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The model of a pilot competency as a factor influencing the safety of air traffic

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ABSTRACT: The level of safety in air transport is affected by many factors: the widely understood human factor, technical factor and environmental factor. The aim of the research is to develop indicators for quantitative assessment of the flight crew status in the context of its impact on the safety of air traffic. The paper presents a new definition of a flight crew status of a formal nature. The proposed approach takes into account functional dependencies between the various factors influencing the air crew status. These dependencies are hardly definable and partly subjective, so the research concerning them belongs to the area of uncertain information analysis. We propose to use fuzzy inference methods using expert knowledge for this analysis. The paper gives a detailed description of the new fuzzy local model of a pilot competence, which is expressed by the linguistic variable values. They are influenced by the pilot's experience, training process and the Crew Resource Management (CRM). A fuzzy inference system corresponding with the model was built. Some examples of membership functions of linguistic variables and sample fuzzy inference rules are presented in the paper. This system was used for the model experiments, which led to the interesting results. These include finding the relationships between the experience of the pilot, the various elements of the pilot training process and the flight crew status. The obtained results allow, among others, to optimize the process of flight crew selection to specific tasks, and to optimize the process of a pilot training.

1 HUMAN FACTOR IN THE AIR TRAFFIC MANAGEMENT SYSTEM

The very important problem in the Air Traffic Management (ATM) is to maintain the control subsystem's ability to interact with the controlled objects in order to achieve the intended objectives. The efficiency of this interaction is affected by many factors like suitable communication or surveillance systems reliability. As well the control subsystem as the controlled objects (aircraft) are strongly human-related and in this paper particular attention will be given to a flight crew as the human component of the air traffic. The crew's ability to proceed with basic tasks of managing flight as aircraft control and positive two-way communication process with air traffic controllers is one of crucial factors determining the main goal—maintaining the flight safety at assumed level. This ability is to a great extent dependent on a crew selection or, saying more widely, on a crew resource management at the air carrier's level. This paper presents the method of flight crew status assessment, particularly the crew competency as one of the most important elements.

Problems concerning human factor's role in the air traffic safety are the point of interest of scientists of different domains. The paper (Afrazeh & Bartsch 2007) presents human reliability as the human ability to perform the task in given frames, covering all the physical and psychological skills, experience and personal characteristics. The other one (Dekker 2006) states that the whole human performance of people taking part in aviation transportation process is located in a specific context that consists of the aircraft and its equipment type, weather, air traffic and other Performance Shaping Factors—PSF. They were incorporated in (Swain & Guttman 1983) as the set of factors affecting human capabilities. They are divided to internal ones—like stress, fatigue, knowledge, personality, experience, and external ones—such as ergonomics, educational programs, organizational structure, motivation and procedures (Pei-Hui 2011).

According to system approach to air traffic safety problem, the human factor is placed in the center of interest. However, the other important factors that influence the operational risk in direct or indirect manner are not omitted. There are two most popular system models of human factor in the air traffic safety. One of them is the SHELL model (Edwards 1972; Hawkins 1993) and the second one—the Reason's model (1990). The first model describes the threats connected with interface between human and environment, software, hardware and other human. The second one presents dependencies among different areas of operations which can include different safety gaps.

The attempt to analyze flight crews and air traffic controllers using fuzzy sets theory was introduced in (Lower et al. 2013). The likelihood of an incident to accident transformation was analyzed assuming adverse human operation.

The literature analysis shows the most common way to divide human factors to four groups: physical, physiological, psychological and external conditions. Physical factors can be expressed in the form of health, growth and strength. The physiological ones include the access to oxygen, changes in pressure, perception capabilities, disorientation, fatigue, biorhythm disturbances, diet and alcohol effects. The psychological factors are: information processing and selection, error management, personality, self-discipline, motivation, operation under pressure, situational awareness, perception, safety awareness, threat identification, decision making and judgment of situation, attention distribution, coping with stress, interpersonal communication, leadership, adaptation capabilities, training, skills and experience. Finally the external conditions consist of workload and task demand, also the all meanings of culture (connected with profession, organization and safety) are included.

