33RD CONGRESS
OF THE INTERNATIONAL COUNCIL
OF THE AERONAUTICAL SCIENCES
STOCKHOLM, SWEDEN, 4-9 SEPTEMBER, 2022

DESIGN & VALIDATION OF A FLIGHT CENTRIC WORKLOAD MODEL INCLUDING ATC TASK CHANGE & CONSIDERING INFLUENCING FACTORS

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Abstract

Airspace capacity is limited by the ATCOs' control resources, which depend on their workload. For a sectorized airspace, a variety of workload models for distributing air traffic equally among controllers exist but approaches for a sectorless airspace are absent. This paper is the first to establish a workload model for Flight Centric ATC by adapting a workload model for sectorized airspace.

Keywords: flight centric, workload model, assignment strategy, human-in-the-loop simulation

1. Introduction

The controller's resources can be considered as a critical factor for airspace capacity. The number of aircraft that can be controlled by an Air Traffic Control Officer (ATCO) depends on the controller's workload. A more even distribution of the workload between the controllers leads to higher capacity and more efficient use of the airspace. This can be achieved with the help of a workload model. Despite the fact that a variety of workload models for sectorized airspace can be found in the literature, there are still no approaches for a sectorless airspace (Flight Centric Air Traffic Control (ATC)) to distribute the workload between controllers more evenly. The concept of Flight Centric ATC describes the assignment allocation of individual aircraft, located anywhere in the Flight Centric Area, to controllers without dividing the airspace into sectors. In this paper, by adapting a workload model of the sectorized airspace, a workload model for Flight Centric ATC is established for the first time.

2. Flight Centric ATC

2.1 The Concept of Sectorless Air Traffic Management

In the conventional airspace usually two ATCOs are assigned to each sector and are responsible for controlling the air traffic in that sector [1]. A distinction is made between Executive Controller (EC) and Planning Controller (PC). The EC is in charge of collision avoidance and prevention of separation shortfall. The PC, on the other hand, is responsible for coordinating with neighboring sectors and monitoring the entry and exit of aircraft (A/C). In addition, the PC schedules the air traffic for the sector and is considered a back-up for the EC [2]. As traffic increases, sectors are further subdivided into smaller sectors to keep the workload of ATCOs at an acceptable level [3]. The resulting additional coordination effort limits this approach. Smaller sectors also reduce the possibility for tactical and strategic maneuvers [1].

Instead of dividing the airspace into different sectors, Flight Centric ATC considers the en-route airspace as one large airspace [3]. Figure 1 shows the conventional airspace structure and the structure in Flight Centric ATC. [4] were the first to address this concept. Instead of assigning a sector with all aircraft inside to a controller team, each controller is responsible for a certain number of aircraft [4]. The assigned aircraft are no longer geographically bound to the sector but can be located anywhere within the airspace [5]. Thereby the controller team of Executive and Planner is replaced by Single Person Operations [2], where one controller is responsible for one aircraft during the entire trajectory in the Flight Centric area [6]. Controllers communicate only with the aircraft assigned to them [7]. Traffic surrounding these aircraft is controlled by other controllers [5]. In a conflict, clear rules determine which ATCO is responsible for solving the conflict [1].

In some cases, the original tasks of the PC (e. g., coordination with other sectors) are eliminated, and the new Flight Centric controller is assigned the tasks, or they are taken over by tools [8].

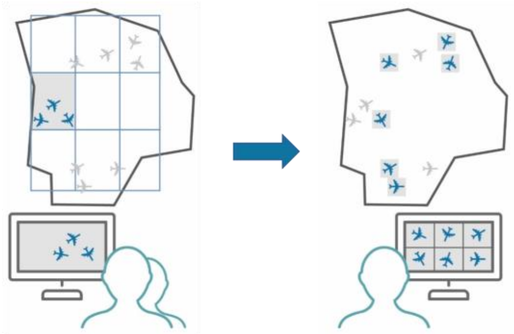

Figure 1: Exemplary depiction conventional airspace and Flight Centric ATC [9]

