Development and Validation in Air Traffic Control by Means of Real-Time Simulations

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1. Abstract

The airspace in Central Europe is already one of the busiest airspaces in the world and the forecasts predict further traffic increases. The current air transport system is reaching its capacity limits, not only at airports but also in parts of the en-route area. This is mainly due to the workload constraints of air traffic controllers.

In the past, many technical system functionalities were developed with the aim of reducing controller workload and thus enabling the safe handling of the predicted traffic growth. But these new functionalities alone will not provide adequate relief to air traffic controllers. Their working procedures and the airspace structure will have to be adapted accordingly. In order to obtain real operational benefits, these technical innovations must be integrated into an overall concept which – in addition to the above-mentioned factors – also takes account of ergonomic aspects and human-machine interfaces.

When developing such an overall concept, additional evaluation and validation measures are indispensable to ensure that the desired operational benefits are achieved. This is why DFS has for many years used fast- and real-time simulations to assess and optimise any changes to be made to the air traffic control system. The working methods of DFS in this context are in keeping with the European Operational Concept Validation Methodology of 2007, in short E-OCVM.

This paper outlines the development and validation activities of DFS using the MSP D/L project as an example. The project deals with the introduction of the new role of air traffic controllers as multi-sector planners (MSP) and new system functionalities, such as air/ground data link (D/L).

The project included the development of an operational concept for using the new functionalities as well as for defining working procedures and the airspace structure. This concept was subsequently evaluated by means of a fast-time simulation and two real-time simulations and gradually optimised.

This paper focuses on how data were collected during the real-time simulation. In addition to collecting traffic-specific indicators and data concerning the taskload situation, we also performed an eye-tracking analysis in cooperation with the Darmstadt University of Technology to analyse changes relating to the working methods and the information used.

Another objective of the paper is to compare the use of the prototype simulation platform for the real-time simulation with the use of operational systems for simulation purposes. Adapting operational systems to new operational procedures and functionalities is always associated with considerable costs. Air traffic controllers, however, need a realistic working environment for such simulations. Otherwise, it is impossible to obtain reliable results. It is not easy to develop a simulation platform that ensures both a realistic environment and quick and flexible adaptation capabilities. The project successfully met this challenge with the help of the Advanced Function Simulator (AFS) of the R&D Centre at DFS Deutsche Flugsicherung. The major features of the prototype simulation platform, i.e. rapid data adaptation, iterative development and automatic compilation of all user interactions, are shown using Project MSP D/L as an example.

An overview of the results achieved in the real-time simulation is given at the end of the paper.

Keywords

Multi-Sector-Planner, Data Link, Air Traffic Control, Prototyping, Real-Time-Simulator

2. Project MSP D/L

The project deals with the further development and assessment of working methods and procedures integrating new system functionalities that will form part of future air traffic control systems. One of the aspects assessed is the new role of air traffic controllers as multi-sector planners (MSP). In addition, the controllers had at their disposal conflict detection and electronic coordination functions as well as air/ground data link.

A total of three real-time simulations and one fast-time simulation are planned within the scope of the project. This paper deals with the second real-time simulation which was performed in March 2007. The preceding simulations were documented in the DFS publication "TE im Fokus" (cf. Herr & Herber [2006]).

Upper airspace in the responsibility of the Upper Area Control Centre Karlsruhe was used as assessment area since this control centre will be the first one to implement these system functionalities within DFS.

3. Operational concept

Prior to performing the simulations, we prepared the essential components of the working environment to be assessed together with operations personnel of the Karlsruhe control centre. This first draft of a future operational concept will gradually be developed further on the basis of the results of the simulation. The operational concept is based on the following key elements:

Airspace structure

The new route structure caters for direct routings of all flights from entering to exiting Karlsruhe airspace. Certain arrivals and departures are guided along standard routes until reaching a defined altitude and then cleared directly to the exit point.