The literature mentioned above however, doesn't try to assess quantitatively the one given flight crew status in the context of the actual flight safety. In (Skorupski & Wiktorowski 2013) a proposal of the mathematical fuzzy inference model with the quantitative crew status assessment as the result is introduced. The estimation is expressed by linguistic variable value where the way leading to the final result takes into consideration many of the essential factors connected with crew's before flight preparation. The calculations consider also the operational and organizational environment influence. The model can become the base for creation of a decision support system that could be useful for people responsible for crew management process.

This paper is the extension of our previous work. It shows how the very important parameter—pilot's training—affects pilot's competency. It also shows how this relationship can be assessed quantitatively with the use of fuzzy sets theory.

The paper is organized as follows. In section 1 a short literature review on human factors in ATM is presented. Section 2 contains the short introduction to air carrier tasks connected with the crew resource management. In section 3 the literature review and general idea of fuzzy inference system for air crew status assessment is given. Section 4 presents one of the most important elements of this system—the local model, where the linguistic variable *Competency* is introduced. Then, in section 5 detailed description of training (represented by linguistic variable *Training*) as the very important part of competency model is given. Section 6 presents and discusses some experiments' results, that can be useful in everyday aircrew management. In section 7 a summary and concluding remarks are presented.

2 AIRLINE OPERATORS' TASKS IN THE AREA OF CREW RESOURCE MANAGEMENT

According to The Annex 6 of Chicago convention, the Safety Management System (SMS) was introduced. This triggered the situation where the airline operators are obliged to manage the safety, covering their all activities including every single flight. First of all, SMS deals with threat identification, ineligible events effects mitigation and risk estimation. The goals listed above can be assisted by the proposed model of the flight crew status in the context of safety. The risk connected with conducting the whole process of flight by the given crew will be easier to estimate in objective and quantitative way. The research of some flight operators (airlines) functioning in the area of SMS was presented in (Pei-Hui 2011). It was to be said that the idea of SMS was realized only partly, therefore some changes at the operational level are to be made. The model and the fuzzy inference system for the flight crew assessment, presented in the following sections, are going to work at the same level. Nowadays the risk management cards are widely used for the operational risk assessment, but they are not sufficient. The discussed model application can possibly extend the risk assessment idea by the whole human factor problem consideration. The flight crew assessment based on the presented method may improve crew resource management and planning process and in result will make the operators able to maintain high level of operational readiness especially in the area of crew availability.

3 THE FUZZY MODEL OF THE FLIGHT CREW STATUS ASSESSMENT IN THE CONTEXT OF AIR TRAFFIC SAFETY

The problem of the flight crew status estimation in the context of proper flight task realization concerns the human factor that is hard to analyze in exact manner. That's why the problem is located in the area where the information is imprecise and uncertain. Therefore the fuzzy logic approach is used in this elaboration.

There are many papers that suggest the usage of the fuzzy logic methods and tools in the area of air traffic management. One of the most interesting (Hadjimichael 2009) describes the expert system that was created to assist the take-off and landing risk assessment. The human factor was taken into consideration however the problem was much simplified. The problem of flight crews duty hours planning was undertaken in the paper (Teodorovic & Lucic 1998). Psychological aspects of pilot's behavior where analyzed in (Wanyan et al. 2011). The research (Xianfeng & Shengguo 2012) includes the attempt of airport security assessment where the human factor was partly taken under consideration. The other examples of fuzzy methods utilization in the area of air traffic management can be found in (Babic & Krstic 2000) and (Netjasov 2004). The other technology sectors also use the fuzzy methods in risk assessment of key elements damage (Torshizi & Parvisian 2012), as well as human factor influence on reliability of system (Bertolini 2007).

In this research we are concentrated on hierarchic fuzzy structure creation considering any possible factors which can influence the crew (not single pilot) ability to perform the flight. We try to consider all the physical, physiological, psychological factors as well as the external conditions. The created model that is still being developed as well as its computer implementation in SciLab can be used to support the decision making process in crew selection.

The fuzzy set A we define as follows (Kacprzyk, 1986):

$$A = \{(x, \mu_A(x)) : x \in X, \mu_A(x) \in [0,1]\} \tag{1}$$

where μ_A is the membership function of this set.