2.2 Change of ATCO Tasks in a Sectorless Environment

A major change in the sectorless environment is the increased usage of tools such as the allocation algorithm, filtering, conflict detection & resolution (CD&R) and probing which support the controller in managing the air traffic. For allocating aircraft to ATCOs different strategies can be applied: Equal allocation of aircraft among controllers, trajectory- or workload-based allocation. The filtering tool will only show the A/C relevant to the ATCO, thus, reducing the information overload and creating a better overview of the relevant traffic situation. Since a larger area needs to be monitored in Flight Centric ATC, the introduction of a CD&R tool becomes a necessity [2]. Through this tool, the controller is warned if conflicts emerge. A distinction is made between Short Term Conflict (STC) and Mid Term Conflict (MTC). Short Term Conflicts warn of loss of separation [10]. If the defined minimum separation is or could be violated within a short look-ahead time (usually two minutes), the controller receives a visual warning on his radar screen [11]. The Mid Term Conflict Detection (MTCD) tool works in a more predictive manner. Here, the tool runs continuously in the background and checks whether a conflict will occur at one of the controller's assigned A/C in the next 20 minutes. If a conflict is detected, the Less Impacted Flight algorithm determines which controller must resolve the conflict. If there is more than one resolution method, a priority list is generated based on the criteria of traffic complexity, the additional flight miles and the additional fuel required [2]. Before a selection is made, the controller has the opportunity to test the different maneuvers through the probing tool. The controller does not have to follow the suggestions regarding possible solutions. If the ATCO decides on a proposed solution, the planned maneuver is selected in the tool and possible conflicts along the trajectory are calculated [10]. Thus, a conflict-free solution can be searched for [7].

3. General Background and Related Work

3.1 Workload Definition

In the literature a distinction between taskload and workload is made. Taskload includes all the tasks that an air traffic controller has to complete. Workload is the subjective experience of demand [12]. Thus, workload describes the interaction of taskload, the controller's experience, age, daily shape, and work environment [13]. It is a non-linear relationship between taskload and workload [14]. Often, the workload is determined based on the time spent on each control task, incorporating the controller's knowledge and workload capacity. Objective factors such as the number of aircraft or conflicts and human factors are included [15]. [16] defines workload as a quantitative measure of work performed and qualitative perception of a person to be able to perform the work. [17] refers to workload as the cost a person must incur to achieve a certain level of performance. [18] establishes a mental workload model where the demanded mental resources (taskload) and available mental resources of the ATCO are compared. Workload defined as a percentage, reveals how much time of an hour is needed to control the aircraft [19]. At 70 %, or more than 41 min. of control activities per hour, the controller is overloaded. According to [20], the average workload should be less than

80 % of the total workload. 90 % workload should be achieved in no more than 2.5 % of the working time. This keeps safety buffers free for mental activities and emergencies [21]. Both, too low and too high levels of workload can lead to errors. If the workload is too low, boredom can cause a reduction in situational awareness [22].

Different workload measurement methods can be distinguished. They can be divided into three categories: subjective measurement, physiological measurement and activity monitoring/behavioral [21]. Physiological measurements as well as observations of controller behavior, are referred to as objective measurement procedures. Subjective measurement procedures are limited by unwillingness to report problems and memory effects when the interview takes place after the simulation has ended [23]. Due to the simple and inexpensive implementation, subjective measurements are nevertheless used for surveys in ATC. For this purpose, ranking scales are defined that differ in the number of factors or dimensions considered. Measurements that consider only one factor are referred to as unidimensional [21]. Multidimensional measurements, on the other hand, use several subscales. The results are then combined into a composite workload rating. This is intended to reduce bias [24]. Subjective workload methods include the Self-Assessment Technique, Workload Assessment Questionnaires (after completing the last task), and Third Person Assessment by an uninvolved person. If the Instantaneous Self Assessment (ISA) scale is used, the controller assigns his current workload to one to the five categories from 1 = under-utilized to 5 = excessive. The query is performed at regularly recurring intervals and indicates the resources currently required [25]. Observing the air traffic controller during the execution of his tasks is an important method for measuring the workload. A distinction is made between observing the primary or secondary task. Hereby, specific performance indicators are measured [26]. If the primary task is considered, the performance of the controller in the primary task is measured. Examples include measuring speed, accuracy, and control activities. If the residual attention or capacity of an ATCO is to be measured, this is done by the secondary task [24]. One way is to measure the time until the secondary task is completed. In this case, work may only continue if the workload of the first task allows it [27]. Several papers describe the physiological measurement. For example [28] is analyzing the heart activity to figure out the stress and corresponding workload and [29] is using an electroencephalograph (EEG) to monitor brain activity. The latter shall investigate the possibility of neural mental monitoring of the workload.

