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The Role of Workload for Work Organisation in a Remote Tower Control Center

Christoph Moehlenbrink, Anne Papenfuß, Jörn Jakobi
Institute of Flight Guidance
German Aerospace Center (DLR)
Braunschweig, Germany

{Christoph.Moehlenbrink | Anne.Papenfuss | Joern.Jakobi}@dlr.de

This paper focuses on the role which workload can play for work organisation in a future remote control tower center. Nowadays you can find a control tower next to each airport. A tower is equipped with a team of controllers which maintain the declared surface movement rate under all weather conditions within the aerodrome visibility operational level (AVOL) while maintaining the required level of safety. Novel concepts for air traffic control (ATC) consider remotely controlling regional airports from a control center that includes working positions for the control of multiple airports. When evaluating such controller working positions, workload is a crucial concept. A thorough analysis of workload in a remote tower domain is used in the paper at hand to draw conclusions for the work design of a remote control center. In a simulator study at the Institute of Flight Guidance of the German Aerospace Center a remote center working environment was realized for controlling two regional airports. In a 3-factor experimental design it was investigated empirically how workload ratings differed when (1) one controller was responsible for two airports; or when two controllers were responsible for two airports with (2) each controller responsible for one airport or rather (3) working in a team responsible for both airports. Workload ratings were gathered online using the Instantaneous Self-Assessment scale and after each simulation run using the NASA-Task Load Index. In addition, expert participants judged specific traffic situations in the single operator condition for two airports in respect to its operational feasibility. The data are analysed and discussed in respect to what can be learned for work organisation and future ATC concepts. This paper, thus, contributes to better understanding the basic conditions a controller needs to meet his obligations as an air traffic controller. Such knowledge is indispensable when developing novel concepts for remote control of regional airports.

remote tower control, work organisation, workload, safety

I. Introduction

Within the DLR-Project RAiCe (Remote Airport Traffic Control Center) novel solutions for air traffic control of small-sized airports are developed. The concept aims at controlling two or more airports from a remote tower center. For this purpose, a live video stream is transferred from the location of the airports to the remote center. The main motivation to develop a concept for remote control of small airports is the cost reduction [1,2]. From a research perspective and the operational side the concept includes the need to understand the changes for the human operator, when air traffic control is shifted from a tower into a remote center. Operational experts therefore have to be involved into the design process as early as possible. Several aspects have been addressed in the recent years concerning this topic: In an early phase of remote tower research a cognitive work analysis at Leipzig airport (Germany) was conducted, identifying the outside view as a crucial source of information to allow for aerodrome air traffic control [1,3]. In one study the influence of replacing the outside view has on the point in time, when controllers detect safety relevant aspects of aircraft [4]. The quality of the video, its resolution, contrast and brightness are relevant variables that influence what and when a controller can detect events on the video [1,2,3]. In another study by Papenfuss and collegues, twelve controllers were confronted with the remote tower concept in a simulator [5]. The participants had to control traffic (VFR and IFR) from a Remote Tower Operations (RTO)-Console including a representation of the outside view on four 21-inch displays. Post-trial questionnaires were used after each simulation run, to evaluate the influence on workload and situational awareness. In addition usability aspects within the novel work environment were considered and interview data gathered broaching the issue of remote control [5,6]. These papers also introduce the issue of controller assistance tools for remote tower. For instance, integrating the callsign into the video panorama or movement detection based on image processing are discussed. Further research highlights different aspects relevant for RTO. Ellis and Liston focus on the controllers' capability to detect changes in the velocity of aircraft from the control tower [7]. Wittbrodt et al. stresses the role of radio communication in the context of a remote airport traffic control center [8]. For a safety assessment of the RTO-Concept Meyer et al. suggest functional hazard analyses, but also pinpoint the dilemma how to get reliable probability values for such models [9]. Oehme and Schulz-Rueckert emphasize a sensor-based solution for aerodrome control to become independent of visibility condition and the tower locations [10]. This objective includes the wide area of research of "imperfect and unreliable automation" and therefore remains a longterm goal for RTOs.

The main focus in this paper is set on work organisation in a remote center. Three variants of work design will be introduced to control two airports from one center. If the remote control center reliably offers all information and communication facilities for ATC, there is a wide range, how roles and tasks can be assigned to the controllers in the control center.

In the next section it will be considered what is meant by the concept of workload and what it matters for the evaluation of ATCO positions. A section about the remote tower center concept follows, before three work design variants will be analysed, accounting for the cognitive demand on air traffic controllers, using the cognitive work analysis suggested by Vicente.