As a linguistic variable we define the variable which is expressed by words or sentences that we call linguistic values of linguistic variable. Our models assume that linguistic variables have *low, average* and *high* values.

The trapezoidal membership function for *low* value with trapezoidal shape and parameters (a,b,c,d) is defined as follows:

$$\mu_{low}(x;a,b,c,d) = \begin{cases} 0, \ x < a = b \\ 1, \ b \le x \le c \\ \dfrac{d-x}{d-c}, \ c < x \le d \\ 0, \ x > d \end{cases} \tag{2}$$

For value *average*:

$$\mu_{avg}(x;a,b,c,d) = \begin{cases} 0, \ x \le a \\ \dfrac{x-a}{b-a}, \ a < x \le b \\ 1, \ b < x \le c \\ \dfrac{d-x}{d-c}, \ c < x \le d \\ 0, \ x > d \end{cases} \tag{3}$$

For *high* value:

$$\mu_{hgh}(x;a,b,c,d) = \begin{cases} 0, \ x \le a \\ \dfrac{x-a}{b-a}, \ a < x \le b \\ 1, \ b < x \le c \\ 0, \ x > c = d \end{cases} \tag{4}$$

In the reasoning process we use the input values fuzzification block, then inference block that uses a set of fuzzy rules, and finally defuzzification block of output values. The set of rules is being created with experts' opinions, in this case aircraft pilots and people responsible for Safety Management System (SMS) organization. As a inference rule for local models we will use the fuzzy rule *modus ponens*, as below (Kacprzyk 1986):

$$\begin{aligned} &I : x = A \Rightarrow y = B \\ &P : x = A' \\ &C : y = B' \end{aligned} \tag{5}$$

where I denotes implication, P—premise, C—conclusion. This rule gives us opportunity to conclude about the successor based on the predecessor logical value. The implication is treated as a fuzzy relation which means that A' doesn't have to be equal to A and B' doesn't have to be equal to B. It's fairly enough when A' is similar to A and this way B' is similar to B.

In the fuzzy inference systems the parameters listed below were chosen for determination of linguistic variable values concerning *CRM, Training* and *Experience*

– s-norm of maximum type:

$$\mu_{A \cup B}(x) = \max(\mu_A(x), \mu_B(x)) \tag{6}$$

– t-norm of minimum type:

$$\mu_{A \cap B}(x) = \min(\mu_A(x), \mu_B(x)) \tag{7}$$

– implication of algebraic product type:

$$\mu_{A \to B}(x,y) = \mu_A(x) \cdot \mu_B(y) \tag{8}$$

– rules aggregation of algebraic sum type:

$$\mu_{A\oplus B}(x) = \mu_A(x) + \mu_B(x) - \mu_A(x)\cdot\mu_B(x) \tag{9}$$

– defuzzification of center of gravity type:

$$Z^* = \frac{\int \mu_B(z)\cdot z dz}{\int \mu_B(z) dz} \tag{10}$$

The literature shows many different factors that influence human activity but only the most effective ones on flight crew performance were chosen for the analyses. We can point out three the most important factors describing the flight crew status. The first of them is competency (which among the others covers skills, experience and knowledge), the second one is situational awareness (that is determined mainly by communication and information processing) and the last one—motivation—the psychological side of performance (especially shows the difference between the actual results of activity and the theoretical abilities). The Figure 1 presents dependence scheme of the factors listed above.

The lack of situational awareness is one of the most important reasons of aviation negative events: incidents, serious incidents and accidents. The awareness is dependent on quality of information processing and communication, where the last one is strongly connected with competency and motivation. Information processing is dependent on fatigue and competency as well. As we can see the connections and dependencies are strongly complicated. This fact causes difficulties in the research and makes us to use expert estimated data, which are subjective and imprecise. Also that was the reason to use the fuzzy method in the research (Zadeh & Kacprzyk 1992).

The model of relations showed at Figure 1 determines the structure of local models. The every rectangle at this figure symbolizes the linguistic variable which is the output of a local fuzzy model with many inputs. The example of local models for *Competency* estimation will be shown in Chapter 4.