3.2 Mathematical Models to Predict Workload

In addition to the presented methods to measure workload, various studies pursue a mathematical approach to predict workload by setting up a workload model for the sectorized airspace. The first model is from EUROCONTROL and provides a simplified formula of the Capacity Analysis (CAPAN) model. All controller tasks are assigned to one of three categories: Routine task, level change monitoring task, such as climb and descent, and conflict monitoring task. The formula is composed of the standard task duration and occurrence. The simplified formula provides good results and it is possible to calculate the workload of the sector [30]. With the introduction of a new ATC system, DFS developed a time-based workload model. The task times are estimated and then validated in real-time simulation considering the occupancy density of the sector and additional workload for conflicts. The parameters are adapted depending on the air traffic control system and the control centers [21]. A distinction between non-telecommunication and telecommunication workload is made in [31]. The corresponding task times are measured from practical ATCO work and the frequency occupation extracted from flight data. A macroscopic workload model is presented by [32] to examine the influence of traffic density, sector geometry, flow direction, and conflict rates on workload. Four aggregated tasks are considered: Background, transition, recurring, conflicts. The formula is composed of the average time and rate of a task. The values are determined by trials and regression. In 2011 [33] complemented the model by a weather component which shows the increase of the coordination effort.

The analytical Total Airspace Workload Measurement Model (TAWMM) of [34] is based on task times and changing priorities of tasks. Using the Turkish airspace as an example, the workload of en-route air traffic controllers is determined. In the considered model, four main tasks, Monitoring

(WL_{MON}), Conflict Detection and Resolution (WL_{CDR}), Coordination (WL_{COR}) and Aircraft Manoeuvres (WL_{ACM}), are defined and evaluated with weights, which are based on ATCOs ratings, and task times.

4. Workload Model for Flight Centric ATC

4.1 Mathematical Model

From the presented workload models, the model of [34] was selected and adapted for Flight Centric ATC. The subdivision into different types of conflicts and maneuvers as well as the possibility to calibrate the workload model by weighting factors created a good starting point and was thus kept. In order to use the workload model of [34] in sectorless airspace, new controller tasks were defined and the existing task formulas were adapted.

Monitoring

The task of monitoring becomes less important in FCA. With the tool support, important situations are automatically displayed to the controller. In the adapted flight centric model, monitoring is defined by the number of aircraft under control of the controller and the corresponding control period. A distinction is made whether the aircraft has already been assumed by the controller (A) or not (B). WL_{MON} gives the summation of all aircraft in both states A and B at a point in time.

$$WL_{Mon} = \sum_{t=0}^{t\_max} WL_{MON_t} \tag{1}$$

The consideration of conflicts is divided into three parts: Conflict Monitoring (Mon), Conflict Detection (Det) and Conflict Resolution (Res). Since the conflicts are displayed at an early stage by the tool support (often before the aircraft is in the airspace), the controller has no longer to actively search for conflicts. The time until the controller has the actual conflict point selected on the radar screen is referred to as conflict detection. If a conflict has already been detected, but the execution of the solution is not yet possible, this period corresponds to Conflict Monitoring.

Conflict Monitoring/Detection

Because conflict monitoring is a persistent task of the controller a constant time is applied in each time interval as long as the conflict exists. Separate implementation of conflict monitoring and conflict detection is difficult on the system side. For this reason, the actions Conflict Monitoring and Conflict Detection are combined into one task. The summation $WL_{CDR_{MON\_DET}}$ of the different conflict monitoring and detection states is shown below.

$$WL_{CDR_{MON\_DET}} = \sum_{t=0}^{t\_max} \sum_{j=0}^{n} WL_{CDR_{MON\_DET}}{}_{j,t} \tag{2}$$

Conflict Resolution

Instead of looking at different conflict types as in the case of [34] the method in Flight Centric ATC is to concentrate on the resolution strategies: FL change, direct to, heading change and turn right/left. WL_{CDR} represents the total conflict resolution time.

$$WL_{CDR} = WL_{CDR_{MON\_DET}} + \omega_{CDR,Res} \sum_{k=1}^{4} (N_{CDR,Res_k} \cdot C_{CDR,Res_k} \cdot T_{CDR,Res_k}) \tag{3}$$

The task coordination listed by [34] is omitted in the Flight Centric ATC simulation. Coordination between sectors of the same ACC is not included in the adapted workload model due to the structure of Flight Centric airspace. In the simulation used, no military units are considered, and the simulation environment does not allow coordination with surrounding countries. In Flight Centric ATC, the coordination tasks are of less importance and can be disregarded in the workload model.