A. Workload

There are different definitions you can find for workload: Workload can be considered as an intervening variable or as a hypothetical construct [11]. The term workload is also used in many papers without giving a definition at all. In this paper the workload definition from Gopher and Donchin is applied. The authors define workload in terms of the limitations on the capacity of an information processing system. In the context of human-machine interaction mental workload data are gathered to show that workload is on an appropriate level so that the operator can perform his task (e.g. [12]). There are different measurements for workload like primary task measure, secondary task measure, physiological measures and subjective measures. The most well-known questionnaire is the NASA Task Load index (TLX) [13].

Further, workload is related to other variables and constructs. In the context of system evaluation in air traffic control the relationship of workload and performance is of interest. It is known that low workload (underload) has a bad influence on performance as it can provoke boredom. It is also known that high workload can result in worse performance due to overload [14]. But it is also possible that high workload will provoke a strategy shift so that the operator will still perform very well. Another relationship is seen between workload and task demand. Simple models of workload were suggested, so called timeline models, predicting workload by the ratio of time required to the time available (Hendy 97). However for a prediction of workload this simple relation is not sufficient.

In ATC a lot of factors were investigated to understand which one significantly impact the controllers' workload. Most of these models consider en route air traffic control [15,16]. Concerning modelling and predicting mental workload in en route air traffic control Loft et al. reminded Sperandios work [17]: He highlighted that the work method of the ATCO is a crucial regulator for workload [18]. The ATCO is able to switch between different ATC strategies to keep mental workload on a moderate level. Loft et al. addressed, that a simple "integration" of task demand and operator capacity is not sufficient to model workload. As long as the strategy shifts are not integrated these models remain incomplete.

Looking at workload models for aerodrome controllers does not overcome this issue. Vogt et al. depicts that workload models used for the characterisation of ATCO positions in aerodrome control a similar to the en route models [19]. In the paper published by Vogts et al. the workload models are not presented, though the factors respected within the models. For tower control three traffic factors are identified: (1) aerodrome complexity, (2) VFR traffic and (3) calculated take-off times relative to overall departures. In addition to the traffic factors (4) staffing and (5) technological support has a significant influence on workload of the ATCOs' positions. These workload models play a major role for air traffic operations as they are used to evaluate those working positions.

B. Designing a Remote Tower Center

Remote Tower Center Concept

Within RAiCe new approaches for air traffic control of regional airports are realized. An airport is considered regional if it has one operating runway and a relatively simple layout of its apron and taxiways. Furthermore there is a relatively high amount of VFR traffic. The concept for remote control includes a technical system for remote tower operations [1,3,20,21]. The suggested system for the remote control of one airport consists of four high resolution cameras and an additional Pan-tilt zoom camera that is built up at the local airport. One such camera system is installed at Braunschweig-Wolfsburg airport, an experimental system for research purposes, which is running without major complications since 2005. The time delay between video sensors and reconstruction of the far view on the video panorama was measured as < 300 ms [1].

To realize a remote tower center two or more such technical systems could be built up on different airports and all the data could be transferred to one center from where air traffic control service is provided. From a research perspective several questions arise when this scenario is technically: Can one controller operate two airports with low traffic? Can an air traffic controller build up a mental traffic picture for two airports? What is the best work organisation, when there are two controllers and two airports that have to be operated? Is it best, when two controllers work in a team (ATCO 1: tower controller for both airports / ATCO 2: coordinator for both airports) to operate two airports? Or is it best when each controller is responsible for one airport separately? In the next section the cognitive work analysis suggested by Vicente is applied to evaluate three different work design variants.

Work Design Variants

For analysing three design variants, realized within this study, cognitive work analyses (CWA, Vicente) can be applied [22]. Werther introduced the application of the CWA for aerodrome control [23]. The value of this approach can be seen in the separate consideration of important aspects for work place design within five phases. The CWA distinguishes between the phases: (1) work domain analysis, (2) control task analysis, (3) strategy analysis, (4) organisational and coordination analysis, and the (5) competence analysis. In the following sections the differences of the three work design variants from the perspective of these five phases are worked out. Table 1 summarizes the main results from this analysis.

TABLE I. COMPARISON OF WORK DESIGN VARIANTS BASED ON THE COGNITIVE WORK ANALYSIS (VICENTE)

Cognitive Work Analysis	**Remote Center Work Organisations** (+ potential contributor to WL)*		
	Single operator	**Team (TC;CO)**	**Single airport operation**
(1) Work domain analysis			
* responsibility for two airports	Yes +*	Yes +	No
(2) Control task analysis			
* taskload is doubled	Yes +	No	No
* set of control tasks is divided	No +	Yes	No +
(3) Strategy analysis			
* redundancy given by a second controller	No +	Yes	No +
* novel task prioritizations required	Yes +	Yes +	No
(4) Organizational and coordination analysis			
* coordination in the team	No	Yes +	No
* telephone coordination and transmissions by one operator (overlap of tasks)	Yes +	No	Yes +
(5) Competence analysis			
* mental traffic picture for two airports	Yes +	Yes +	No