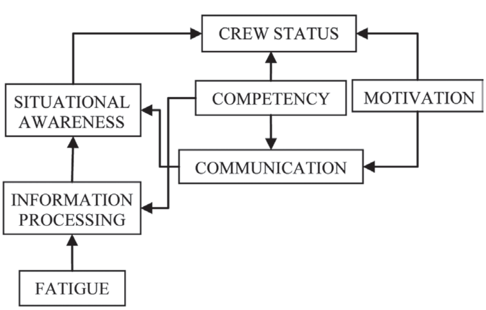

Figure 1. The general fuzzy model of factors that have influence on flight crew status.

4 THE FLIGHT CREW STATUS ASSESSMENT METHOD—LOCAL MODEL COMPETENCY

In this section we will concentrate on the local model destined to estimate the linguistic variable *Competency* which is the key factor for crew status assessment. That's because the *Competency* influence the linguistic variable of crew status directly and indirectly through the inputs to *Communication* and *Situational awareness* as well. Contributory factors of aviation events analysis indicate the last two factors are frequently direct reasons of flight incidents or belong to the circumstances that are conducive to negative events.

The linguistic variable *Competency* is determined by three input variables (Fig. 2): *Training, Experience* and *CRM* (Crew Resource Management), assumed as the ability of the crew to cooperation. We assumed the variable *Competency* will accept three values: *low, average* and *high*.

The three input variables influence the *Competency* in different manner. We assume the *Experience* has the highest weight because it mirrors crew flight capabilities with reference to their performance on current and the previous types of aircraft as well. The variables *Training* and *CRM* affect the *Competency* with the information about the so-called pilots currencies (length of breaks in flying) and important trainings participation which are

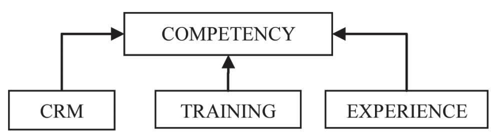

Figure 2. The local model *Competency.*

Table 1. The example of some fuzzy reasoning rules for *Competency.*

Rule	*CRM*	*Training*	*Experience*	*Competency*
10	*Average*	*High*	*Low*	*Low*
13	*Average*	*Average*	*Low*	*Low*
14	*Average*	*Average*	*Average*	*Average*
17	*Average*	*High*	*Average*	*Average*
18	*Average*	*High*	*High*	*High*
24	*High*	*Average*	*High*	*High*

especially key factors for young pilots. For more experienced pilots trainings and in-flight or simulator checks secure the safety from routine and conviction about their excellence that can become dangerous.

The Table 1 presents several fuzzy reasoning rules used in the fuzzy inference system for determining the *Competency.*

5 THE METHOD UTILIZATION EXAMPLE—TRAINING ASSESSMENT IN THE CONTEXT OF HIGH LEVEL OF CREW COMPETENCY

Between the others, the linguistic variable *Training* characterizes a member of flight crew in the area of currency in flying, and also accepts three linguistic values: *low, average* and *high*. One of the determinants can be the time that has passed since the last flight. The other one is the time (in months) since the last simulator training which is valuable index in relation to crew capabilities to cope with flight emergencies. Usually once a year every pilot is subjected to pass the checkride (an examination during flight) which causes the need to update and refresh his knowledge and this way improves his general professional performance in routine flights. That's why we can accept the time since the last checkride as the next *Training* determinant.

According to EU-OPS the every airline operator is responsible for implementation of procedures that guarantee their flight crews have all the proper licensees, suitable trainings, experience and are eligible to fulfill all the pilots duties (European Commission, 2008). Generally the every pilot is supposed to complete the aircraft class rating and aircraft type rating. Any change of operator by a pilot, forces him to complete the proper courses and trainings before he/she starts to fly without supervision.

The young pilots after completing suitable tests should execute minimum four flights under supervision in maximum 21 days period and 6 takeoffs and landings on simulator (sometimes the number of the operations can be flexible). The captains should have proper experience and they are obliged to complete aircraft commander training for multicrew operations that consists of:

- simulator training;
- captains airline training;
- captains skills examination;
- airports and en-route knowledge and competency training;
- CRM training.