First/Last Contact

As an additional controller task first/last contact is introduced in the Flight Centric ATC workload model as WL_{CON}. Aircraft flying into the airspace from the sides and from below have to be accepted by the controller. To achieve an overview about the aircraft under control the initial contact is made (CON_1). For the pilot, it is the confirmation that the aircraft has been identified. After passing the airspace, the aircraft is handed off at the airspace boarder to the next frequency/ATCO (CON_2). In the paper of [34] these tasks are included in the coordination category.

$$WL_{CON} = \omega_{CON} \sum_{l=1}^{2} (N_{CON_l} \cdot C_{CON_l} \cdot T_{CON_l}) \tag{4}$$

Top of Climb/Top of Decent

Two special types of first/last contact are aircraft which are entering or leaving the Flight Centric airspace and hence having their Top of Climb (TOC) or Top of Decent (TOD) within the Flight Centric area. A separate consideration of TOC and TOD does not take place in the workload model since this is executed by a simple change of the flight level. TOD and TOC are considered in the adapted formula by WL_{TOC}.

$$WL_{TOC} = \omega_{TOC} \sum_{h=1}^{4} (N_{ACM_h} \cdot C_{ACM_h} \cdot T_{ACM_h}) \tag{5}$$

Aircraft Manoeuvres

Aircraft maneuvers are calculated identically to [34] in the workload model adapted to Flight Centric ATC and correspond to the resolution strategies explained in the task conflicts. Compared to [34], a right or left turn is listed as a separate manoeuvres. This leads to the four manoeuvres,

- FL change (ACM_1)
- Direct to (ACM_2)
- Heading change (ACM_3) and
- Turn R/L (ACM_4),

which are summed up in WL_{ACM} as follows:

$$WL_{ACM} = \omega_{ACM} \sum_{h=1}^{4} (N_{ACM_h} \cdot C_{ACM_h} \cdot T_{ACM_h}) \tag{6}$$

Total

This concludes by the total workload formula *WL,* supplemented by the components WL_{TOC} and WL_{CON}.

$$WL = WL_{MON} + WL_{CDR} + WL_{CON} + WL_{TOC} + WL_{ACM} \tag{7}$$

4.2 Human-in-the-Loop Simulation Scenarios

For calibration and validation of the workload model, a human-in-the-loop simulation is performed. The DLR TrafficSim provides the Flight Centric ATC simulation environment of the Hungarian airspace (above FL325) according to the airspace data published in the Hungarian Aeronautical Information Publication (AIP). The assignment of aircraft to the controller is executed by the assignment center. The data used for the Flight Centric ATC simulation of the Hungarian airspace is from 06/2015 and was provided by EUROCONTROL in the "EUROCONTROL R&D Data Archive". From the data, the medium, high and very high scenarios can be extracted.

The anticipated conflicts during the simulation can be divided into the conflicts within the Hungarian Flight Centric Airspace (HUFCA) and at the boundaries of the airspace. Furthermore, multiple conflicts are listed separately. A multiple conflict exists if there is another separation violation for an aircraft within a period of five minutes. Laterally the separation is set at 6 NM. Vertically a separation of 950 ft is specified when the aircraft is at a constant altitude, and a separation of 2950 ft is specified when the aircraft is climbing or descending. In the experiments of this work, these two scenarios are used to test the workload model over a wide range of activity.

5. Calibration and Validation

5.1 Simulation Design

The simulation is divided into two phases. The first round of experiments has a scope of five days and deals with the calibration of the workload model. Six simulation runs take place in succession per day. Three aircraft controllers are tested with two scenarios each. This results in a total of 30 simulation runs in the first round of testing. For the second round of testing, the validation, eight days are scheduled, divided into two weeks. During this time, 30 simulation runs are performed. In the validation, however, not one controller is tested at a time as in the calibration, but five controllers participate in the simulation at the same time.

Due to the change of task times in Flight Centric airspace, it is necessary to determine new times for each task. Therefore, Flight Centric Experts are used as pseudo controllers and each of them runs through the medium scenario once and once through the very high scenario. The task times of the particular controller tasks are calculated by averaging over all time measurements. The average task times are used as input for the validation. During the simulation, the controller must also indicate his workload through the ISA. The ISA is queried at recurring intervals of five minutes. In addition to the task times, weighting factors are determined in the calibration. For this purpose, each controller fills in the so-called Assessing the Impact of Automation on Mental Workload questionaire after running the simulation. The adjustment of the weighting factors is done in such a way that the workload measured by ISA and calculated by the formula differ as little as possible from each other. The results of the first round of runs are thus average task times and sets of weighting factors. Both quantities are inserted into the workload formula and used as input for the validation runs.