(1) A single controller operating two airports

In this design variant a single controller is responsible for two airports. From (1) the work domain perspective, there are two operating runways, several taxiways and stands. There are two sets of arrival- and departure routes depending on the runway in operation (e.g., 26/28). This infrastructure is represented by means of two live video streams. In addition approach radar, weather data and flight strips are available for each airport. For communication there is one microphone and a frequency coupling is realized so that each airport has its own radio frequency but the controller is listening to both frequencies at a time. A telephone allows for coordination with radar center. (2) The control task analysis for this single operator condition is concerned with pre- and post conditions of the control tasks. The control tasks themselves do not differ from the control tasks at a previous tower. For (3) the strategy analysis it has to be evaluated whether or not the single operator will use strategies for handling traffic to always guarantee safe operations. It might be possible that he will delay an arriving aircraft so that he will not end up with two simultaneously landing aircraft. Due to the fact that this design variant includes just one controller it is not possible to use strategies like “handing traffic over” to another controller during peak times. But he might use more reports from pilots so that during periods with heavy traffic load he can free his mind. For instance, the pilots will report, when the RWY is vacated or when he reached the position. The central element of this work design variant is that two airports are operated by one controller. So (4) for the organisational and coordination analysis it results that there are no direct coordination tasks between two aerodrome controllers. Everything has to be coordinated by the single controller, directly with the pilots, radar center, or the fire brigade. (5) The competence analysis is concerned what abilities a controller must have for this kind of job. If only one controller is operating two airports he has to build up a complete traffic picture for two airports and to monitor the double amount of areas in contrast to normal tower operations. These pictures must be evolved from two video panoramas representing the outside view from the tower cabs. It also has to be mentioned that within this single operator variant a single controller, not a team of controllers, is in the position to guarantee for safe operations.

(2) Two controllers working in a team (Tower Controller, Coordinator)

In this team variant there is one tower controller for both airports and one coordinator for both airports, working together as one team providing safe operation for both airports.

There are no differences in the (1) work domain analysis and the (2) control task analysis compared to the single controller condition. For the work domain analysis neither the infrastructure of the airports and traffic restrictions, nor (2) the available information and communication advices (one microphone, two video panoramas, two approach radars, one coupled radio frequencies, flight strips) are varied. It has to be mentioned that the amount of control tasks one controller is responsible for is divided onto the two working positions. So, the start-up-clearance is delivered to a departure flight by the controller, but the squawk (transponder code) release is requested by the coordinator. However, (3) the strategy analysis depicts differences: Operating two airports as a controller team offers additional strategies how the team members can support each other during peak times. For the team there are more possibilities for compensatory strategy shifts compared to a single controller working position. For phase (4) of the CWA the role definitions are derived from nowadays operations: One controller is working as a tower controller (responsible for radio communication) and the other as the coordinator. However, a significant difference is that both controllers are fulfilling their job not just for one airport, but for two. For (5) the competence analysis this team variant also requires that controllers are able to build up an actual mental traffic picture of both airports, derived from the technical systems of the remote tower center.

(3) Two controllers operating two airports, one controller responsible for each airport

As a third work design variant it is realized that two controllers operate two airports, one airport each. Again, no differences are present for Phase 1 and Phase 2 of the CWA, except, that in this condition there are two microphones, one for each controller. For (3) the strategy analysis a strict separation of tasks between two controllers causes that both controllers have to find work methods for their airport, that ensure that no time periods of cognitive overload appear. Each controller has to identify strategies relevant for the airport he is responsible for. Each controller cannot rely on support from the other one. The (4) roles and responsibilities in this work design variant can be compared to nowadays operation, when air traffic service is provided by a single controller for one airport during off-peak times or night shifts. So the areas that have to be monitored by each controller are restricted to one airport.

Each controller applies the set of control tasks not on two, but one airport. From (5) the competence analysis perspective the demands for controllers working these positions differ in comparison to the single operator- and team variant. The controllers here do not have to build up a traffic picture for both airports, but like in the single operator condition team aspects are eliminated. One single controller has to guarantee for safe operations on the airport.

C. *Technological Support*

Beside the staffing Vogts at al. worked out that technological support available for the controller is another relevant predictor for workload [19]. With the enhancement of technology it is of interest to consider, whether image processing for object detection or transponder data can be used to support the controller at work. It was mentioned in the introduction that the idea to overlay additional information into the video is one research topic of interest for remote tower control. In our last simulation studies for remote tower research, the information augmentation was realized as a within-subject factor [5]. No significant influences on workload were found. It is possible, however, that the effects of additional information on the video panorama cannot be tested in a within-subject-design of 30 minute simulation trials. This is the case, as the controller is going through a learning phase first. He has to adapt to new features of the work environment and find out, whether he can benefit from the new means to access the information of the callsign form the video panorama. This is why within this simulation experiment, visual augmentation (displaying the callsign next to each aircraft in the video) is realized as a between-subject factor. Hence, a controller team will work either always with augmentation or without, for all simulation runs to investigate its influence on workload within the RTC setting.

