Task-based workload models for the evaluation of conceptual changes in air traffic control

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Zusammenfassung

Mit neuen Systemfunktionalitäten in der Flugverkehrskontrolle kann in der Regel nur dann der gewünschte betriebliche Nutzen erreicht werden, wenn eine gleichzeitige Anpassung der Luftraumstruktur und der Arbeitsverfahren erfolgt. Die Komplexität dieser neuen Arbeitssysteme erfordert strukturierte Untersuchungen während des Entwicklungsprozesses, um die Merkmale und Auswirkungen des neuen Systems möglichst genau zu kennen. In diesem Artikel wird der mögliche Beitrag von tätigkeitsbasierten Arbeitslastmodellen in diesem Bereich diskutiert. Nach einer kurzen Beschreibung des zukünftig geplanten Arbeitssystems für den deutschen oberen Luftraum wird die Entwicklung und Validierung eines Arbeitslastmodells auf Basis dieses Systems dargestellt. Die abschließende Analyse ergibt, dass tätigkeitsbasierte Arbeitslastmodelle ungeachtet des noch bestehenden Optimierungsbedarfes eingesetzt werden können und zur Verbesserung des Entwicklungsprozesses neuer Arbeitssysteme beitragen.

Abstract

New system functionalities in air traffic control do not provide adequate benefits in terms of safety or capacity without the respective adaption of the airspace structure and working procedures. Given the complexity of these new socio-technical systems, it is necessary to assess the characteristics of these systems during the development process. This article discusses the potential contribution of task-based controller workload models in this area. After the brief description of planned new system functionalities and working procedures for the German upper airspace, the development and validation of a controller workload model based on this system will be shown. It will be concluded that in spite of some need for optimization, task-based workload models can deliver value to the development and validation process in air traffic control.

Introduction

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. For the en-route part 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. In most cases new functionalities alone without simultaneous adaptations to the airspace structure and the working procedures will not provide the requested operational benefit.

In advance of the implementation of such socio-technical systems it has to be assured that key performance criteria like safety, capacity and efficiency can be achieved. In air traffic control the necessary validation activities are normally performed by running real-time simulations. However the preparation and analysis of real-time simulations involve a high amount of effort. Therefore it would be beneficial if the main features of the new socio-technical systems could be evaluated also in a different way, thus reducing the effort for real-time simulations.

A number of studies have analyzed the impact of air-traffic related parameters like number of aircraft, potential loss of separation or vertical movements on controller workload. As a result workload models have been developed that forecast the expected controller workload on the basis of the predicted traffic in current operations. It will be analyzed in this article whether similar models can be used for planned socio-technical systems that are not yet in operation. Is it feasible to derive valid conclusions from these models even without an extensive set of validation data?

New working procedures and system functionalities for air traffic controller – the operational concept

Within this chapter the essential components of the new working environment for air traffic controllers will be described. This operational concept forms the basis for the development of the controller workload model. Further information on the concept can be found in Herber (2008). The concept is based on the following key elements:

Technical functionalities

- 4-D trajectory prediction on the basis of flight plan data and an underlying aircraft performance model
- Short term conflict detection on the basis of ATC clearance and actual data (e.g. cleared flight altitude, actual position of aircraft)
- Medium term conflict detection on the basis of flight-plan data
- Monitoring tools to detect deviations from ATC clearance and flight-plan
- All changes made to planning data are forwarded to all working positions concerned, including the immediate display of updates.

Working procedures

- Verbal co-ordination will largely be replaced by appropriate electronic communication channels. In some cases new procedures do not require any co-ordination because of the more comprehensive picture of the traffic situation that is provided to controllers.
- System input is required for all clearances and co-ordination so that the system has the most recent data at all times.
- Air traffic controllers are supported by a medium term conflict detection tool in order to identify potential separation infringement, i.e. the planning controller has no need to perform manual conflict search any more.
- Air traffic controllers are also supported by short term conflict detection and flight path monitoring. These tools may increase safety or the maximum capacity, however they do not change the principle working procedures, e.g. the Executive controller still has to perform manual conflict search.

