at least, the mental break between two different work environments inside one tower lead to a certain degree of doubt.

2.1.2 Workplaces of existing tower using available technology

The conceptual work performed by DFS into the physical relocation of the airport controllers began at the end of 2000, beginning of 2001. First of all, a preliminary concept was drawn up for fundamental parameters concerning the areas of operation, technology, national and international guidelines and cost effectiveness [3].

As work continued, the concept of the "Remote Tower Erfurt" arose, which led to operational trials in 2005 and 2006 [4]. Within the framework of the project, a workplace was set up in the control tower at Leipzig, fitted out with the relevant equipment and certified for temporary operational trials. Airport control for the distant control zone of Erfurt was provided during the night-time hours from this "remote workplace". The following results were documented in the comprehensive final report [5]:

- airport control was able to be provided for the distant control zone under the defined operational parameters;
- the initial scepticism of the airspace users and the airport has basically been overcome;
- more detailed studies and assessments are necessary before the project can be expanded to daytime operation and before a permanent "airport control for distant control zones" environment could be installed.

DFS is striving to conduct further investigations on this basis (see also Section 3).

2.1.3 Remote Tower Centre (RTC)

Whereas the "remote workplaces" for airport control are designed for just one distant control zone, the study into the "remote tower centre" is pursuing the visionary goal of using “state-of-the-art” image projection technology, installed in a windowless control room, to regenerate a realistic image of the controller's outside view for several control zones assigned to him.

The platform planned for generating the outside view is comparable with the augmented vision video panorama view described above. The technical limitations connected with this potential solution consequently also apply to its use in a RTC. Due to the objective of implementing airport control for several distant control zones simultaneously in one RTC, one must presume that the disadvantages cited above are most likely to be intensified.

The workplaces of the air traffic controllers in a RTC are arranged in a semi-circle or circle in the same way as in a tower today. In the centre, the controllers sit in front of workdesks equipped with the same systems for communication, accessing data and other interactions as are to be found in a real tower.

In front of the workdesks, facing the controllers, the outside view of the respective control zone and airport movement area is displayed on virtual windows. Whether the outside views will be used next to one another or a tower control desk will be used as the working environment per control zone currently remains an open question in the investigations.

The outside view can also be superimposed with additional information (e.g. weather conditions or flight timetable information) or, alternatively, presented in a conventional manner on data displays. The studies into the RTC are also emphasizing truly realistic generation of the outside view.

2.1.4 Virtual tower environments

Figure 3 shows a virtual airport scenario. Using a "head-mounted 3D system" that has been developed by the Human Factors Department of NASA Ames, a traffic scenario can be simulated on the basis of recorded radar data. The projection is fixed to the spatial coordinates. When the operator moves his head, the projection of his display moves accordingly, so that the airport layout and the moving objects on the display (e.g. aeroplanes) follow [16]. In this way, the actual outside view of the controller is replaced by a virtual reality.

Figure 3: Virtual Tower research with Head Mounted Stereo Display. Latency Effects [Ellis et.al., NASA-Ames, Human Factors Lab.]

Airport operators such as FRAPORT AG are also conducting comparable research. The aim in this case is to produce an equivalent projection of the apron of the airport. It is not air traffic controllers who are responsible for managing and controlling movements around Frankfurt/Main Airport but apron controllers employed by FRAPORT AG. Their tasks are to a certain extent comparable with those of the air traffic controllers; for instance, apron controllers also use primary information from the outside view [9].

3. PRINCIPLES OF DESIGN

As described above, most studies focus on the realistic generation of air traffic controllers' outside view for distant control zones. In the process, as the basis ergonomic architecture, this outside view is superimposed with additional information, so that the air traffic controller is provided with a quasi-real image of the view of the distant area of responsibility as a new human-machine interface.

In acknowledgment of the motivations cited in Section 1 and in criticism of the preliminary study results presented in Section 2, DFS's potential solution is founded on a fundamentally different basic ergonomic architecture that is further developed with the aid of design principles. The following description focused on the vision that a virtual traffic operation centre (ViTOC) should become a substitute operational environment for one or more airport control towers for the contingency case or permanently for airports with a low volume of traffic.

3.1 Non-homogeneity and workload fluctuations in an airport traffic control centre

Air traffic in control zones is always controlled in accordance with one of two operating modes, depending on the meteorological conditions seen from the viewpoint of aviation requirements. With ground visibility of at least 5 km and a cloud base of at least 450 m above ground or water, one speaks of visual meteorological conditions (VMC); when the ground visibility and/or cloud base values are worse than this, one speaks of instrument meteorological conditions (IMC). Accordingly, flights are conducted in accordance with visual flight rules (VFR) or instrument flight rules (IFR), which has consequences for the respective instructions of the air traffic controllers.