D. *Identification of Safety-Critical Situations*

In the last sections an evaluation of the cognitive demands on the controllers was derived looking at staffing and technological support. In addition to these considerations it has to be analysed, whether the parallel operation of two airports does not provoke safety-critical traffic situations. In this section we will not address questions concerning a verification of the technical system so that data are reliable available for the controllers in the remote center, but questions concerning the safe operations on the airports. The following simulation study was used as a work probe for identifying such safety-critical situations. The advantage of the simulation environment is that the operational limits can be tested without causing harm and crucial factors can be identified which need to be considered for real operations. Within the single operator work design variant a second controller was observing the developments of traffic and judged the situations the single operator was going through. Therefore a questionnaire was developed similar to the Cooper-Harper-Scale, using a hierarchical structure of questioning [24].

In the next section the experimental simulation study is introduced, including the experimental design, the procedure and the development of the questionnaire so that operational relevant situations within the remote tower context can successfully be identified by expert observers.

II. METHOD

A. *Hypotheses*

For the experimental simulation study workload hypotheses are defined for the traffic factor (1a-c) and the augmented vision factor (2a) as follows:

Traffic hypotheses

H1a: For online workload ratings (2 min. interval) it is expected that the workload ratings are higher for the heavy traffic than for low traffic.

H1b: It is hypothesized that under low traffic, the single operator has significantly higher workload ratings compared to all other working conditions. The same assumption is made for heavy traffic.

H1c: From a theoretical point of view it can be predicted that the workload of the single controller operating two airports under low traffic load is not significantly higher, than the workload of controllers operating one airport with low traffic.

Augmented vision hypotheses

H2 For the between-subject-factor it is predicted that working with the callsign displayed on the video, workload is significantly lower compared to working without the callsign in the video. It is assumed that this effect is independent from the working positions or traffic load.

Expert Ratings

In addition to the hypotheses the results of the expert observer judgements will be introduced, identifying safety-critical situation when one controller is operating two airports. These data support the identification of crucial constraints for the remote tower concept.

B. *Sample*

Twelve male tower controllers from the Deutsche Flugsicherung (DFS) participated in the experimental simulation study. They were between 25 and 60 years old (m = 34,67 years; std = 10,92 years). All controllers held a valid controller license and came from four different airports. Two controllers were from airports operating less than 15.000 IFR movements p.a., six controllers from airports with more than 15.000 but less than 35.000 IFR movements. Four controllers came from an airport operating more than 100.000 IFR movements p.a..

C. *Simulation Environment*

The setting represented a work environment to the professional controllers that allows for controlling two airports remotely, that is, the actual airports might be several hundred kilometres away from the actual location of the control center. The arrangement of the displays within this center is depicted in Figure 1. The work environment was named “Combined Tower Braunschweig-Erfurt” simulating Braunschweig airport (top row) and Erfurt airport (lower row) in Figure 1. Beside the simulated far view the setup included approach radar for each airport (right screens, Figure 1) and flight strips. On the left side a touch panel was used to control and display the zoom camera for Erfurt and on the left side one for Braunschweig. Within the touch panel, a virtual joy stick, preset buttons and a reduced panorama display could be used to guide and control the zoom camera. The zoom camera affords to have a closer look at any object on the airport or to check for arriving traffic. These cameras replace the function of binoculars in the tower cab. In two experimental conditions radio communication offered one combined frequency BWE/ERF. In the other condition there was one frequency for each airport.

Figure 1. Work environment: Remote Tower Control Center in the simulator at the Institute for Flight Guidance (DLR)

D. *Traffic Scenario*

For the simulation runs eight different traffic scenarios were generated. There was mixed traffic of IFR and VFR (50/50). Each scenario included about 16 aircraft evenly distributed for BWE and ERF, while more VFR traffic referred to BWE. Each simulation run was aborted after 25 minutes. The scenarios were designed to raise traffic load over time and to provoke events of interest like “two parallel landings”, or “parallel start and landing”. Moreover for VFR departures flight strips existed, assuming that for the Remote Center such flights have to pre-file their flights.

E. *Experimental Design*

Here the 5*2*2 factor repeated measurement design will be introduced relevant for this paper. It includes the between-subject factors *working position* (single controller (SC), tower controller (TC) Coordinator (CO), Controller for BWE (BC) and Controller for ERF (EC), *augmentation* (no augmentation, callsign) and the within-subject factor *traffic* (low, heavy) Beside the five working positions, the design controlled for the 3-fold *team* factor (SC, TC+CO, BC+EC). The experimental design is depicted in Table 2.

