OPERATORS (PILOTS, ATCOS)’ LOAD MONITORING AND MANAGEMENT

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Summary

The revolution in information, computer, navigation and communication technologies catalyse to development of large highly automated systems in operators’ (Pilots, Air Traffic Controllers- ATCOs) environments, such as future aviation systems. In parallel to these rapid technological changes, a large number of aerospace companies, universities, and institutes have been initiated intensive research on the future of autonomous systems. Worldwide several mega international and national projects have been initiated for the research, development and implementation of systems, regulations and procedures for future aviation systems such as SESAR [1], and Next-Gen [2]. One of their main objectives is to bring an extensive range of innovative solutions to the current and future aviation issues to cope with growing air traffic, under the safest and environmental friendly conditions. These investigations have been introduced to countless technological and system innovations in operators’ working environments. The aviation industry has already come a long way, but the efforts are and will be never enough. There have been rapid and significant changes in aviation technologies in recent years. Thereby the level of automation, aviation systems and the working conditions of the operators are continuously changing and being redesigned [3]. Aviation operations, therefore, must continue to adapt respectively and meet the needs of the growing aviation industry. In a continually changing world, the role of operators, namely pilots (on-board and remote) and ATCOs, are in transition from active endogenous control to passive monitoring due to the introduction of the intensive automation. This means before operators were actively taking part in the controlling process, however now they are in a position of monitoring the current system. During active control, the operator simultaneously is involved in a series of actions (situation awareness – decision making – control actions) while automated systems, the operator monitors the operating system and only in abnormal and/or an emergency situation operator should engage active control. With continuous evolution of
the flight systems, including aircraft capabilities, radar, and sensor systems, operators are supported by vast amounts of available data and relevant information. In this current modern operator environment, the role of the operator became an information manager than an operator instead. Available too much information confuses operator during operation, particularly while decision-making time in abnormal/emergency situation.

In parallel with these changes, operator load systems have been significantly changed as well. This highly automated system may be accompanied by unbalanced operator load systems (vary from under load to overload), unintended reductions in situation awareness, decrease in the quality of decision-making, increased the level of stress. The future operator environment (cockpit, future ground control tower of pilots, air traffic control towers) needs to be redesigned by taking into account various psychological parameters, human factors and operator loads.

The main objective of this thesis is to develop general load monitoring and management systems of operators working in highly automated systems. Therefore, the sub-objectives (tasks to be performed) of this study are in fourfold: first, to develop operator load models for pilots and ATCOs, second, to develop concept of load measuring systems, to create some sensors and performing test measurement, third, to investigate some special aspects that influence safety like misunderstanding of communication systems and last, build operator load management systems by using the measurement.

**Thesis Content**

This thesis aims at building load monitoring systems in operators 'working environments and managing their total loads. To achieve this, four chapters were designed in this thesis. In the first chapter, the role of operators in future aviation systems was described, such as operators’ roles, working environments, human factors and model. In the scope of the SESAR project, the real data from the validation exercise were used in testing the dynamic sectorization method [4]. In the second chapter, several well-known operator models were studied and adapted to the human operator work in highly automated systems, such as Endsley “load model”[5], Rasmussen “situation awareness and decision-making model”[6], Kasyanov “subjective decision model”[7], and Wickens “information model”[8]. The role of mental condition was found to be increased in highly automated systems, and task and workload become more interconnected, and information load and communication load were detected as a new type of operator loads. Thereby a new operator load model was created and divided into five categories, namely work, task, information, communication and mental load [9]. The created generalised model was used in developing the ATCOs environment [10]; [11]; [12] and less skilled pilot support [10]; [11]; [13]. The subjective decision-making of the different level of experience of pilots, namely (i) student pilot, (ii) less-skilled pilot, (iii) experienced pilot and (iv) well-experienced, were modelled on Matlab by the modified Lorenz attractor (Figure 4). During the final approach hesitation frequency and decision-making time were calculated for landing and go-around situations. In addition to this, some unique aspects of operators were investigated in this chapter which influence on safety like misunderstanding. A questionnaire was conducted to 212 operators (168 ATCOs and 44 pilots) in order to investigate the reasons for communication errors, avoid pragmatic failure and minimise the risk of misunderstanding of operators (pilots, ATCOs) related to several factors such as cultural norms, social relations, regional accents and poor language skill. Once the areas of pragmatics and other possible linguistics sources of misunderstanding and their impact on air safety have been identified. Some approaches were proposed for native and non-native English speaking operators, and also for both to improve their aviation communication particularly via the radio-telephony communications [14].