Two types of validation are to be performed. In the first variant, the workload model calculates the workload separately from the simulation. The frequency of a task, which serves as the input variable of the model, is extracted from the simulation. The calculated workload is then compared with the workload specified by the controller in the ISA. In this first step, the aim is to check whether the new workload model can correctly identify the workload of the controllers, given a random distribution. The second variant is the indirect verification of the workload model. Here, the workload is calculated dynamically for each change in the situation. Thus, a statement about the current workload of the controller can be made at any time. If a new aircraft has to be assigned to a controller, the current workload is compared and the controller with the lowest workload level is selected. The equal distribution of the taskload is intended to achieve the best possible equal distribution of the workload between the controllers.

Table 1: Average task times

Task	Average task time in s
Conflict Resolution	
FL change	17,41
Direct to	19,48
Heading change	18,87
Turn R/L	17,44
First/Last Contact	
First contact	13,32
Last contact	11,27
Top of Climb	19,64
Aircraft Manoeuvres	
FL change	17,41
Direct to	15,84
Heading change	24,97
Turn R/L	22,01

To check whether there is an even distribution, scenarios where the new workload model is responsible for the allocation must be compared with scenarios with random allocation, divided according to traffic volume. Based on the values of the ISA, which is queried every five minutes, a comparison is possible. For objective measurement the heart data of the controller is recorded. Because the variability of the human heart already differs at rest and therefore cannot easily be compared, it is necessary to determine the difference within a person. The baseline measurement is taken directly before each simulation run, measuring the resting heart rate for approximately five minutes.

5.2 Results

5.2.1 Simulation Campaign 1: Calibration

In the first campaign, 15 subjects between the ages of 24 and 49 participated as pseudo ATCOs. Of these, five were females and nine males (one person did not provide any information). The experience with Flight Centric ATC and the operation of a controller interface varied from 1 = hardly any experience to 5 = well informed/participated in several simulations. Eight subjects had previously participated in a simulation as a controller and seven subjects had even participated in a Flight Centric ATC simulation before. Five subjects do not have previous pseudo controller experience but were able to demonstrate partial knowledge as a pseudo pilot. In addition, before participating in the runs, all subjects underwent a four-hour training session.

The evaluation of the task times was carried out sequentially. With the help of the click record, the individual inputs of the controller into the system can be traced and through screen and voice recordings a comprehensive picture of the controller actions in the simulation can be set up. Thus, the start and end times for each task can be determined and the actual task time calculated. From the calculated task times, an average task time is then formed for each controller task. The average task times are shown in Table 1 and are used as input to the second set of simulations.

Table 2: Weighting sets of the workload model

Tasks	Symbol	Set 1 (W1)	Set 2 (W2)	Set 3 (W3)
Conflict Resolution	$\omega_{CDR,Res}$	2,00	2,11	2,00
FL change	c_{CDR,Res_1}	1,20	1,20	1,20
Direct to	c_{CDR,Res_2}	1,40	1,40	1,40
Heading change	c_{CDR,Res_3}	1,30	1,30	1,30
Turn R/L	c_{CDR,Res_4}	1,20	1,20	1,20
First/Last Contact	ω_{CON}	1,00	1,70	1,00
First contact	c_{CON_1}	1,00	1,89	1,00
Last contact	c_{CON_2}	1,00	1,80	1,00
Top of Climb	ω_{TOC}	1,70	1,96	1,70
Aircraft Manoeuvres	ω_{ACM}	1,70	1,86	1,70
Flight level change	c_{ACM1}	1,20	1,20	1,20
Direct to	c_{ACM2}	0,90	0,90	0,90
Heading change	c_{ACM3}	1,60	1,60	1,60
Turn R/L	c_{ACM3}	1,50	1,50	1,50
Conflict Monitoring und Detection				
Before assuming, responsible	$\omega_{BeforeEntry,orange}$	0,80	0,80	0,80
Before assuming, not responsible	$\omega_{BeforeEntry,yellow}$	0,60	0,60	0,60
In FCA, responsible	$\omega_{FCA,orange}$	1,40	1,40	1,40
In FCA, not responsible	$\omega_{FCA,yellow}$	1,20	1,20	1,20
Monitoring	ω_{MON}	0,05	0,05	0,07

Before assuming	$\omega_{BeforeEntry}$	0,10	0,10	0,10
In FCA	ω_{FCA}	0,20	0,20	0,20