F. *Questionnaire for Expert Observer*

Based on the Cooper-Harper-Scale [24] a questionnaire was developed with controllers to evaluate remote tower center aspects from an operational perspective. The design of the questionnaire was discussed with two controllers beforehand to match the language of experts with the formulations of the questionnaire. In contrast to the Cooper-Harper-Scale the questionnaire is not designed to judge a new technical system, but to evaluate *situations*, when one controller is responsible for two airports. This questionnaire and the Cooper-Harper-Scale have in common, that they show a hierarchical structure (2 levels) so that the controller will be guided to get quick answers for ratings on a 10 point scale by answering simple “yes or no” questions. These questions determine one of four answer categories. Afterwards a 3-point ranking is made within the categories 1-3. In the first category the controller does not see major problems for operations. Within the second category (2) the efficiency of handling traffic is negatively influenced. In the third category the workload of the controller is too high and therefore the situation is rated to be safety critical. The fourth category has only one answer, saying that the situation is impossible to handle (independent of workload).

TABLE II. EXPERIMENTAL DESIGN

Exp. Conditions		Between subject factor (1)**: Augmentation**					
		(1) no augmentation			**(2) callsign**		
		within subject factor (2): **working design variants C1-C3** *working positions (SO, TC, CO, BC, EC)					
within-factor (3)		**C1**	**C2**	**C3**	**C1**	**C2**	**C3**
Traffic(3)	**(1) low**	SO	TC/CO	BC/EC	SO	TC/CO	BC/EC
	(2) high	SO	TC/CO	BC/EC	SO	TC/CO	BC/EC

Each expert observer was instructed to evaluate the *situations* the other controller is going through and not to rate the performance of the controller operating the simulated traffic scenario. Six situations were instructed to the controller as predefined situations, listed in the following:

S1: Landing on airport A + taxing traffic on airport B

S2: Similar call signs for aircraft of airport A and B

S3: Simultaneous pilot requests at airport A and B

S4: Simultaneous starts at airport A and B

S5: Simultaneous landing at airport A and B

S6: Conflict on airport A, start/landing on airport B

Furthermore the observers were asked to identify situations that seem relevant from their background as a controller. This rest category (S9) circumvents that important situations are neglected that are relevant for controllers in regard to efficiency and safety.

G. *Procedure*

Each controller team participated for two days:

The first day was used for training. The two controllers learned the treatment in the simulator, the AIPs for BWE and

ERF and the handling of the system components like the zoom camera. They were trained for the radio phraseology “Combined Tower Braunschweig-Erfurt” and had to add the “Braunschweig” and “Erfurt”, when giving clearances for the operating RWYs. Each controller trained the single controller condition twice (one controller responsible for both airports), while the other controller was asked to rate the “events of interest” while observing his colleague operating traffic. Within these simulation training runs, the team was already confronted with the visual augmentation (callsigns displayed in the outside view) when their team was assigned to the condition with augmentation.

During the second day each team was operating all three design variants twice (min. six simulation runs). The controllers were randomly assigned to the experimental conditions and the order in which the teams were operating different work design variants and traffic scenarios were varied respectively. With the Instantaneous Self-Assessment (ISA) scale workload data were collected so that each controller was asked every two minutes to rate workload on a 5-point Likert-Scale [25]. In the single controller condition the second controller once more observed “events of interest”. After each simulation run the controllers filled out the NASA-TLX.

III. Results

The statistical results for the analysis of the ISA-Workload scale were calculated, using a repeated measurement ANOVA for the five working positions. The 12 repeated time points were categorized into the factor traffic (2) and time (6), due to the fact that the traffic scenarios were designed that the traffic rate continuously increased over the scenario run time.

In the following section first the traffic related hypotheses will be considered, afterwards the results concerning augmented vision aspects will be presented.

A. *Traffic*

A highly significant main effect was found for the between-subject factor position (F(4,40)=33.28; p<.00; , f^2 = XX) and for the within-factor traffic (F(1,40)=107,64; p<.00). The interaction traffic*position also became significant (F(4,40)=3.06; p=.03). The effects are illustrated in Figure 2.

The interaction effect has to be analyzed in more detail. For Hypothesis 1a no interaction effect was expected. Post hoc tests reveal that the for the single operator condition, there is no significant difference in workload between the first and the second half of the simulator. However for the working positions in the team variant (TC, CO) and the single operator workload ratings rise significantly.

For Hypothesis 1b post hoc tests reveal that in the single controller condition workload is rated significantly higher than in all other conditions (3.5 versus BC=1.7; EC=1.8, CO=2.5; TC=2.9) for low traffic load. This result is in line with H1b. However, for heavy traffic the single controller and tower controller conditions are significantly different from the others (SC=2.4; TC=1.7 versus BC=1.1; EC=1.3 and CO=1.5). This result depicts, that heavy traffic load is rated similar independent of working as a single controller (SC) or working as tower controller (TC) who is working in team with the coordinator.