Airspace structure

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

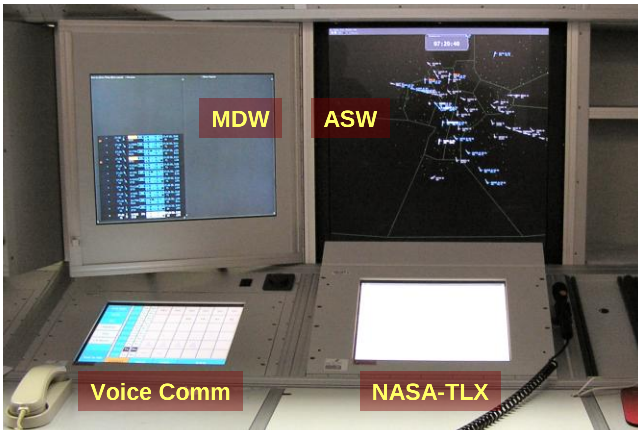

Fig. 1: Controller Working Position at the DFS R&D simulator (ASW=air situation window; MDW=main data window for flight-plan data). The lower right display is used to collect subjective workload measurements (e.g. NASA Taskload Index)

Model description

A number of models calculate controller workload directly from air-traffic related parameters like number of aircraft, vertical movement or number of potential conflicts. The models have been developed using several mathematical methods (e.g. regression analysis). Respective studies have been published by Kastner (2001), Kopardekar (2007) and many others.

However these models do not take into account different working procedures and the usage of system functionalities. Furthermore most of the models concentrate on one human actor. This is normally the controller position that is expected to be the bottleneck for further capacity increase.

Task-oriented models can take into account all human actors and have the ability to model changes in working procedures and system functionalities. There are also studies on these models. For example the DORATASK model developed by the ATC provider of Great Britain models around 10 main air traffic controller tasks (Phillips 1995). The task durations during a specific traffic situation are added and the capacity limit is reached at 70% of the total available time. The CAPAN model developed by Eurocontrol, which is used by a significant number of ATC providers in Europe is similar to the DORATASK approach, but models around 110 controller tasks (Cook 2007). As it was necessary for the approach to integrate procedures and system functionalities and to look at all human actors involved, the decision was taken to use a task-oriented approach.

In addition to the existing task-oriented models the model described in this article takes into account role availability, i.e. only if no other task of equal or higher priority is pending a task can be fulfilled, otherwise the task has to wait. The same applies for tasks that involve interaction between controllers, i.e. only if both controllers are available the task can be fulfilled. Furthermore activities that are expected to be processed in parallel according to the operational concept have been included in the model respectively.

In figure 2 the main components of the model are displayed. As input data for the ATC simulator the desired airspace and sectorisation is required as well as the flight-plan data and appropriate aircraft performance files. The ATC simulator generates a list of events along a timeline that are associated with controller tasks. For this study the DFS R&D simulator has been used. Those events include e.g. sector entries or exits of aircraft in the cruise phase or vertical transition and potentially conflicting aircraft. The event list is fed into the process model that represents the operational concept of the new socio-technical system. The software Bonapart® has been used for the process modeling.

