2015

Concept of Flight Instructor Assistance in Helicopter Emergency Medical Service Using Pilot Trainee's Workload Determination

Felix Maiwald

Axel Schulte

CONCEPT OF FLIGHT INSTRUCTOR ASSISTANCE IN HELICOPTER EMERGENCY MEDICAL SERVICE USING PILOT TRAINEE'S WORKLOAD DETERMINATION

Felix Maiwald and Axel Schulte
Universität der Bundeswehr München (UBM),
Institute of Flight Systems (LRT-13), 85577 Neubiberg, Germany
{felix.maiwald, axel.schulte}@unibw.de

This article focuses on the development of a tool chain to support the training of helicopter rescue pilots. The aim is to support the training instructor for comprehensible, objective and reliable assessment of the mental state of pilot trainees. Hence this article investigates a method for on-line estimating the mental workload of the pilot and his free/needed cognitive and sensorimotor resources during flight. We further provide a description of the methodological approach and details on the implemented prototype of a flight instructor station as part of our research simulator. In a first simulator study with four subjects the system has been rated as helpful and effective. A possible application can be found in the more objective evaluation of the pilot students' learning progress. For this purpose the recorded missions are analyzed during debriefing in order to identify workload peaks. Furthermore, the continuous analysis of workload can be used for an on-line adaptation of the training lessons. However both application fields require further development and validation of the methods used in this specific task environment.

Introduction

The training for commercial helicopter pilots CPL (H) is divided into a theoretical part and a practical flight training. In accordance with the rules of the EASA Part-FCL the practical training (at least 30 hours with a flight instructor) comprises the type rating, IFR-training and skill tests. Depending on the intended application purpose, civil helicopter pilots are also trained in rescue missions (Helicopter Emergency Medical Service, HEMS), off-shore or mountain operations. Proficiency checks (e.g. "OPC" and "TRPC") have to be passed by the pilots semi-annually.

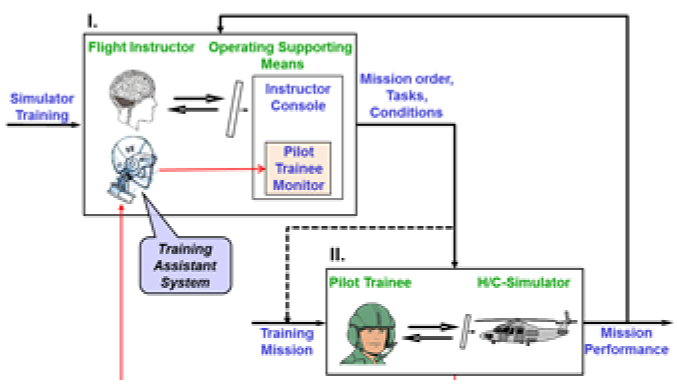

Figure 1. Work system configuration for flight instructor and pilot trainee

In recent years, practical training has been shifted to helicopter simulators more and more. Highly accurate helicopter cockpit replica in conjunction with realistic dynamic simulation of the aircraft can provide great cost savings. Furthermore independence of flight time and outside weather conditions is achieved. Such an integrated air ambulance training center for helicopter pilots (HEMS-Academy) is operated by the German ADAC for instance.

While analyzing simulator training for helicopter pilots the following work processes are of importance: (I) work process of the flight instructor and (II) the work process of the pilot trainee. Subsequently, the mutual dependencies of these processes are revealed with Figure 1 (cf. Onken & Schulte 2010).

The work process of the flight instructor is hierarchically superordinate to the work process of the pilot trainee. Basis for every work process is the specific mission order. Figure 1 also outlines the functional components, mandatory for the execution of the mission order in the two work processes. In the considered use case, the mission order of the flight instructor is made up of simulator training of pilot trainees. For this purpose the flight instructor enters mission orders into his instructor console or manipulates environmental conditions (e.g. weather). The results of his work process are inputs to the pilot trainees work process. This comprises the work objective ("training mission") and other information relating the environmental conditions for the work process of the pilot trainee.