In line with Hypothesis 1c, the ratings for BC, EC, TC and CO condition under heavy traffic (BC=1.7; EC=1.8; TC=2.9; CO=2.5) are not significantly lower compared to ratings of the single controller (2.4) in the low traffic condition. This result is in line with H1c and it will be discussed what conclusions can be drawn from this finding. The traffic related effects are illustrated in Figure 2.

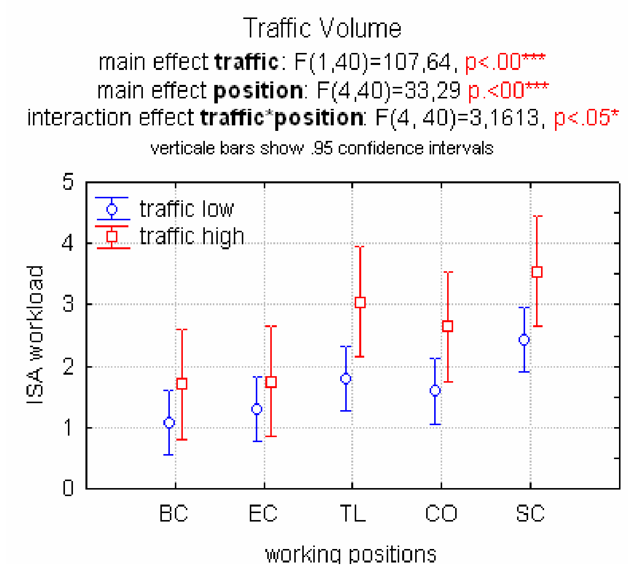

Figure 2. Effects of traffic on the ISA-workload-ratings

B. *Augmented Vision*

For the between-subject factor augmentation a significant main effect was found (F(1,40)=25.34; p<.00), as well as for the interaction effect of position*augmentation (F(4,40) = 3.95; p<.00).

Like for the factor traffic post hoc tests for the factor augmentation revealed that working without the callsign as tower controller (3.0) or coordinator (2.4) or single controller (3.4), workload ratings were significantly lower, compared to working with the call sign (TC=1.9; CO=1.7; SC=2.6) For working a single airport with call sign (BC=1.6; EC=1.3) or without call sign (BC=1.5; EC=1.6) such an effect is not apparent. The results are depicted in Figure 3.

Controlling for the team variable shows that there is a significant team effect (F(4,25)=17.85; p<.00). A further analysis showed that the team variable highly correlates with the augmentation variable (r=.87; p<.05) Due to this fact the interpretation of the augmentation effect has to be considered with caution.

For a complete report of the data analysis the results for the time variable are also reported. The main effect time became highly significant (F(5,200)=10.81; p<.00) The interaction time*traffic was also highly significant (F(5,200)=6.84; p<.00).

No significant two-way interactions were found for time*augmentation ($F(5,200)=1.24$; $p=.29$) and for time*position ($F(5,200)=1.55$; $p=.07$). Table 3 summarizes the main- and interaction effects.

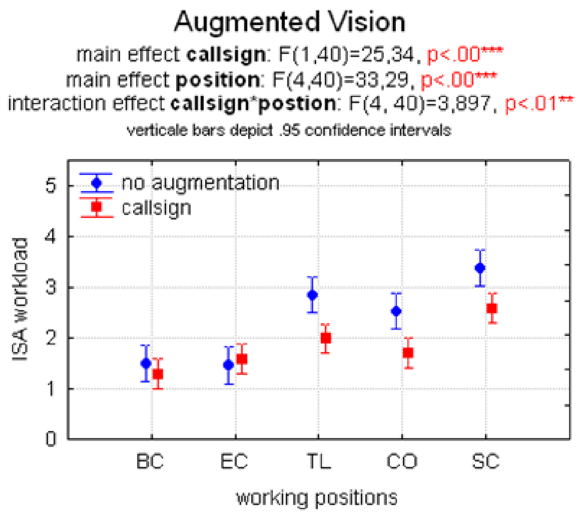

Figure 3. Effects of augemented vision on the ISA-Workload ratings

TABLE III. ISA-WORKLOAD RATINGS

factors	indep. variables	*df*	*F*	*p*
between-subject	augmentations	(1, 40)	25.34	<.00***
	position	(4,40)	33.28	<.00***
	augment.*position	(4,40)	3.95	.01**
within-subject	traffic	(1,40)	107.64	<.00***
	traffic*augment.	(1,40)	2.09	.16
	traffic*positions	(4,40)	3.06	.03
	time	(5,200)	10.81	<.00***
	time*augment.	(5,200)	1.24	.29
	time*position	(20,200)	155	.07
	time*traffic	(5,200)	6.84	<.00***

C. *Expert Judgements*

Beside the workload ratings events, the ratings of the expert observers are summarized in this section. 216 situations were commented by the observers and are distributed over the four categories as follows: (1) no major influence ($n=81$), (2) influence on efficiency ($n=74$), (3) influence on safety ($n=33$) and (4) impossible to handle ($n=28$). Looking at the different situations (S1-S6) it turns out that Situations S2 and S3 no ratings were given for Category 4: impossible to handle. Similar callsigns at both airports and parallel requests had no influence on safety (category 3), but once.