The second objective of the first round of experiments is to determine the weights for the workload model. For this purpose, six simulation runs are selected and the workload is calculated using the workload model. The workload is summed up over all tasks and calculated in five-minute intervals. Then the workload values are converted to the ISA scale. The conversion allows a comparison of the ISA values given by the controllers in the simulation and the calculation of the workload model. The data can be used to create step diagrams. The weightings previously set to one in the calculation were now be adjusted. The aim was to minimize the deviation between the curves, which can be achieved with the weights. Three sets were defined. Set 1 is the basic set. With this weighting, the deviations of the curves are minimized. In the second set, the results of the AIM questionnaires are used as weights. Set 3 is based on Set 1 and differs only in the weighting of monitoring. Instead of 0.05, the general monitoring weight is set to 0.07 to analyze the impact of monitoring on the overall workload.

5.2.2 Simulation Campaign 2: Validation

In the validation five air traffic controller are working at the same time. In one run ten subjects (five controllers and five pseudo pilots) take part. As controllers 18 different people between 24 and 49 participated with the division six female and twelve male. Every controller runs through scenario one to five with the same weighting set.

The first step of the evaluation is comparable to the first experimental campaign. For all scenarios with random allocation of the aircrafts, the workload has to be calculated first.

The first variant of validation is to check whether the model can identify the subjective workload. For this purpose, two scenarios without the inclusion of the workload model as an allocation strategy are used. A good representation of the workload by the model can be seen in the step diagrams (Figure 2). The level of the curves of the ISA and the workload calculation is on the same level, only shifted forward in time by five minutes. This means that in the calculation the workload drops to one earlier and rises to two earlier. On the right graph, the curves match up to minute 40. After that, the calculated workload decreases, the ISA evaluation remains at a higher level. Both examples confirm a possible identification of the subjective workload by the model.

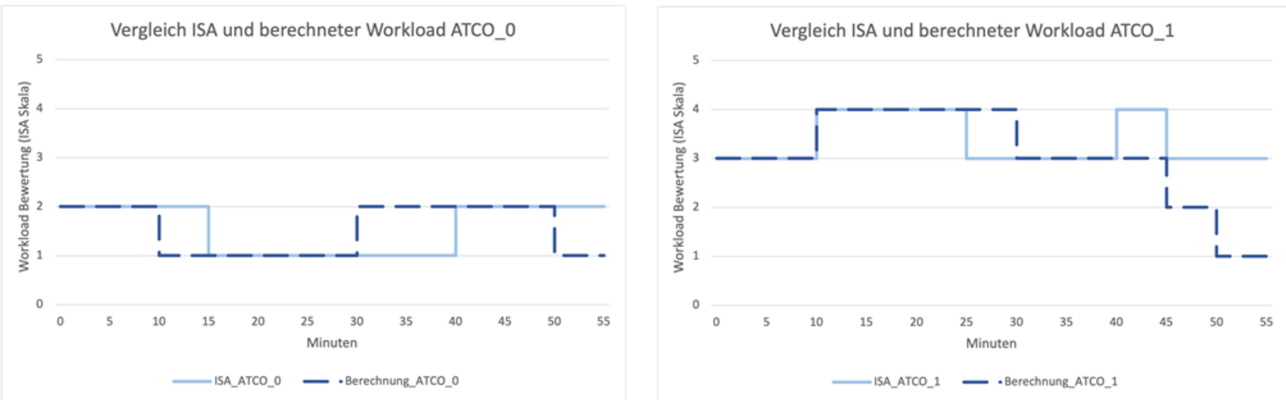

Figure 2: Comparison ISA and calculated workload in the medium scenario (left) and very high scenario (right)

Nevertheless, not all scenarios can be mapped well by the workload model. In some scenarios the self-assessment is on a higher level than the calculation of the workload model. A possible solution is to adjust the thresholds of the workload model conversion to the ISA scale. It is striking that short changes in the level of the ISA are often not adequately represented by the model. Since the ISA is a subjective scale that each subject interprets differently, it is difficult to establish a generally valid model for all subjects. A certain degree of deviation is to be expected.

The second variant is the indirect examination of the workload model. The simplest comparison is to look at the ISA scores between the medium scenarios with random allocation and with workload-based allocation and to do the same for the very high scenarios. The values show, in both groups and all weights, a lower average ISA score in the very high workload scenario compared to the very high random scenario. This confirms that with the workload model in the very high scenario a better distribution of the workload between the controllers can be achieved than with a random allocation. This cannot be confirmed for the medium scenario. The average ISA values of the two scenarios differ only slightly, although the evaluation of the medium, random scenario is somewhat lower. Due to the low traffic volume in the medium scenario, the different number of assigned aircraft do not vary as much as in the very high scenario.