In the third chapter, the load monitoring systems was developed and the measurements were performed such eye-tracking ([9]; [11]; [15]), integrated
microsensors and motion cameras ([9]; [16]; [17]), heart rate measurement ([9]; [11]; [15]), and (iv) EDA (Electrodermal Activity) device ([15]; [17]; [19]. In the fourth chapter, operator load management systems were built by using the measurements. Two different variety of total load management methods were defined based on workload, task load, information, communication and mental load for overload and underload situations: (i) assign a scoring method - say in [0,1] to all the measurements and (ii) mathematical modelling [19]; [20]. Finally, the summary, major results, theses, and recommendations for the future works were presented.

**Major Results**

- Several well-known operator models were studied and adapted to the human operator work in highly automated systems, such as Endsley “load model” [5], Rasmussen “situation awareness and decision-making model” [6], Kasyanov “subjective decision model” [7], and Wickens “information model” [8].

![Figure 1: The created model of situation awareness and decision making in future dynamic ATM environment (Own publications: [9]; [10]; [11])](image)

- The role of mental condition was found to be increased in highly automated systems, and task and workload become more interconnected, and information load and communication load were detected as a new type of operator loads. Thereby a new operator load model was created and divided into five categories namely work, task, information, communication and mental load (Figure 2).

![Figure 2: The new operator load model (Own publications: [9];[20];[11])](image)

- The research was done on developing a working environment enhanced with integrated sensors to collect information on operators’ activity, thereby increasing situational awareness, the quality of decisions and balance loads on the subject. By analysing the test results, the applied methodology showed that the developed system could be applied in the pilot training [9], ATCOs’ working environment [18], and as well as car drivers’ environment [21].

- TOBII eye-tracker has been used to record the visual patterns of the pilots through an engine failure scenario. Eye movement and the area of interest of pilots were defined through three flight scenarios. By analysing...
The result of operator eye-movements, eye-tracking systems can be a useful tool for pilot and ATCO training.

- Eye movements are very depending on the task, experience, and human behaviours. A strong relation found between task and operator working behaviours like during taxi, take-off and landing (experienced and less-skilled pilots) [9]; [16]. Based on the eye movement results, the less-skilled pilot makes more eye movements during taxi (35%), take-off (37%) and landing (41%) compared to experienced pilots.

- The complexity of the task is directly proportional to the number of eye movement per second. In other words, if the complexity of task increases, the number of eye movement per second also respectively increase. Concerning this, the number of eye movement of the experienced pilot is (i) 1.31 per second under Visual Meteorological Conditions (VMC) scenario, (ii) 1.82 per second under Instrument Meteorological Conditions (IMC) scenario, and 2.38 per second under IMC with Attitude Directional Indicator (ADI) failure.

- The number of eye blink (full blink and half blink) of experienced pilot increased significantly in parallel to the task complexity: (i) 0.25 per second under Visual Meteorological Conditions (VMC) scenario, (ii) 0.29 per second under Instrument Meteorological Conditions (IMC) scenario, and 0.39 per second under IMC with Attitude Directional Indicator (ADI) failure. In addition to this, it is also noticed that eye flutters (rapid muscle movement in the eyebrow area) also increased.

- The subjective decision-making of the different level of experience of pilots, namely (i) student pilot, (ii) less-skilled pilot, (iii) experienced pilot and (iv) well-experienced, were modelled on Matlab during final approach by the modified Lorenz attractor. According to the results, the decision-making time and hesitation frequency are increasing while the level of experience is decreasing. This model is well usable for the investigation of the decision-making process of pilots from different skills and experience. This method improves pilot training and help instructors to understand the weaknesses of pilots better as well. During the final approach, the less-skilled pilot requires about six times more time for making the final decision on go-around than the well-practised pilot. These results demonstrate that the model is suitable to investigate the different level of pilots while checking their way of thinking and decision-making process.