Working procedure

The current working procedure was modified as follows:

- Use of a multi-sector planner (MSP). The MSP is a planning controller who is in charge of more than one sector. This means that he is the point of contact for more than one executive controller. Electronic coordination relieves the MSP from routine work so that he can perform his tasks for more than one sector. Since he has an overview of the traffic situation in several sectors, he is in a position to solve problems in a comprehensive way. The concept of the MSP has already been analysed in numerous studies. More information on this subject along with further bibliographic references can be found in Marsh (2001) and van Gool & Schröter (2002). The potential introduction of the MSP has also been assessed within the US Airspace. Results can be found in Corker K., Liang D. et al (2007).
- A stricter standardised assignment of tasks to the roles of executive controllers, planning controllers and multi-sector planners. The system used supports this assignment by means of status indicators, i.e. the system shows who is responsible for the individual aircraft.
- Air traffic controllers are supported by conflict detection tools.
- Verbal coordination will largely be replaced by appropriate electronic communication channels.
- System input is required for all clearances and coordination so that the system has the most recent data at all times.

Technical functionalities

- 4-D trajectory prediction on the basis of flight plan data and an underlying aircraft performance model
- Conflict detection by means of a medium-term conflict detection module (MTCD) working on the basis of planning data with a leadtime of up to 15 minutes
- All changes made to planning data are forwarded to all working positions concerned, including display of changes (electronic coordination)
- Air/ground data link is used between controller and pilot for the electronic transmission of frequency changes and clearances
- The human-machine interfaces are adapted to the envisaged procedures and working methods

4. Design of the study

Objective of the real-time simulation

The objective of the simulation was to test the following assumptions:

- With a multi-sector planner, traffic can be handled with the same level of safety and cost-effectiveness as with the traditional division of roles.
- With 35% of all aircraft being equipped for air/ground data link, this does not negatively affect the taskload and strain situation of controllers.
- The above-mentioned assumptions were made on the basis of today's capacity limits as well as on the basis of a 20% traffic growth.

Simulated airspace and sectorisation

The simulated airspace is a section of the area of responsibility of the Karlsruhe control centre. Four sectors were assessed (the upper and lower sectors of the areas WUR and KRH, see Figure 1). The activities in the surrounding sectors were simulated with respect to their effects on the sectors assessed. All of the air traffic controllers participating held the required ratings for the sectors they were in charge of.