The work process of pilot trainee is then transferred to the more technical view of a work system (c.f. Figure 2). Here, the work system of the pilot trainee is considered under the specific terms of observability by the flight instructor. As a result, the pilot trainee follows the mission order provided by the flight instructor under the given environmental conditions. The overall performance of the pilot trainee work system is measured through the fulfillment of the work objective and the achieved work results. The performance is heavily dependent to the behavior parameters, i.e. the interactions of pilot trainee with the helicopter simulator. Behavior parameters, e.g. the learning success are available to the training staff by cameras, built-in the training simulator. The observable behavior of the pilot trainee is an expression of his inner states. In this context Pina, Donmez & Cummings (2008) coin the term "behavior precursor". This includes the topics of mental workload (WL), trust in automation and emotional situation of humans.

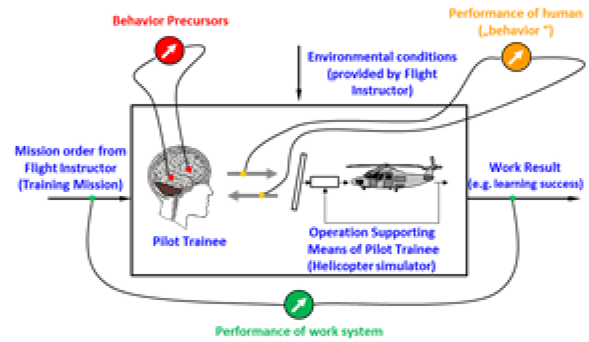

Figure 2. Observability of the pilot trainee work system by the flight instructor (according to Schulte, 2014, Lecture Notes "Flight Guidance & Automation")

One challenge of the flight instructor is the understanding of the hidden internal states of the pilot trainee (behavior precursor). This will be based on the behavior and learning progress of the pilot trainee. Information regarding the workload can be used during training to push the pilot trainee into his mental limitations temporarily. In addition, training schedules are adapted on the basis of the acquired skills and knowledge of the pilot trainee. However, it can be expected difficulties in objective and always comparable assessment of pilot trainee's mental workload from the flight instructors' individual experiences. Therefore a continuous and objective documentation will not be available. Furthermore, behavioral changes (i.e., "self-adaptive strategies"; Sperandio, 1978; Donath, 2012) of the pilot trainee due to high demands have to be interpreted correctly by the flight instructor. Due to these factors, an objective comparison between different pilot trainees and instructors is not possible.

To address this problem, this article focuses on a technical approach to support the flight instructor in pilot state determination (see pilot trainee monitor in Figure 1). The aim is to on-line identify an objective estimation of the current mental workload of the pilot trainee and his remaining resources. The results should be made available to the flight instructor by a "pilot trainee monitor". This "pilot trainee monitor" is a first step towards the development of an instructor-assistant system. Suitable implemented and tested concepts are derived in later sections of this article.

Detailed concept for determining Workload

In the domain of ergonomics, however, there is no standard definition for workload. Following Gopher & Donchin (1986) workload is understood as psychological construct subjectively perceived by the human and therefore not directly measurable. However, there exist different approaches and methods to operationalize workload.

	Question-naires	Analytical approaches	Performance measures	Physiological measures	Behavior analyzes
Proactivity	-	(X)	-	(X)	X
Real-time capability	-	X	X	X	X
Broadbent sensitivity	X	X	-	X	-
No intrusion	(X)	X	(X)	(X)	X

Table 1. *Evaluation of common methods for workload determination*

The workload determination for our pilot trainee monitor should meet the following requirements: (I) Proactivity, able to predict future states of workload, (II) Real-time capability of the measurement, (III) Broadband diagnosis in a wide workload area and (IV) Non-intrusive. An overview of common methods (c.f. summarized in Table 1) is available in Young et al. (2015), Gopher & Donchin (1986), Donath (2012). Maiwald & Schulte (2014) applied an analytical concept for determination of workload and the mental state of a pilot in military missions. Maiwald (2013) proposes an analytical approach to estimate workload to direct dialogues generated by a pilots' assistant system to the perceptual modality and code, which can be assumed to provide spare resources. The implemented methods provided a broadband sensitivity, high user acceptance and real-time capability. Therefore, we will apply and enhance the method to the domain of civilian helicopter rescue missions (HEMS). The implemented concept is summarized in Maiwald & Schulte (2014). For realization of the pilot trainee monitor we incorporate two models:

1.) *Model of pilot tasks* for the purpose of determining the current tasks of the pilot
2.) *Model of pilot resource consumption* to estimate the resource consumption and WL for current tasks