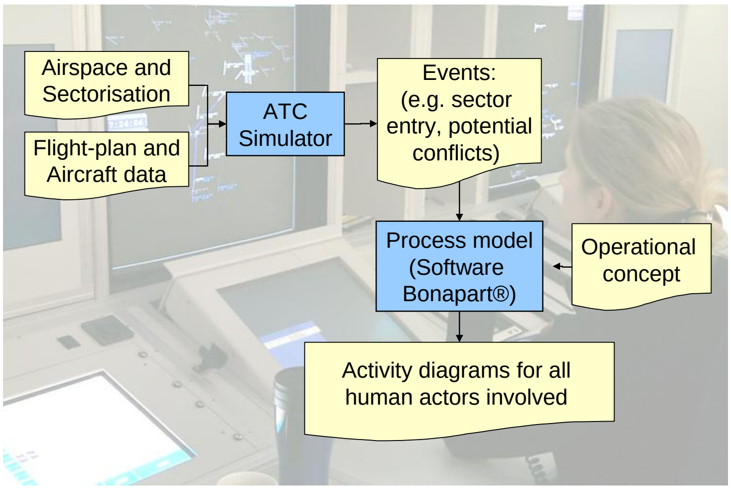

Fig. 2: Main components of the controller workload model

The process model generates activity diagrams for all human actors involved. In the diagram the resource occupancy time and the number of tasks in the waiting list are displayed. An example of the activity diagram is shown in figure 3.

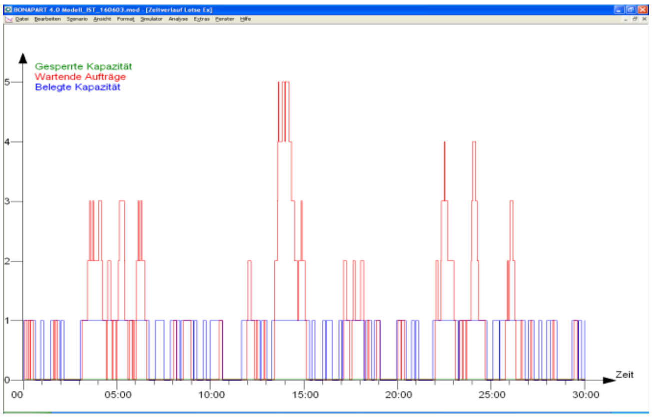

Fig. 3: Activity diagram for one air traffic controller (source: Bonapart® software). The blue graph shows the occupancy of the controller along the time line, while the red graph represents the number of tasks waiting to be processed.

Results of the model validation

Validation Data

In order to validate the model, data is required from air traffic controllers working according to the operational concept. This data was generated from a real-time simulation that took place in April 2007. The simulation was conducted at the DFS R&D facilities using a prototype ATM system that provided the new system functionalities. Further information on the real-time simulations and the operational concept can be found in Herber (2008).

Design of the study

Four sectors of the Karlsruhe control centre were assessed. All of the air traffic controllers participating held the required ratings for the sectors they were in charge of.

The traffic samples were based on real flight-plan data of the past. They were evaluated and optimised by air traffic controllers in order to increase the degree of realism. The traffic volume corresponded on average to today's capacity values, with peaks at around 150% of that value. The data for each of the two simulation runs was recorded for a period of one hour.

Comparison of the model with validation data

In order to judge the sensitivity of the model with regards to the traffic volume, the recorded data was divided into 5 minutes intervals. For each interval the model was compared with the simulation data. From past experience the categories <80%, 80-120% and >120% of today's capacity limits have been found suitable for analysis.

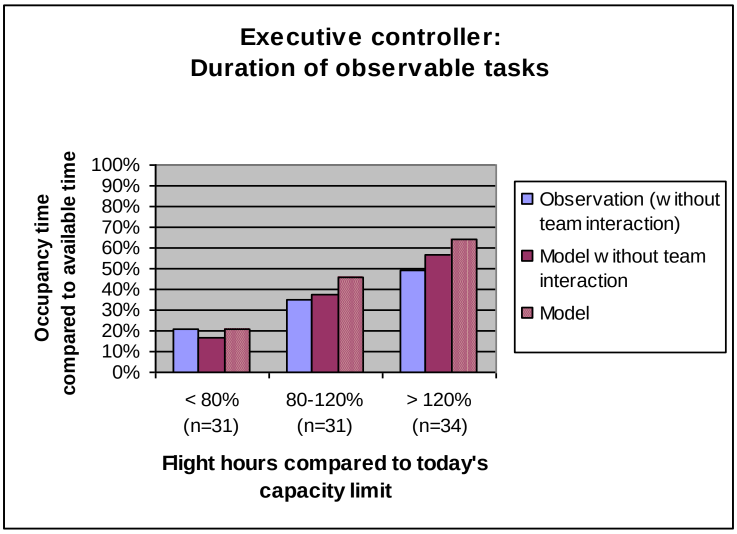

Fig. 4: Comparison of the model data and the observation data for the executive controller.