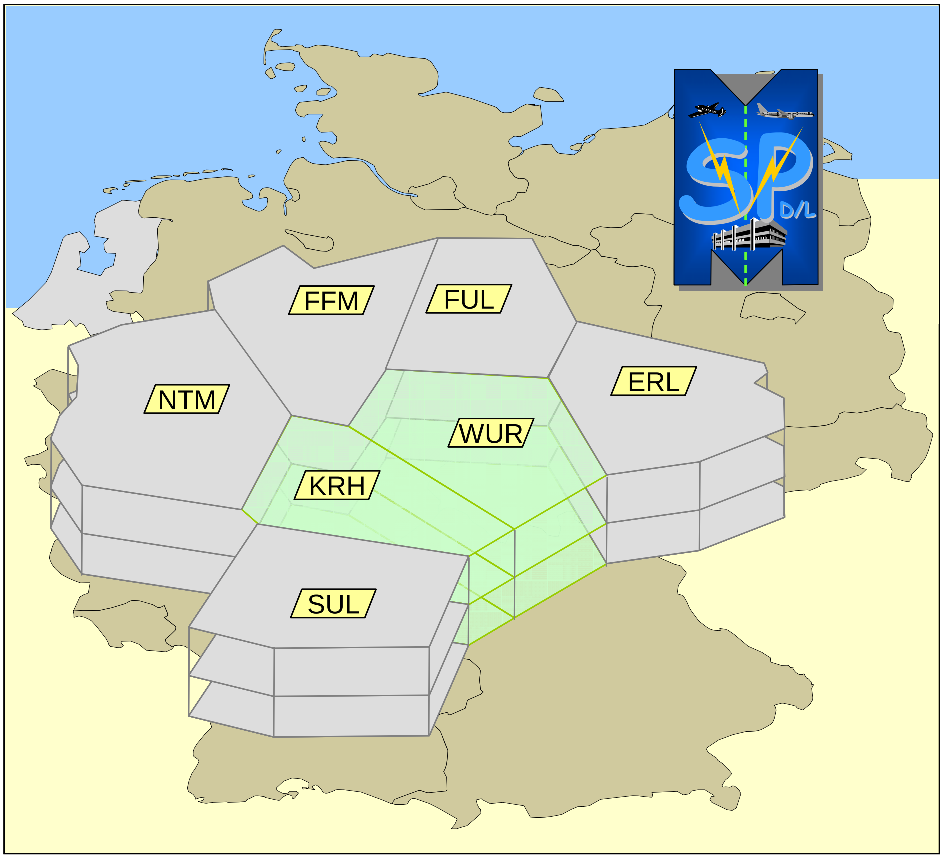

Figure 1: Simulated German airspace and sectorisation

Traffic samples

The traffic samples were based on real flight plan data of the past. They were evaluated and optimised by air traffic controllers so that they would be as realistic as possible. The traffic volume corresponded to 100% scenarios, i.e. the number of aircraft in one sector reached the current capacity limit, and 120% scenarios with 20% more aircraft, thus allowing for the predicted increase. The data for each simulation run were recorded for a period of one hour.

Simulation process

Since four sectors were assessed in each simulation run, eight working positions were staffed according to the traditional division of roles with one executive and one planning controller. In the new configuration, six working positions were staffed since each multi-sector planner was in charge of two sectors. A total of twelve air traffic controllers participated on the eight simulation days. Some of them simulated the effects that surrounding sectors had on the assessed sectors, and others acted as observers.

5. Evaluation

In order to assess the simulation runs with respect to effects of the new airspace structure and the new role division, we collected objective data by recording the activities during the simulation and also subjective data by questioning the participating air traffic controllers.

Objective data collection

The objective data compiled and evaluated included:

- Number of aircraft and time spent in sector
- Number of vertical movements
- Number and type of air traffic control clearances
- Number and duration of verbal coordination
- Number and duration of the required system inputs, divided into:
  - Inputs to update control-relevant data
  - Inputs to perform planning tasks
  - System interaction to maintain situational awareness

Figure 2 shows the average time needed for system interactions. There were three input options:

Control for inputs of control-relevant data
Planning for performing planning tasks
Information for interactions to maintain situational awareness