During the tests, it was found that despite the random distribution, each controller was assigned a similar number of aircraft. Especially in the medium scenario, the workload is mainly dependent on the monitoring of the aircraft. Necessary actions, such as conflict resolution, occur only sporadically. Thus, equating the workload with the pure number of aircraft could lead to similar results as the workload model.

Heart rate variability (HRV) is listed as an objective variable for evaluating workload. The heart rate refers to the number of beats of the heart per minute. HRV describes the variation of beat intervals and can be determined by different methods [35]. In this work, the frequency domain method was used. In the study by [35], it was found that heart rate variability demonstrates a significant response to stress.

In the simulation runs, after the baseline measurement, the heart rates of the subjects are recorded by a chest strap while running through the scenarios. One way to compare the data is to plot the LF/HF ratio as a third variable in a step diagram. The ISA and the workload model refer to the primary axis and the LF/HF ratio to the secondary axis. In Figure 3, left, a similar progression of ISA and LF/HF ratio can be observed. If the ISA rating increases to three between minute ten and 15, the LF/HF ratio is also increased and then decreases again. Also, the two further spikes from one to two of the ISA rating are slightly shifted forward in time in the LF/HF. Similar results can be extracted from Figure 3, right. As in the ISA, three elevations in the LF/HF ratio can be seen there, although in general the fluctuations are small, as in the ISA assessment.

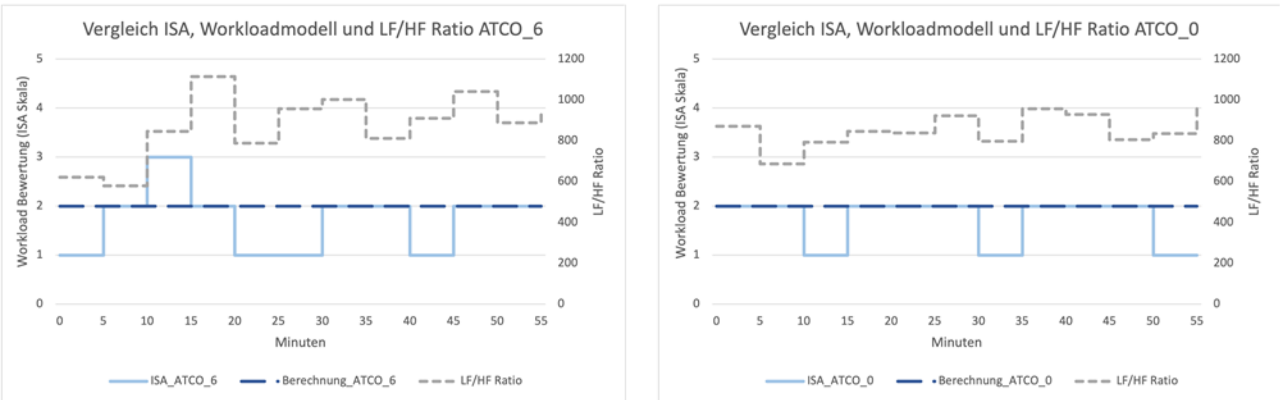

Figure 3: Comparison ISA, workload model and LF/HF ratio in the medium WL scenario between two subjects

Another way to compare the data is to indirectly check the workload model. Within a scenario with WL allocation strategy, it is analyzed whether the modified LF/HF ratio of all ATCOs in this scenario show a similar course and level. If this is the case, this can be interpreted as a uniform distribution of WL between controllers, thus confirming the functioning of the model. Before the comparison it is necessary to subtract the baseline measure of each controller's data from the LF/HF ratio. The results of the modified LF/HF ratio are shown in Figure 4. The graph on the left describes the modified LF/HF ratio of ATCO 0, 1, and 7 in the medium scenario. The curves of ATCO 0 and 7 are at a comparable level, whereas the modified LF/HF ratio is higher overall despite similar peaks for ATCO 1. In the very high scenario only the data of two controllers are available. These represent the fluctuations of the LF/HF ratio in both curves and are similar in the level of the ratios.