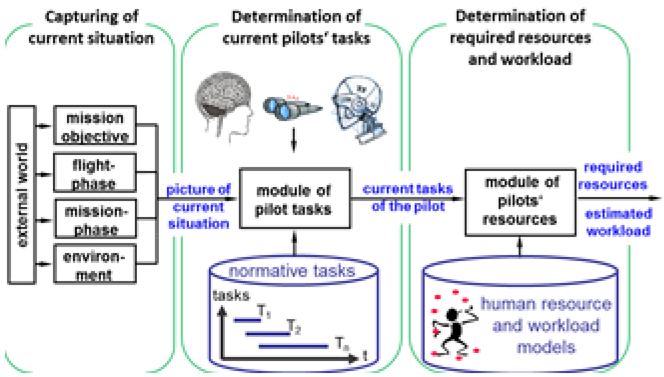

Figure 3: Concept for determination of workload and available/required resources of the pilot trainee

Model of pilot tasks

In the first step, we capture all external influences on the pilot during the HEMS mission (i.e. the state of the helicopter, the mission objective as well as environmental conditions). The flight status is derived from the simulated flight systems and sensors (e.g. navigation). A planning function generates the initial H/C-task agenda, which serves as a basis for the evaluation of the mission progress. This agenda represents a rough mission framework and combines mission relevant tasks with each other. After aggregating all available data into a full situational picture the current tasks the pilot should be executing will be determined. For this purpose, we implemented normative models of mission-typical task situations using state transition networks representing the knowledge acquired in experiments with professional pilots. In a next step we synchronize the tasks described by the static model with the tasks the pilot is actually executing. Therefore, human-machine-interactions such as visual information acquisition (i.e., measures eye fixations) as well as manual interactions are analyzed (cf. Maiwald & Schulte, 2014). In this context, simple models are used to draw conclusions on the tasks actually processed by the human operator from measurements of the eye movements and observations of the manual interactions. Manual interactions taken into consideration are the currently displayed page on the various screens, pushed buttons, current system settings (e.g. landing gear), as well as manual control stick inputs. Visual interactions taken into account are provided by a commercial camera based eye-tracking system (Smarteye®) and its integrated object-related gaze tracking.

Model of pilot resource consumption

Task	information acquisition				processing		reaction	
	VS	*VV*	*AS*	*AV*	*CS*	*CV*	*M*	*V*
Approach to Pickup-Zone	3	2	2	0	2	2	3	0
change zoom on map	1	0	0	0	2	0	1	0

Table 2. *Demand vectors for two sample tasks*

In the next step the actual task(s) are associated with task-specific values of mental resource consumption. Our model of resource demands is based on Wickens' (Wickens & Hollands, 2000) so called multiple-resource theory and describes the required resources by use of eight-dimensional demand vectors (Wickens, 2002). Every demand vector represents the demand a single task poses on the human operator expressed in the terms of information acquisition, information processing and response. Hence, data were gathered through knowledge acquisition experiments, in which helicopter pilots had to rate individual resource demands that arise during the various mission tasks. To eliminate subjective influences from these models as far as possible, laboratory experiments have been conducted to better match the predicted resource conflicts within distinct task situations with the objectively measured pilots' performance (c.f. Maiwald & Schulte, 2014). Table 2 shows an example of demand vectors in detail for the sample tasks "Approach H/C to Pickup-zone" and "Change zoom on map". To estimate the current individual resource utilization, a modified Visual-Auditory-Cognitive-Psychomotor model (VACP; Aldrich & McCracken, 1984) is used. Based on the assumption of a maximum capacity provided by the VACP model a measure of the remaining individual resources of the pilot trainee can be calculated. In addition we look at the resource conflicts which stem from simultaneous task performance to compute the current overall pilots' workload. For this purpose, the demand vectors of the current tasks are fed into a modified workload index model (W/INDEX; Wickens, 2002). The modification we applied to the W/INDEX computation eliminates any limitation on the number of tasks to be examined in parallel (for details c.f. Maiwald & Schulte, 2014).

Preliminary Experimental Testing

A first engineering test has been conducted in our flight simulator to investigate our functional chain predicting the workload und resource utilization of the pilot trainee. The purpose is to gain knowledge how to support the flight instructor by suchlike information. Here we focus on the appropriateness of the implemented methods and possible enhancements of functions in the context of instructor assistance.