- I have defined how to interpret operator measured heart rate depending on the situation (flight scenarios and traffic situation). A strong relationship found between the complexity of the task and heart rate of pilots. The heart rate of the pilot is significantly changing on the complexity...
of task scenarios: (i) Average Heart Rate: 82.4 bpm - Standard Deviations (SD): 10.8 - Root Mean Square (RMS): 83.1 under Visual Meteorological Conditions (VMC) scenario, (ii) Average Heart Rate: 96.8 bpm - Standard Deviation: 6.95 - RMS: 97.0 under Instrument Meteorological Conditions (IMC), and (iii) Average Heart Rate: 103.9 bpm - Standard Deviation: 6.98 - RMS: 104.1 under IMC with Attitude Directional Indicator (ADI) failure scenario. Based on the results, it can be also found that if the complexity of the task is increasing, the average of the heart rate is also significantly increasing. I found that the heart rate variability can be used as a major indicator for detecting the mental load that even may indicate the task complexity monotony and the ratio of automation (Figure 5).

- The Skin Conductance Level (SCL) of a pilot was recorded by OBIMON devices (an Electrodermal activity device) during all phases of the flight through “a poor visibility and instrument failure” flight scenario. The results suggested that emotional arousal was highest during flight take off in comparison to en-route and landing. In addition to this, based on analyses of the measured EDA, the arousal was found to be high, when the flight took turns (Figure 6, [15]; [17]; [19]. According to the results, the actual mental condition can be estimated, which means, it is possible to determine if an operator is tired, unbalanced loaded (overloaded or underloaded) or nervous at a moment.

- I was taken part of a SESAR project dealing with airspace design and dynamic sectorization on the evaluation of the verification and validation results. I was detected that the task load, as defined by NASA - TLX, can be managed by defined by airspace design and dynamic sectorization, and I found that the dynamic sectorization and air space configuration may eliminate the task overload and reduce the actual load by 30-40 per cent [4].

- Operator load index calculation method was defined by the current researcher, by the following formula:

$$ i_{Load} = \sum_{i=1}^{5} w_{ei}(u, z)L_c $$

where $i_{Load}$ is total load index, $w_{ei}$ is weighting coefficient and $L_c$ is the load coefficient, $u$ is the control and $z$ is the environmental characteristics.

$$ i_{Load}[k] = \sum_{q=1}^{r=9} (A[k]i_{Load}[k] + w_{qu}B[k]u[i_{Load}[k]] + w_{qz}F[k]z[k]) $$

when $u[k, i_{Load}[k]]$ is the management definition, and $z[k]$ is the scenario. $u_1 = Work\ load$, $u_2 = Task\ load$, $u_3 = Information\ load$, $u_4 =$
Communication load, $u_5 = \text{Mental load}$, and $z_1 = \text{Structure}$, $z_2 = \text{pilots}$, $z_3 = \text{ATCOs}$, and $z_4 = \text{Surroundings}$.

- I found that in a highly automated system, large mental load, such communication overload loads are increasing. According to my investigation, I have recommended to include the English conversation using by different cultural norms and social relations into the pilot and ATCO training [14].
- All the developed load monitoring and management methods were supported by measurements and applied load monitoring in the screen of pilots (Figure 9, [10]; [11]; [13]) and ATCOs (Figure 10, [10]; [11]; [12].

New Scientific Results

Statement I:

I have investigated and analysed the role and load of the human operators (Pilots and ATCOs - Air Traffic Controller) working in highly automated complex active, endogenous, ergatic, technogenic systems including investigation of the operator situation awareness - analysis – decision-making process by using (i) outside measurements (like motion camera [9]; [17]; [18], eye-tracking [9]; [11]; [15]), (ii) microsensors integrated into working environment (for example computer mouse, side stick, skin resistance, skin temperature [9]; [10] (iii) connecting directly to the operators body (heart rate/heart rate variability [9]; [15]; [22]; [23]; [24]; [25], ECG [26]; EEG [22]; [23], EMG [29], EDA-Electrodermal Activity [13]; [16]; [30], sensors integrated into operator clothes), (iv) adapting simulation methods like using method of subjective analysis (Figure 4).