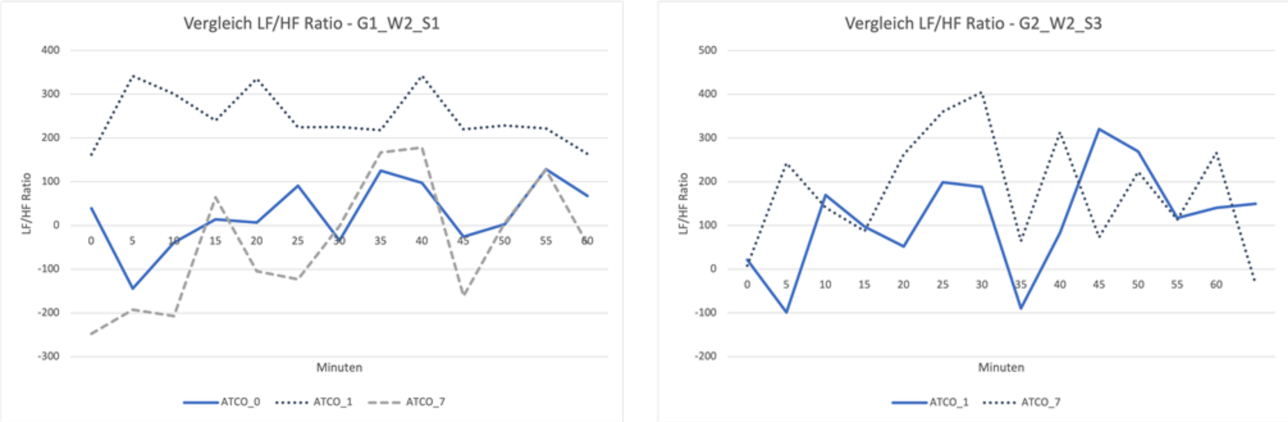

Figure 4: Comparison modifies LF/HF ratio of different ATCOs

Fluctuations of the heart rate variability of different subjects is not unusual and can be traced back to factors like sleep deprivation, coffee and alcohol consume and family stress.

The medium scenarios do not show significant differences in HRV between subjects. The analysis of the very high scenario shows smaller differences of the curves than in the medium scenario. A better accordance of the curves levels describes a more equal distribution of the workload. This interpretation must be taken with caution. It is necessary to compare more scenarios and to calculate metrics to support the statement.

As a last step of the evaluation the influencing of the weighting factors is considered. Because of the high variation of factors (subjects, days, scenarios, etc.) it is not possible to draw conclusions for each of the weighting sets. However, none of the tested sets show remarkability in the function. But the task monitoring is still a big part of the calculated workload.

6. Conclusion and discussion

In this work different thesis are examined. The first goal is to determine average task times for Flight Centric ATC and to be able to use these in an adapted workload model. In the future it may be necessary to re-measure these times with active air traffic controllers. In the second step it is tested if the adapted workload model can identify the subjective workload of a random allocation of aircraft without regards to the traffic volume (medium/very high) and the subject. The results of the direct examination of the workload model show in many of the random scenarios a good agreement between the ISA and the workload calculated separately from the simulation. Nevertheless, inaccuracies and deviations occur in some scenarios. This is not surprising, since the ISA with its scale from 1 to 5 has only a low resolution. Likewise, the limits for converting the workload model to the ISA scale are the result of testing. This could be improved by an analytical determination of the limits. The workload value is mostly composed of the controller's taskload and is supplemented with individual mental factors and tuning parameters. The tuning is done after the first test campaign based on the ISA. It must be kept in mind that the ISA is an imprecise, error-prone parameter. Since the subjects differed to some extent between the first and second campaign and the subjective ISA can nevertheless be identified well by the workload model, it shows a transferability of the tuned model to different subjects. In addition, there are no noticeable differences between the medium and very high scenarios. In general, the data shows a good agreement, so that the second thesis can be accepted.

In addition, the workload model is tested as an assignment strategy in the experimental campaign. No significant differences can be achieved in the medium scenario compared to the random scenario. In the very high scenario, the ISA evaluation decreases with the implementation of the workload model.

Lastly it is analyzed if the LF/HF ratio can be used as an objective metric to measure stress and therefore the controller’s workload. The project report by [35] confirms that heart rate variability responds to stress. The individual scenarios considered fit into this picture. The correlation between the increase of the heart rate variation and the increase of the ISA is observable. However, this is not confirmed by all scenarios.

Overall, it must be stated that measurement procedures are always subject to a certain degree of inaccuracy. They can be influenced by a multitude of unknown factors, which can introduce noise or superimpose correlations.

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8. Copyright Statement

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