Apparatus

Figure 4. Workplace of the flight instructor with three display elements. Left: operator console, center: resource monitor, right: cockpit displays

To test the functional chain, the method has been implemented as a prototype in our generic two-person side-by-side helicopter simulator, used for research projects at the Institute of Flight Systems. Our simulator consists of four multi-function displays (MFDs), each equipped with a multi-touch screen. Depending on the configuration, display formats such as a Primary Flight Display (PFD), a digital map, BOS-transponder status (non-public mobile VHF land mobile service) and pages for radio communication as well as transponder settings can be shown. The pilot is provided a digital map where he enters mission-relevant constraints (e.g. "pickup injured at position X") via touchscreen. Based on this information, the automatic mission planner generates the task agenda by using simple hierarchical task networks. The terrain-conformal route is generated by sample based route planning algorithms (A*-search). Mission specific information such as radio communication and transponder settings may be entered into a Control and Display Unit (CDU). For the simulation of the external environment, a three-channel projection system with a lateral field-of-view of approx. 180° was used. Gaze tracking is realized via four cameras.

The configuration of the prototype workstation for the flight instructor includes the following three displays (cf. Figure 4). The screen on the right position depicts the display formats of the pilot mirrored for evaluation purposes. The resource monitor (center position) represents the utilization of the eight considered resources and the overall workload for a period of 200 seconds. The operator console (left position) shows the telemetry data of the helicopter. It is additionally equipped with the scene camera representing the current visual focus of pilot trainees' information acquisition. Additionally, the instructor is allowed to manipulate mission parameters and individual system parameters of the helicopter. As part of the evaluation the instructor may initiate an engine failure. The telemetry and workload data are recorded and can be replayed by the instructor during debriefing.

Mission

In our scenario, we consider a typical civilian HEMS mission recovering an injured person in the northern Alps in a single pilot configuration. A second trained pilot acts as a flight instructor. At first, the rescue helicopter is located on his base and receives the mission order via voice communication. To keep the mission plan up to date, the pilot has to coordinate with several agencies (e.g. flight information services, land-based emergency services on ground) throughout the mission. Additionally the pilot has to re-plan the mission one or more times (e.g. concerning selection among several suitable hospitals). The overall mission takes about 25 minutes.

Subjects

Three helicopter pilots of the Germany Navy and one rescue helicopter pilot of the ADAC participated in the experimental campaign. The age of the subjects ranged from 25 to 48 with an average of 32 years. The flight experience ranged from 300 to 3500 hours at an average of 1139h with different helicopters (EC135, EC145, BO105).

Hypotheses

The examined scientific questions relate to the following hypotheses:

(1) The implemented functional chain reflects the workload of the pilot.

(2) The implemented functional chain correlates with individual and observable behaviors of the pilot.

(3) The realized instructor station is a valuable tool for pilot training.

As dependent variable we used the predicted workload value and the subjective observations of the experimenter. In addition the manual pilot control inputs ("steering entropy") were used as dependent measure. The assumption to correlate workload with manual steering activity is supported by the research of Nakayama et al. (1999) in the field of vehicle guidance.

Test procedure

Due to the small number of subjects we choose a within subject design for the experiments. Hence, test subjects alternate in the role as flight instructor as well as pilot trainee. To get into routine each subject first conducted a training mission in the Alps. It consists of all elements of the following measurement mission. Landing in the mountains and emergency procedures for engine failure were rehearsed several times. After completing the training mission, the experimental mission was executed. During flight from the pickup injured to the hospital the flight instructor initiated an unexpected engine failure (independent variable).

Findings

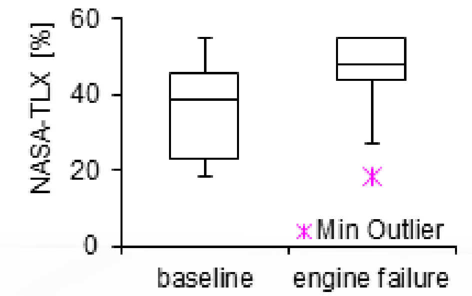

Figure 5. NASA-TLX in baseline and during engine failure

NASA-TLX questionnaires were presented to the pilots for a baseline measure (i.e., during enroute, takeoff, landing) and then for the engine failure condition. Due to inter-individual differences of the workload scales, all NASA-TLX-ratings were normalized. As depicted in Figure 5, pilots rated the baseline with 35.5% workload at the average. In contrast the engine failure condition was rated with an averaged workload level of 48.2%. The increase of workload was proved weak significant by a two side t-test (t(33)=1.75, p=0.0897, SD=13.2, n_1=26, n_2=9).