Considering situations concerning events on the runway on one or two airports, draws a different picture. Parallel landing and taxiing (S1) was rated five times to have an influence on safety (Category 3) and five times as (Category 4) impossible to handle. For two parallel landings and two parallel starts seven (or rather six) situations were identified influencing safety and seven (or rather six) situations were judged as impossible to be handled by the controller. Noteworthy that (S1) parallel landing and taxiing, (S4) parallel starts and (S5) parallel landings were rated as uncritical (Category 1) in 21, 14, or rather 4 cases. Controllers remarked here, that when there are no deviations from normal, the parallel operation of both RWYs was uncritical because both RWYs were in the controllers field of view and therefore directly visible for the controller (compare setup of the remote tower center)

Eighty-six additional situations were rated by the controllers: (1) no major influence ($n=24$), (2) influence on efficiency ($n=42$), influence on safety ($n=11$) and (4) impossible to handle ($n=9$). An overview of the controllers` judgments is given in Table 4.

TABLE IV. CONTROLLER RATINGS: EVALUATION OF SITUATIONS IN THE REMOTE TOWER CENTER CONCERNING EFFICIENCY AND SAFETY.

Situations of interest (N=216)	**No major influence**	**Influence on Efficiency**	**Influence on Safety**	**Impossible to handle !**
(S1) land / taxi	21	6	5	**5**
(S2) callsign	8	1	1	**0**
(S3) requests	7	8	0	**0**
(S4) start / start	14	7	6	**6**
(S5) land / land	4	6	7	**7**
(S6) conflict /land	3	4	3	**1**
rest	24	42	11	**9**
TOTAL	**81**	**74**	**33**	**28**

IV. DISCUSSION

Within this experimental simulation study three design variants for a remote tower center were realized and workload data gathered, to discuss the issue of workload for the work organisation for a remote tower center. Significant effects were found for the factors (1) traffic, (2) work positions, and (3) augmentation. These data are in line with previous research that (1) traffic, (2) staffing and (3) technological support are workload relevant factors [19].

In the next section the results of this study will be discussed in respect to what can be learnt from workload data for an operational concept for remote control of multiple airports. The question is, what is an appropriate workload level and what other factors are relevant to decide the staffing and work organisation of a remote tower center.

A. Role of Workload for Work Organisation

For the working positions in which controllers were responsible for two airports (SC, TC, CO) a significant increase of workload was measured. However, for the working conditions when one controller was responsible for one airport the traffic increase did not cause higher values on the workload scale. This interaction effect was not expected (H1a). Looking at the work analysis, this result can be explained, if we assume that the task to have an actual mental traffic picture for two airports is becoming significantly more demanding when more traffic is apparent, compared to have one mental traffic picture present. Another explanation can be that the task prioritization of requests on the one airport compared to requests on the other airport is more demanding.

For low traffic load, workload ratings conform to H1b: Workload ratings are higher for the single operator condition in comparison to all other conditions. This hypothesis seemed trivial as it is based on the assumption that one controller operating two airports experiences higher workload compared to the condition that two controller operate the same amount of traffic on the two airports. However, the results revealed that this finding is only true for the low traffic load condition. Looking at the results for heavy traffic it turned out that the workload of the tower controller working in a team with a coordinator experiences a contrastable amount of workload as the single controller operating two airports. This finding can be explained by the fact, that for the team variant, the responsibility for safe operations on both airports is not split between the two operators like in the single airport operation variant. Both controllers are responsible for both airports. The single operator and the tower controller have in common, that both are responsible for the radio communication of both airports. This task might explain the higher workload ratings experienced by these two controller positions for heavy traffic.

Another interesting finding was that in line with Hypothesis 1c the workload in the single airport operation condition (BC, EC) and in the team condition (TC, CO) under heavy traffic was not more demanding than low traffic in the single operator condition. These relative workload comparisons between different traffic conditions have to be discussed. What can be concluded, if workload is on an appropriate level? Is the workload concept such a strong concept, that an appropriate level of workload is for a proof for the operational feasibility? Is an appropriate level of workload a sufficient or even an essential condition for operational feasibility? From an operational perspective, it cannot be more than a sufficient condition that has to be met but further basic conditions have to be complied. These basic conditions are discussed in Section C.