Figure 4 shows the occupancy time for the executive controller in comparison to the available time. According to the model the executive controller is occupied by observable tasks around 65% of his available time in the category >120% of today's capacity limit. As the task "team interaction" between executive and planning controller could not be recorded during the real-time simulation, the comparison has to take place without this task.

The data above shows a general match between the model and the observation. In low traffic volume the controller is a little more occupied than would be needed according to the model, whereas in high traffic conditions the controller seems to be more efficient than the model forecast.

In spite of the good match on average the standard deviation of the difference between observation and the model is quite high (around 42 seconds or 14% of a 5 minutes interval). One reason for this high spreading can be seen in the different application of the working procedures by different air traffic controllers. Although the operational concept describes the working procedures in more detail than in today's operations, the strong inter-personal differences continue to exist.

The respective analysis for the planning controller shows similar results with regards to the general match and the standard deviation (deviation around 30 seconds or 10% of a 5 minutes interval). Remarkably the model has forecasted the real low occupancy time of the planning controller which has not been expected by most experts for the new socio-technical system. Furthermore the model and the observation shows no increase from the 80-120% to the >120% category. As traffic increases conflict resolution becomes more complex and more likely has to be resolved by the executive controller on short notice. The potential for the reduction of complexity by early resolution of conflicts seems to be limited in the new socio-technical system.

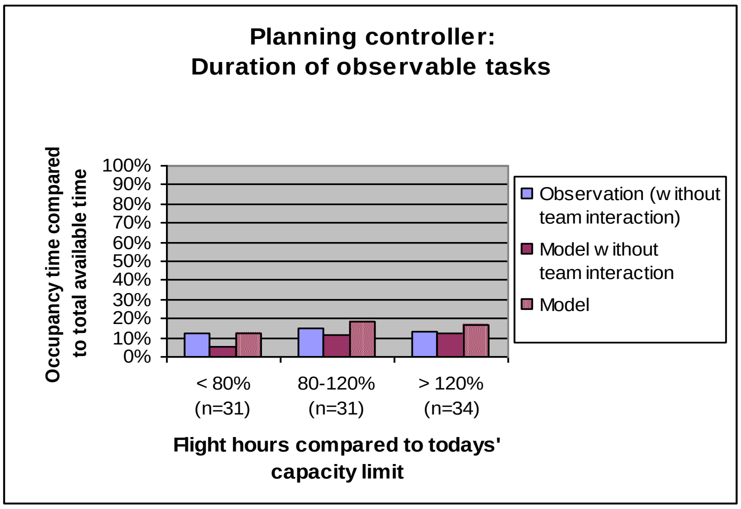

Fig. 5: Comparison of the model data and the observation data for the Planning controller.

Conclusion and future work

From the results shown it can be concluded that task-based workload models have the ability to predict the characteristics of future socio-technical systems in air traffic control. On average the model showed a good match with the validation data. Therefore future enhancements to the operational concept can be evaluated even without extensive validation data. Following this approach there is the possibility to achieve a higher level of maturity for the operational concept before entering the real-time simulation phase.

However the standard deviation between model and observation for single datasets appears to be quite high. This indicates inter-personal differences in the application of procedures and/or a variety of traffic situations that cannot be resolved by standardized actions. Therefore the model has its limitation when looking at a specific traffic situation. On the other hand a stronger standardization of the working procedures would help workload models in achieving better results.

Future work includes the optimization of the model as well as the validation with more extensive data. As the new system functionalities are expected to become operational in the Karlsruhe upper area center in 2011, training for all controllers will take place in 2010. It is planned to record controller tasks and system inputs during this training phase. The model is expected to be used for the evaluation of further enhancements to the operational concept. For the medium term it can be envisaged to use task-based workload models for the estimation of expected controller workload in daily operations.

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