The volume of air traffic to be expected in a control zone is subject to the same fluctuations as in the airspace. Most travellers want to set off on their journey early in the morning. Business travellers fly to the venue of their negotiations in the morning and would like to be back home by the evening. Cargo should arrive at its destination in the morning, etc. For all of these flights, timetables usually have to be issued in advance, so that an air traffic control organisation is able to prepare for these demands. Control zones, however, are also subject to additional occasional traffic that for the most part does not have to be pre-registered in the flight timetable. For this reason, this share of traffic cannot be planned for and leads to varying workloads in control zones, which are difficult to forecast.

Extra activities, such as controlling airport systems, observe the weather or coordinating special situations (e.g. construction work on the airport), lead one to suspect a non-linear connection between flight movements and the workload of the controllers. Depending on the operating mode, traffic situation and tasks assigned to the controllers in a VITOC, the relevant information should therefore be managed adhoc, in line with the respective activity, by means of an *Air and Surface Adaptable Situation Display Function (ASDF)*.

With a *Flow Management Monitoring Control Function (FMMC)*, the air traffic demand in the distant control zones could be controlled in such a way that a flexible and optimum deployment of staff in the responsibility group of the respective VITOC is supported.

3.2 Airport control under low visibility conditions

Air traffic controllers already suffer from an inconsistent supply of visual information in their work environment, the tower. Visual contact with the area of responsibility is to some extent considerably restricted at night-time, in bad weather (e.g. heavy rain or fog) or due to structural changes made to an airport.

To ensure that air traffic services remain free of interruption, special requirements apply for these low visibility conditions (LVC). Under such conditions, controllers already make use of information about ground vehicles and aeroplanes in their area of responsibility supplied to them by electronic displays (SD) of sensor-based system functions (see Figure 4).

Figure 4: Possible future virtual electronic display (SD)

Among these system functions are, in particular, the airspace and ground situation monitors, the weather information systems, the lighting systems, the navigation systems and the camera systems. All of these systems are in use in towers operated by DFS, and they are all implemented and certified in such a way that they *can also be used by controllers at distant locations (e.g. in a VITOC).*

3.3 Continuity of the environment

From the point of view of the overall air traffic system, towers are optimally integrated in the organisational and technical environment of the respective airport owing to their importance with regard to the safety, efficiency and capacity of the airport system. Every change and modification therefore requires detailed examination of the potential repercussions before being made. The physical relocation of the activities of an airport control room away from the existing structures that have evolved must consequently adhere to the principle of continuity of environment from the outset.

This means that systems or tasks that do not belong to the original standard activities of air traffic control must be 'migrated', too.

For example: the airport lighting system. The control and display element for the airport lighting system must be controlled by the controllers depending upon the control zone operating mode (see above) and the prevailing traffic situation. This role in the human-machine interface cannot be transferred to any other human function that exists at the airport without calling the matters of consistency and efficiency into question. *Consequently, a solution must be found that maintains this system functionality of the human-machine system*.

3.4 Uniformity of the air traffic control system

Adequate and standardised interfacing of the airport control room with the corresponding centre is an important design criterion in light of the uniformity demanded for the air traffic control system. The "gate-to-gate" concept for best-possible support for planned turnaround times by airspace users through connecting up airline operation centres or the demand for innovative concepts by Single European Sky ATM Research could be achieved through standardisation of the airport control rooms in the form of an airport air traffic control centre. The greater the number of control zones controlled by one or more VITOCs, the more comprehensive, forward-looking and therefore better the service provided to the users of the air traffic system.

With the *Flow Management Monitoring Control Function (FMMF*) mentioned above, temporal interdependencies between the airspace and ground could be exchanged with the aid of the systems.

3.5 Safety Network

With a concept such as that of the airport traffic control centre, the maximum possible level of safety must be striven for. The controllers must be able to rely hundred percent on the information supplied to them. If control zones are simply being monitored, because for example there is no traffic demand at a given moment, tools should be made available to the controllers that guarantee safety in the distant control zone.

This includes functions such as *Restricted Area Observation and Alerting (RAOA)*, which monitors, for instance, ILS safety zones or the boundaries of the area of responsibility on the ground and in the air. These functions detect unauthorised entry into the areas defined and warn the controllers. Cameras that operate in the visible or invisible frequency range or microwave sensors can be used to visualise the situation. Thanks to the system of sensor-based information gathering, other assistance systems such as *Conflict Detection, Alerting and Advisory (CDAA)* can be implemented to warn controllers and act as a safety net. The standard of safety increases and potentially the capacity of the control zone, too.