B. Role of Augmented Vision Effect

In contrast to Hypothesis 2a positive effect on workload was not apparent for all working positions. Interestingly workload was yet reduced for all working conditions in which the operators were responsible for both airports. It seems that the overlay into the video panorama does not have a great impact on workload when controllers are responsible for one airport (like in the BC, EC conditions). Though, if the controllers are responsible for two airports, the additional information of the callsign into the video might help to build up a mental traffic picture for both airports. It was mentioned in Section 1c that no effects were found for this augmented vision variant in previous studies. These results support the null result in the previous study and can compensate the methodological concerns that were discussed. However, this finding should also be considered with caution: Beside the augmented vision effect a further analysis was conducted for the control variable team, which also revealed a significant team effect. Due to the high correlation between the team and the augmentation, it is statistically not possible to give a final statement on which variable has a causal influence on workload. This is the disadvantage of the between-subject design, when individual differences become a confound variable.

C. Identification of Critical Situations for the Remote Center Concept

Supplementary to the workload data expert judgements were gathered, to scrutinize the remote tower center concept from the perspective of air traffic controllers in service. The ratings indicate that during smooth operations, parallel starts of aircraft, or even parallel landings were rated as uncritical events. Contrary to these values it is noteworthy that there were only two situations that were not rated to end up in a safety critical situation (Category 3) or in a situation that is impossible to handle (Category 4). These situations did not describe traffic situations but the setting that two aircraft had similar callsigns (S2), or that pilots from different airports requested simultaneously (S3). These situations also become relevant when operating one airport. For the traffic situations involving two airports the observers judged in total 33 situations as safety critical and 28 were judged as impossible to handle by one single controller.

For the question if appropriate workload is a sufficient or efficient condition for an evaluation of work organisation of a remote tower center, these expert judgements indicate that it can only represent a sufficient condition. Further basic conditions have to ensure that the work organisation avoids safety-critical situations and situations that are impossible to handle. From this perspective the advantages of team work in safety-critical situations have to be reflected as well as the fact that if a team is responsible for two airports there is more redundancy for the detection of safety critical events compared to single tower operations.

D. Conclusion and future work

Within this paper the role of workload for the design of a remote tower center was addressed. It can be concluded that for the evaluation of different work design variants in ATC, the workload concept is not sufficient to evaluate operational feasibility. As Sperandio pointed out, workload is not only a dependant variable, but also an independent one that defines controller work methods or strategies. Therefore, it has not only to be considered, which effects different work organisations have on workload, but also what work methods are offered by different staffing concepts to keep workload in an appropriate range. This aspect becomes clear, when it is considered that a single controller can operate low traffic with an appropriate workload level, but expert judgements identified situations that are impossible to handle by a single controller. Aside from this, the data indicate the potential for controller assistance through the use of additional technological tools.

In future work it has to become clear how the workload findings and the expert judgements can draw one coherent picture for future ATC concepts. What is the impact of traffic mix (VFR+IFR) on the expert judgements? Is it possible to identify work methods, that can eliminate the situations rated as impossible to handle. Comprising robust traffic concepts are another research issue that might significantly eliminate the challenges that one controller can operate two airports.

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AUTHOR BIOGRAPHY

Christoph Möhlenrink got his M.A. in psychology from the University of Konstanz, Germany in the year 2005. Since 2006 he is a research fellow at the Human Factors Department, Institute of Flight Guidance, Braunschweig Germany.

He was involved in the remote tower project RApTOr (Remote Airport Tower research, 2005-2007). He now works for the project RAiCe (Remote Airport Traffic Control Center) that started in 2008 and is involved in further research projects as a human factors expert. He is interested in understanding controllers' and pilots' behaviour at work, modelling interactive behaviour, and eye-tracking research.

Dipl.-Psych. Christoph Möhlenbrink is member of the Human Factors and Ergonomics Society Europe.

Anne Papenfuss gained a M.A. degree in media sciences, media technology and politics at Technical University Braunschweig and Braunschweig University of Arts in 2007.

Since 2008 she is a research fellow at the Human Factors Department of the Institute of Flight Guidance at the German Aerospace Centre in Braunschweig (Germany).

M.A. Anne Papenfuss is interested in cooperative work procedures, team situation awareness, and team communication.

Jörn Jakobi received his M.A. in psychology from the University of Göttingen in 1999. Since 2000 he is a human factors expert at the DLR's Institute of Flight Guidance, where he works in the domain of airport airside traffic management with the focus on A-SMGCS concept operations and validation. Since 2009 he works in national- and international funded projects dealing with validating innovative concepts for airport operations control centers. In 2010 he performed a three months visiting research at NASA Ames in the Aviation System Devision. In October 2010 he became a business manager responsible for all ATM related issues at DLR's Institute of Flight Guidance.
Jörn Jakobi acts as point of contact for the NASA/DLR cooperation.