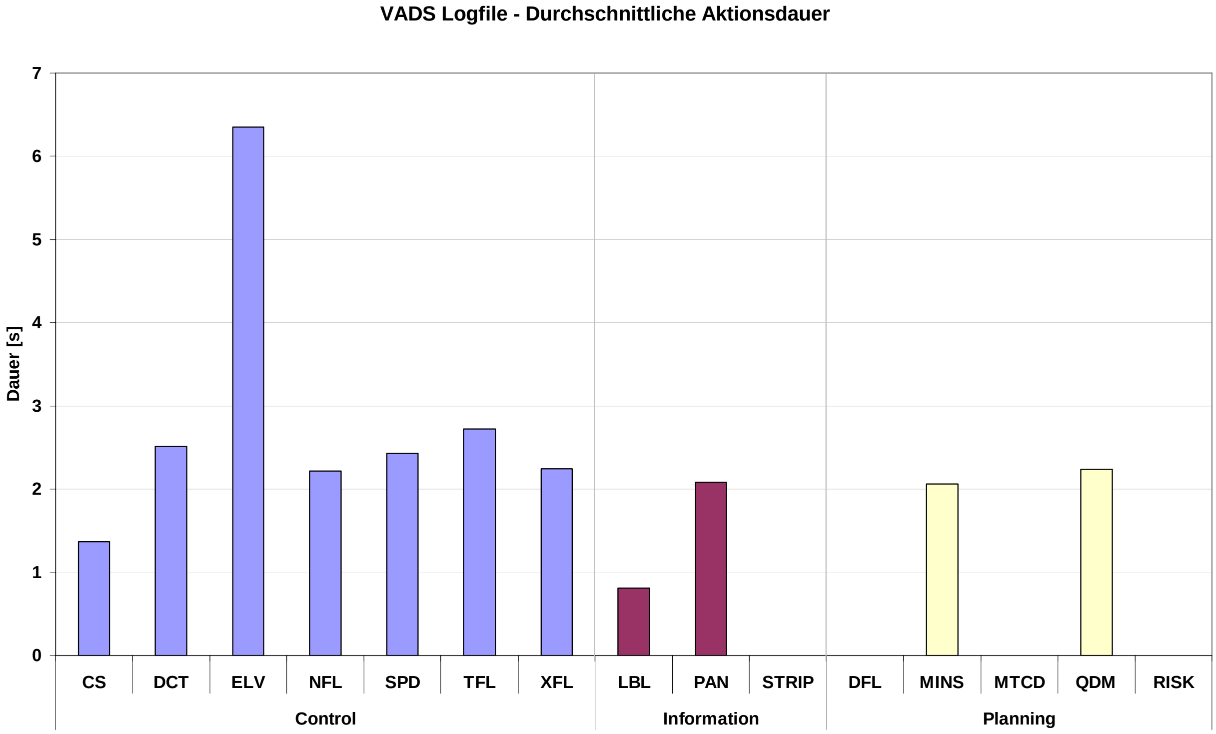

Figure 2: Average time in seconds needed for system interactions, e.g. input of frequency change in call sign menu (CS), input of heading with subsequent return to original route of flight with Elastic Vector (ELV), change of entry and exit level (NFL, XFL), as well as moving the aircraft label (LBL)

Subjective data collection

The following subjective data were collected:

- Electronic recording of the subjective ISA score (instantaneous self-assessment) and situational awareness of air traffic controllers in five-minute intervals during the simulation run.
- Questionnaires to be completed after each simulation run and according to the experimental conditions. The questions focused on the applicability of procedures, technical system functions and the airspace structure. The participants were also asked to assess team interaction and team performance.
- A structured interview at the end of each simulation run gave the group of air traffic controllers the possibility to discuss important aspects.

In addition to these conventional assessment methods used in earlier real-time simulations, we also recorded the eye movements of one controller per simulation run. This eye-tracking analysis was performed in cooperation with the Institute of Ergonomics of the Darmstadt University of Technology.

6. Simulation platform

Reasons for using a prototype platform

Real-time simulations have become a generally accepted and important tool for designing systems in air traffic control. But the real question is: how should the platform for real-time simulators be designed.

The choice of the platform is simple when work processes are to be changed. All it takes is the provision of the operational system, i.e. the system at which controllers work, with the necessary data: The effectiveness of the changes can then be evaluated by monitoring the controllers in their normal working environment. This method is relatively easy to handle and inexpensive.

The desire to optimise work processes of air traffic controllers often also involves adding new technical capabilities to existing tools. This was also the case in our MSP D/L simulations. The introduction of data link requires considerable modifications to the display functionality. We are thus faced with the problem of having to perform a work process with the help of a technical system which does not yet exist, or a technical system is to support a work process which has not yet been fully defined. This interdependence can be managed by using an iterative approach where technical functionality and work process are alternately upgraded in steps.

This approach of integrating the prototype of a technical functionality into an operational system is not always easily possible. Changes to operational systems are subject to demanding quality and safety processes. This makes changes expensive, time-consuming and inflexible. The method will therefore not be first choice in cases where the function has not yet been defined in detail and where it is doubtful if the changed function will remain in operation.

A simulation platform must provide a high degree of flexibility in order to make best use of the time during which air traffic controllers are available for the simulation.