Thesis I:

I had discovered three new possible phases of operator working behaviour in highly automated systems (investigated by measuring reactions of operators by initiating fault scenarios).

- The first mode is during the beginning of operation determining the effect of attention disappearing due automation trust (like pilot working very well during take-off and relaxing during the climb).
- The second mode is a mental overload because of the monotony supervising and monitoring systems (en-route phase) [10]; [13].
therefore, need to have breaks at least every two hours.

• The third mode is that operators are overloaded or underloaded (mainly task, mental and information load), thereby using decision more procedure than being creative (like during landing phase of the flight)).

• The differences between the modes are raised in reaction time, increasing the time required for situation awareness, analysis decision-making, increasing the reaction time and frequency and amplitude of “hesitation” (Figure 4).

Statement II:
I have taken part in developing sensors and methodology for monitoring of human operator loads (developed eye-tracking systems, integration of microsensors into operator environment like side stick, computer mouse). Based on the eye-tracking measurement, I have developed a recommendation for using eye-tracking systems for pilot training in the flight simulator [16]; [19]. Moreover, eye movement and the area of interest of pilots (experienced and less-skilled pilots) were defined through three flight scenarios: (i) Visual Meteorological Conditions (VMC), (ii) Instrument Meteorological Conditions (IMC), and (iii) IMC with Attitude Directional Indicator (ADI) failure. The number of eye blink (full blink and half blink) of experienced pilot increased significantly in parallel to the task complexity: (i) 0.25 per second under Visual Meteorological Conditions (VMC) scenario, (ii) 0.29 per second under Instrument Meteorological Conditions (IMC) scenario, and 0.39 per second under IMC with Attitude Directional Indicator (ADI) failure. In addition to this, it is also noticed that eye flutters (rapid muscle movement in the eyebrow area) also increased.

• Eye-tracking and eye movement measurements were supported by measurements and applied load monitoring in the screen of pilots (Figure 9, [10]; [11]; [13] and ATCOs (Figure 10, [10]; [11]; [12]).

• I have defined how to interpret operator measured heart rate depending on situations (flight scenarios and traffic situation). I found a strong relationship between the complexity of the task and heart rate. As seen in Figure 5, the heart rate of the pilot is significantly changing on the
complexity of task scenarios: (i) Average Heart Rate: 82.4 bpm- Standard Deviations (SD): 10.8- Root Mean Square (RMS): 83.1) under Visual Meteorological Conditions (VMC) scenario, (ii) Average Heart Rate: 96.8 bpm- Standard Deviation: 6.95- RMS: 97.0 under Instrument Meteorological Conditions (IMC), and (iii) Average Heart Rate: 103.9 bpm- Standard Deviation: 6.98- RMS: 104.1 under IMC with Attitude Directional Indicator (ADI) failure scenario ([9]; [11]; [15]). The heart rate of the pilot significantly increases under instrument flight rules – IFR (Task 2) and IMC failure. In case of the first scenario, the average of the heart rate (82.4 bpm) and the amplitude have the smallest value where the Standard Deviation (SD:10.8) has the highest value compare to the second and third scenarios. Based on the results, it can be also found that If the complexity of the task is increasing, the average of the heart rate is also significantly increasing ([9]; [11]; [15]).

Based on analyses of the measured EDA, I found that the emotional arousal of the pilot was highest during flight take off in comparison to en-route and landing. In addition to this, the arousal was found to be high, when the flight took turns ([15]; [17]; [19]).

Statement III:
I have studied the well-known operator models like load model by Endsley, situation awareness model by Rasmussen, subjective characters of decision making by Kasiaanov, and information model by Wickens. I have generalised these models and adapted to the human operator work, working in highly automated systems ([10];[21]).

Thesis III:
I have improved and adopted Endsley and Rassmussen models enabling study human operator situation awareness and decision process.

- I have integrated Rasmussen situation awareness model into the generalised model created by using the Endsley model for the description of the working behaviours of the operators monitoring and managing the highly automated systems ([11]; [17]).

- I have included the subjective decision model into the created generalised model (Figure 1, [9]; [10]; [11]).

- I have included human behaviours (knowledge, tacit knowledge) into the created generalised model (Figure 1, [9]; [10]; [11]).