In a second step we observed the manual control stick activity of the pilots. During the baseline condition enroute-flight all pilots showed only little control activity (cf. Figure 6). Although pilot 1, 2 and 4 were almost equally experienced, they showed much different control activity during landing and take-off. Huge differences in control inputs are observed under the engine failure condition. In particular, pilot 2 showed a very high control activity. In contrast, pilots 3 and 4 exhibited much less control activity in this situation. To sum up, the experiments revealed individual pilot behavior in comparable situations.

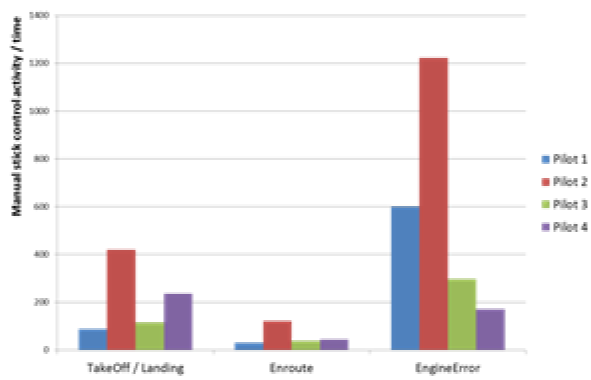

Figure 6. Manual control input of test subjects in examined mission phases

Figure 7 depicts the predicted workload of the pilot during enroute-flight and during engine failure condition. Therefore, one engine had been shut down by the flight instructor at approximately $t = -150s$. For the examination of hypothesis (1) we compare the relative values of the predicted workload with the experimenter's subjective observations and additionally with the manual stick control activity and the NASA-TLX. As depicted in figure 5, the NASA-TLX revealed an increased workload in engine failure condition. The increase of workload (predicted by our functional chain for the test subjects) between enroute flight and the emergency maneuver "engine failure" (c.f. Figure 7) show a similar characteristic. However, for each test subject a different workload was estimated. Despite the emergency maneuver the estimated workload for pilot 4 is in moderate range. This is consistent with the experimenter's subjective observations of the test person's behavior, because he acted in a very structured way with only a few control inputs. A higher workload was estimated for subject 1 and 3. Nevertheless both subjects performed well the mission tasks. In contrast to this, a very high workload was estimated for subject 2 in the emergency situation. This finding is consistent to the observed behavior of the pilot because he did not respond to auditory communication with the flight instructor in this situation.

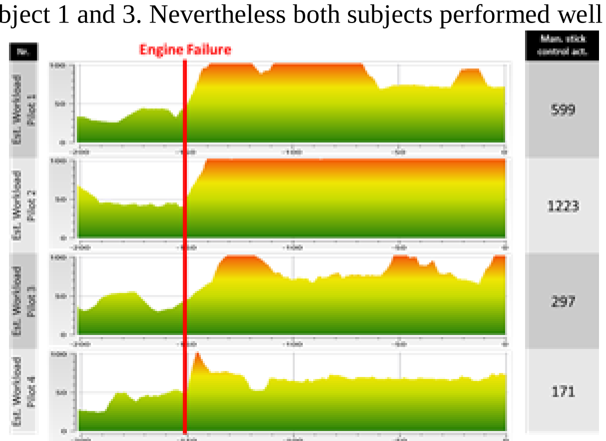

Figure 7. Estimated workload for 4 subjects during enroute with transition to engine failure. Manual stick control activity is excluded in workload determination

The results encourage using individual behavior parameters (manual, visual and auditory interactions) as part of workload prediction. Figure 7 shows a correlation between the manual control activity and the predicted workload. So, in future models the control activity shall be included in addition to the manual, auditory and visual interactions of the pilots. Consequently hypothesis (2) is worthwhile to be further examined.

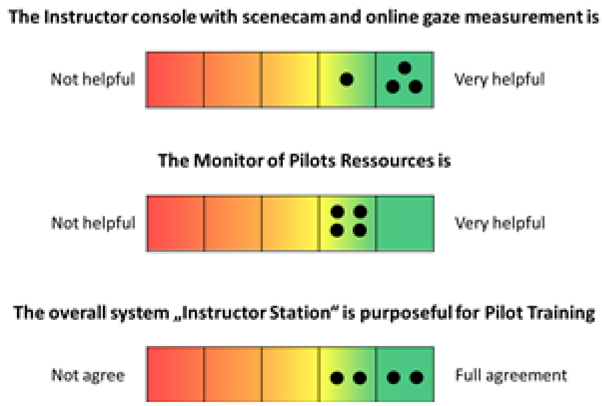

Figure 8. Questionnaires (subjective ratings) of pilots for instructor assistance

Using further questionnaires (cf. Figure 8) the pilots rated the instructor station and integrated tools (e.g. scene camera, workload monitor) as helpful and purposeful for pilot training. They felt well supported in assessing the workload of the pilot. The hypothesis (3) can thus be confirmed.