These requirements finally led to our decision to produce a prototype air traffic control system and to use it for real-time simulations whenever necessary and possible.

What we needed was a system that – with respect to the necessary functions – would be close enough to the original to draw meaningful conclusions concerning the workload of controllers but that would also be simple enough to permit easy preparation of simulations and rapid prototypical implementation of new functions.

Additional functions for measuring controller interactions with the system were also integrated.

A positive side effect is the fact that the same prototype with a few minor changes can be used for the ab-initio training of air traffic controllers. Our system fully meets the requirements for the training of procedures without having trainees become too accustomed to a specific system.

Advantages and disadvantages of prototype real-time simulators

Prior to each simulation, the advantages and disadvantages have to be thoroughly weighed before making the decision whether to use a prototype or an operational system for a real-time simulation.

The following tables show the advantages and disadvantages in relation to the simulation requirements (cf. Table 1 and Table 2).

Requirement	Prototype	Operational system
New functionality	New functions can be easily implemented at low cost	New functions are expensive and time-consuming
Complexity of adaptation	The prototype can easily be adapted since it has been designed accordingly	Adaptation is expensive since the system is tailored to operational use
Assessability	Offers many assessment options	Assessments are only possible within the limits of legal recording
Iterative approach	Misdirected developments can be avoided since the prototype is available within a relatively short period of time and can be adapted to the users' needs, if necessary.	In most cases, the functionality must be fully specified. Only the finished result is presented. Misdirected developments may therefore occur.
Flexibility of simulation process	The simulation may be stopped or fastforwarded.	Operational systems have long leadtimes, cannot be stopped or fastforwarded.

Table 1: Advantages of the prototype system over the operational system

	Prototype	Operational system
Training	It is not the original operational system. Air traffic controllers have to be trained on the prototype system to get used to the differences.	No training required.
Usability of the result concerning software	New functions of the prototype must later be implemented in the operational system.	New functions are available right after validation.
Usability of the result concerning procedures etc.	Due to the differences between the prototype system and the operational system, the portability of the results must be closely examined.	Portability of results is normally ensured.
Simulator effect: controllers know that it is only a simulator and thus act and evaluate their behaviour differently	The simulator effect for controllers is stronger.	The simulator effect is less evident.

Table 2: Disadvantages of the prototype system over the operational system

The advantages of a prototype simulation platform clearly prevail when it comes to validating new airspace structures, new controller tools and operational procedures. The operational system has significant advantages only when it comes to validating if an operational system is suited to a certain environment.

The Advanced Function Simulator at DFS

The Advanced Function Simulator (AFS) is located in the R&D Centre of DFS in Langen, near Frankfurt. It provides a prototype simulation platform for systems that are currently in use or will be implemented at DFS in the near future. In addition the AFS is able to simulate an environment to run an operational system.

At the moment, the system has a capacity of 12 controller working positions with radiotelephony contact to up to six pilots. The simulation is controlled from a supervisor working position.

Interfaces with a Tower simulator enable integrated simulations from push-back of an aircraft at the gate to docking at the gate after landing.

The system can be connected to the full-flight simulator of Lufthansa to perform joint simulations and the same interface can be used for simulations with Unmanned Aerial Vehicles (UAV).

Figure 3: Real-time simulation at DFS

Recording of user interactions

It may be important to know what kind of inputs the controller makes during a simulation run. The conventional method here was to place an observer behind the controller who would record in writing all interactions of the controller with the systems. This is still done today when performing simulations with operational systems.

The prototype simulation platform of our R&D Centre automatically records the beginning and the end of all controller interactions. These recordings are available for post-evaluation.

Software architecture

Thanks to the modularity of the simulator, the system behaviour can easily be adapted to the specific requirements of the simulation. All major functions are self-contained software units, so called tasks (see Figure 4), which can be exchanged or parameterised via configurations. In our MSP D/L simulation campaign, the conflict detection (MTCD) behaviour was modified in order to test different variants.