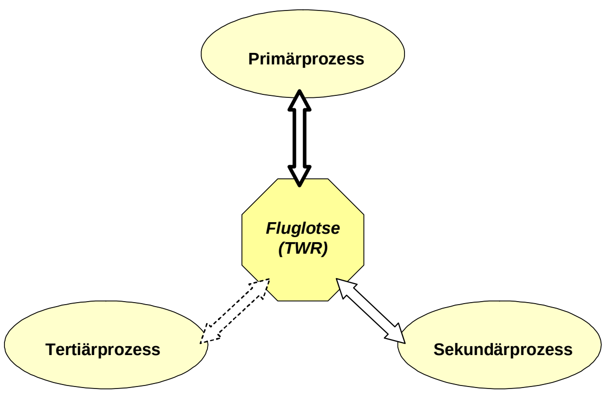
3.6 Evolutionary implementation strategy

One of the most important design principles of DFS's VITOC is its modular and phased approach to implementation. This is followed with a view to the ambitious and to a certain degree visionary objective. Implementing a VITOC in a single step – a sort of "big bang" approach – would appear to be too radical a paradigm shift for the human-machine system. A number of the above-mentioned assistance systems, however, bring about an improvement for the controllers even in the given work environment. Early deployment of these functions in the controllers' familiar environment also offers the advantage of enabling them to familiarise themselves and become confident in them.

As the above-mentioned design principles show, it would make little sense to design a VITOC without introducing large-scale automation of human-machine interactions. The shifting of tasks to the system should take place in evolutionary, reversible steps. The level of automation would then have to be in keeping with the ability of humans to adapt and the availability of certified system components.

4. FURTHER INVESTIGATIONS

The next phase of DFS's activities will be focused on extensive analysis and modelling of human-machine interactions in both the existing and the future work environment. The present information model used by air traffic controllers in the tower can be visualised with three differently prioritised processes (see Figure 5):



- information gathering by taking in the outside view (primary process);
- use of controller assistance systems for communicating and sensor-based information gathering (secondary process);
- supplementary non-ATC information (tertiary process).

To widen the scope of analysis of controller activities in the tower, the continuing investigations being conducted by DFS will be extended to include tasks that are atypical for ATC, but which controllers at smaller airports in particular have to perform, such as keeping the flight log.

This completes DFS's task analysis, an analysis that describes the full range of activities performed by a controller in the control zone as a generic concept.

One of the initial hypotheses for future work by DFS is as follows:

The worse the real or subjectively perceived information from the primary process (outside view) is for the controller, the more the controller bases his decisions on substitute information from the secondary process (system data). As of a certain negative quality of the outside view, the controller bases his decisions totally on the information presented to him by the system.

On the basis of this hypothesis, the work environment of an VITOC is not different from a tower under non-visibility conditions (NVC), for instance, with greatly restricted visibility due to fog. As such, it would appear inadequate simply to transport a "1:1" reproduction of the view from the control tower to a different location where the controllers can do their job without enhancing the quality of the information they are supplied and thus of the service they provide.

One can currently assume that a 1:1 presentation of an airport's 'local zone' will not be a suitable work environment for the controllers working in an VITOC. Working on the basis of the above hypothesis, the controllers in an VITOC will be able to base their decisions on the sensor-based information on the positions of the moving objects in the area of responsibility and the information relating to intended movements and weather and airport conditions.

The key to success will lie in increased automation. An increase in the level of automation leads us to expect a reduction in the number of tasks performed by and the workload of the controllers, which in turn can lead to an increase in capacity, efficiency, productivity and safety. The deployment of automated air traffic controller assistance functions can assist controllers right now in their current work environment, irrespective of their deployment in an ATOC. As such, it would make sense to speed up their application and to deploy them in existing airport control towers.

However, this means all moving objects in a distant control zone would have to be fitted with appropriate sensors. This could be done in accordance with the current principle of a transponder mandatory zone (TMZ). It may be possible to introduce incentives for the airspace users to purchase "low cost" sensors (e.g. by using onboard units from truck toll systems). Visual information from the outside view can also be supplied.

No doubt, the most important challenge is that of designing the work environment of air traffic controllers in line with the principles cited above. Air traffic control activities for distant control zones must be free of interruption and at least offer the standard of safety already reached by DFS. There is also an opportunity to find a way to significantly reduce the asymmetry between the control philosophies for air and ground activities, in order to improve the performance capability of the air traffic system as a whole.

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