Conclusions

The implemented system represents an initial approach to assist the flight instructor in the objective and continuous assessment of the pilot trainees' mental state. A possible application is the support of debriefings by use of offline analyses of recorded missions. Thereby, workload peaks could be identified in correlation with specific behavior. Such an assessment could form the basis for future adaptations of workload intensive procedures and may result in improved aviation safety.

Benefit is also expected through the online analysis of workload to optimize the training of pilot trainees. This would enable the training staff to continuously monitor the pilot trainees' mental state and allow the flight instructor to purposeful stimulate the workload (e.g. maxing out trainees).

However, the presented approach requires a further development and validation in the domain of helicopter emergency missions. Our future work will incorporate trials for a profound validation of our resource model prototype, in particular the demand vectors. Also further effort has to be placed in the secure determination of pilots' activity. Here we are investigating on the application of uncertainty theories.

References

ALDRICH, T.B. & MCCRACKEN, J.H. (1984). *A computer analysis to predict crew workload during LHX ScoutAttack Missions*. Vol.1, Fort Rucker, Alabama, US Army Research Institute Field Unit.

BILLINGS, C.E. (1991). *Human-Centered Aircraft Automation: A Concept and Guidelines.* NASA Technical Memorandum 103885. Moffet Field, NASA-Ames Research Center.

DONATH, D. (2012). *Verhaltensanalyse der Beanspruchung des Operateurs in der Multi-UAV-Führung („Behavior Analysis of Workload of multi-UAV Operators").* Dissertation. Universität der Bundeswehr München.

GOPHER, D. & DONCHIN, E. (1986). Workload – An Examination of the Concept. In: BOFF, K.R., KAUFMAN, L. & THOMAS, J.P. (Eds.) Handbook of Perception and Human Performance. Vol.2 (41), pp .1–49. New York: John Wiley.

MAIWALD, F. (2013). *Maschinelle Beanspruchungsprädiktion zur ressourcengerechten Adaption eines Pilotenassistenzsystems („Automatic Workload Prediction for Ressource Adaptive Pilot Assistence").* Dissertation. Universität der Bundeswehr München. (in print)

MAIWALD, F. & SCHULTE, A. (2014). Enhancing Military Helicopter Pilot Assistant System Through Resource Adaptive Dialogue Management. In: VIDULICH, M., TSANG, P. & FLACH, J. (Eds.) *Advances in Aviation Psychology,* Ashgate Publishing Ltd, ISBN: 978-1-4724-3842-3.

MCCRACKEN, J.H. & ALDRICH, T.B. (1984). Analysis of *selected LHX mission functions: Implications for operator workload and system automation goals*. Fort Rucker, Alabama, US Army Research Institute Aircrew performance and Training.

NAKAYAMA, O., FUTAMI, T., NAKAMURA, T., BOER, E. (1999) Development of a Steering Entropy Method for Evaluating Driver Workload. In: *Society of Automotive Engineers Technical Paper Series*: 1999-01-0892

ONKEN, R., & SCHULTE, A (2010). *System-ergonomic Design of Cognitive Automation-Dual Mode Cognitive Design of Vehicle Guidance and Control Work Systems*. Heidelberg: Springer.

PINA, P.E., DONMEZ, B. & CUMMINGS, M.L. (2008). *Selecting metrics to evaluate human supervisory control applications* (No. HAL2008-04). Cambridge, MA: MIT Humans and Automation Laboratory.

SPERANDIO, A. (1978). The regulation of working methods as a function of workload among air traffic controllers. In: *Ergonomics*. Vol.21, No.3, pp. 195–202.

WICKENS, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science*, 3(2), pp. 159-177.

YOUNG, M.S., BROOKHUIS, K.A., WICKENS, C.D. & HANCOCK, P.A. (2015). State of science: mental workload in ergonomics. In: *Ergonomics*, Vol.58, No.1, pp.1-17.