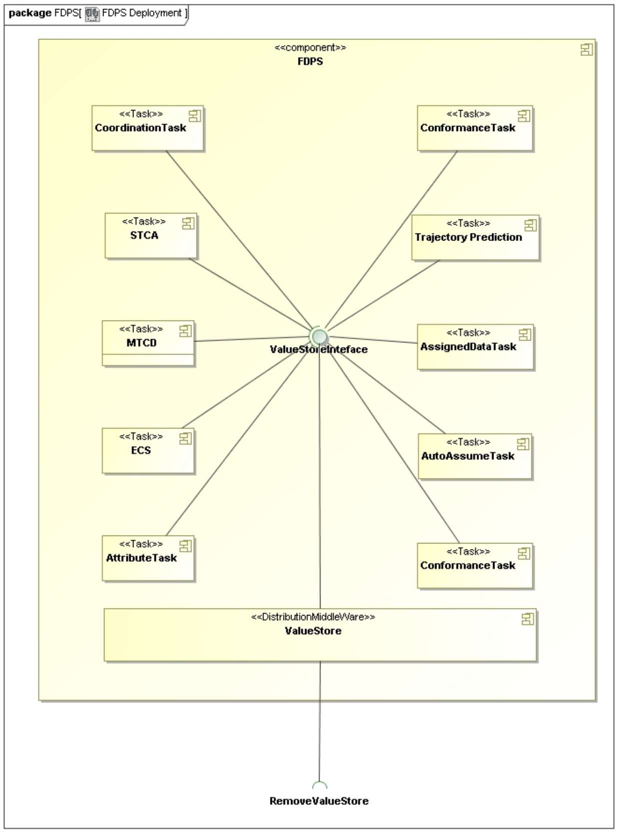

Figure 4: Excerpt of deployment diagram Flight Data Processing System (FDPS). Individual functions, such as Executive Conflict Search (ECS), Short Term Conflict Alert (STCA), are self-contained tasks

For economic reasons, the necessity of a prototype simulation platform has to be justified in regular intervals.

The flexibility and the savings in time and money that can be realised when solutions are rapidly implemented justify the continued use of a prototype simulation platform when developing future systems.

7. Results

This paper focuses on the methodology used for developing and validating changes in air traffic control. The results of the simulation are therefore presented in abridged form.

- The new airspace structure was seen as positive in combination with the available technical functionalities. The fact that fewer clearances had to be issued was seen as a reduction in workload. The efficiency of flight profiles slightly increased due to the direct routings.

- It was possible to apply the envisaged procedures and working methods and the majority of them were found safe. Some of the procedures will have to be revised on the basis of the simulation results.

- Conflict detection on the basis of planning data for overflights was generally considered positive. Conflict detection was not very helpful in connection with vertical movements, since the data basis was not stable enough during the preceding time horizon of up to 15 minutes. Due to clearances and changes in aircraft performance, there were too many data updates affecting conflict detection. According to the participating air traffic controllers, conflict detection could be improved by more fully integrating clearance and radar data and by shortening the time horizon.

- Particularly in high-workload scenarios, the multi-sector planner tended to lose track of the situation as a result of the traffic volume. During these scenarios, only a few planning solutions were offered to reduce the executive controller's workload. Due to a lack of situational awareness, the MSP cannot be considered safe with respect to the simulated traffic volumes of the high-workload scenarios.

- The use of air/ground data link was considered safe in all traffic scenarios. Data link communication was used for clearances that were not time-sensitive. It did not lead to a higher taskload as compared to scenarios without data link. Frequency transfer by data link reduced the workload during high traffic volumes.

The simulation proved that the new system environment is suited to handling high traffic volumes. Some of the procedures, however, require revision or further details.

A further real-time simulation for the project MSP D/L is scheduled to be performed in April 2008. The optimised airspace structure and working procedures will be examined in this simulation, which will entail an additional conflict detection display with a shorter time horizon and a modified data basis.

8. References

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