- The created generalised model was used in developing the ATCOs environment and less skilled pilot support [9].

Statement IV:
I was investigated and created a generalised model in simulations, in-flight and ATCO simulators. I have found that the role of mental condition is increased in highly automated systems, and task and workload become more interconnected, as well as information load and communication load were detected as a new type of operator loads. I was taken part of the SESAR project dealing with airspace design and dynamic sectorization on the evaluation of the verification and validation results [14]. I have made a series of measurements by using different sensors and methodologies (hearth rate, EDA, skin resistance, skin temperature, etc.).
Thesis IV:

I was created a new operator load model, including five types of loads that were tested and verified in simulators and partly validated in real situations.

- I was detected that the task load, as defined by NASA - TLX, can be managed by the defined airspace design and dynamic sectorization, and I found that the dynamic sectorization and air space configuration may eliminate the task overload and reduce the actual load by 30-40 per cent [14].

- I found that the workload used by most of the previous researchers as the major characteristics of the operator load must be used in further according to highly automated systems.

- I found that the heart rate variability can be used as a significant indicator for detecting the mental load that even may indicate the task complexity monotony and the ratio of automation [9]; [19].

- I was detected the raising of information overload because of supporting the operator by too much information may be not well-correlated; therefore, an operator may be confused and its situation awareness, analysis, decision-making and reaction time are increasing in highly automated systems. Information overload depends on human behaviour like the ability to multi-task, ability to filter out information, mental conditions, and concentration.

- I have investigated the different load systems found that today in highly automated systems, communication load can be defined as a separate load ([14]).

- I found that in a highly automated system, large mental load, such communication overload loads are increasing. According to my investigation, I have recommended to include the English conversation using by different cultural norms and social relations into the pilot and ATCO training [14].

Statement V:

I was investigated the possible operator (Pilots and ATCOs) load management methods for overload and underload situations.

Thesis V:

I was created two different variety of total load management methods based on workload, task load, information and mental load for overload and underload situations: (i) assign a scoring method - say in [0,1] to all the measurements and (ii) mathematical modelling.

- I defined thresholds for each load independently for overload situation as warning signals, calling special attentions (continuously monitoring the operating condition), and immediate actions required, respectively 0.8, 0.9 and 0.95 (according to the defined scoring method) ([11]; [20]).

- I defined thresholds for the combination of at least two loads for overload situation, namely in a case when two types of load coefficients in any combination, reach to 0.7 or above as warning, monitoring, and immediate actions required, respectively 0.7, 0.8, and 0.9 (according to the defined scoring method) ([11]; [20]).
• I defined thresholds for each load independently for underload situation as warning signals, calling special attentions (continuously monitoring the operating condition), and immediate actions required, respectively 0.2, 0.1 and 0.05 (according to the defined scoring method).

• I defined thresholds for the combination of at least two loads for underload situation, namely in a case when two types of load coefficients in any combination, reach to 0.3 or below as warning, monitoring, and immediate actions required, respectively 0.3, 0.2, and 0.1 (according to the defined scoring method).

• Operator load index calculation method was defined by the following formula:

\[ i_{\text{Load}} = \sum_{i=1}^{5} w_{ei}(u, z)L_c \]

where \( i_{\text{Load}} \) is total load index, \( w_{ei} \) is weighting coefficient and \( L_c \) is the load coefficient, \( u \) is the control and \( z \) is the environmental characteristics.

\[ i_{\text{Load}}[k] = \sum_{q=1}^{r=9} (A[k]i_{\text{Load}}[k] + w_{qu}B[k]u[i_{\text{Load}}[k]] + w_{qz}F[k]z[k]) \]

when \( u[i_{\text{Load}}[k]] \) is the management definition, and \( z[k] \) is the scenario. \( u_1 = \text{Work load}, \quad u_2 = \text{Task load}, \quad u_3 = \text{Information load}, \quad u_4 = \text{Communication load}, \quad u_5 = \text{Mental load}, \quad z_1 = \text{Structure}, \quad z_2 = \text{pilots}, \quad z_3 = \text{ATCOs}, \quad \text{and} \quad z_4 = \text{Surrounding}. \]

References


Own Publications