Pilots should maintain their currencies (not to exceed maximal time between flights). The general rule is minimum 3 takeoffs and landings in the period of 90 days, but the period can be extended up to 120 days in cases pilots fly under supervision. When the break is longer, the compulsory additional flight under supervision or simulator training is required (European Commission, 2008). Not earlier than after 2 years of continuous flight operations, the periods of time listed above can be changed by the proper aviation authorities. In such cases ATQP (alternative training and qualification programme) and LOE (line oriented evaluation) allow the time spaces between checkrides to be extended to 12 months, and between emergency management checks-up to 24 months.

According to the previous assumptions and with respect to the flight crews operational rules we chose the input variables for linguistic variable *Training*:

- The period of time since the last flight: the *Pause* linguistic variable accepts three fuzzy values *low, average* and *high.* It's defined on the universe of discourse equal to the real numbers from the interval [0,90] days.
- The period of time since the last simulator training: the *Simulator* linguistic variable accepts three fuzzy values *low, average* and *high*. It's defined on the universe of discourse equal to the real numbers from the interval [0,12] months.
- The period of time since the last checkride in flight: the *Checkride* linguistic variable accepts three fuzzy values *low, average* and *high*. It's defined on the universe of discourse equal to the real numbers from the interval [0,24] months.

The Figure 3 shows the example of *Training* fuzzy model using the three listed above fuzzy variables as inputs. The Table 2 presents the trapezoidal membership functions parameters (a,b,c,d) of input variables while the trapezoidal membership functions parameters of output variable are shown in Table 3.

The factors listed above are searched for the importance and weigh that they have on *Training* and the results were taken into consideration in fuzzy reasoning rules creation. We assume the *Pause* is the most important. Pilots have to rely on their knowledge and experience and also they have to take care of the learnt good skills and habits. The longer the time since the last flight the faster proper skills and habits are forgotten. Less important are *Simulator* and *Checkride* while still they influence the output variable value. Some of the fuzzy reasoning rules are shown in Table 4. They were defined on the basis of expert evaluations. The group of experts consisted of pilots, safety managers and persons responsible for investigating the causes of air accidents.

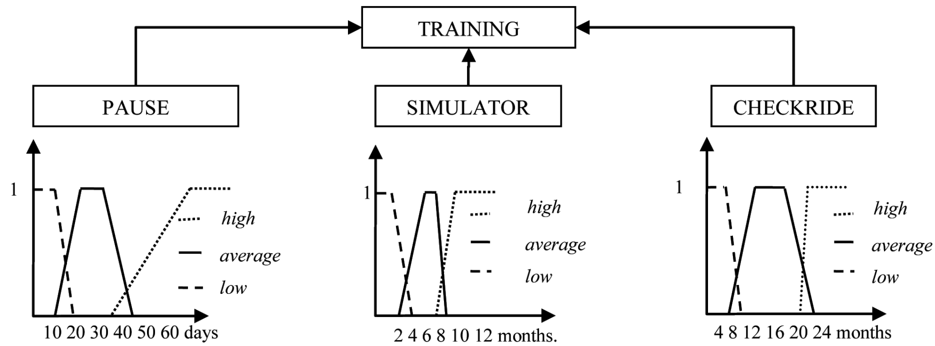

Figure 3. The local fuzzy model of linguistic variable *Training*.

Table 2. The (a,b,c,d) parameters of trapezoidal membership functions of input linguistic variables for *Training* model.

	a	*b*	*c*	*d*
Pause				
Low	0	0	10	20
Average	10	20	30	40
High	30	60	90	90
Checkride				
Low	0	0	4	8
Average	6	12	16	20
High	18	20	24	24
Simulator				
Low	0	0	2	4
Average	3	6	7	8
High	7	9	12	12

Table 3. The (a,b,c,d) parameters of trapezoidal membership functions of output linguistic variable for *Training* model.

Training	*a*	*b*	*c*	*d*
Low	0	0	1	2
Average	1	2	3	4
High	3	4	5	5

Table 4. The examples of fuzzy reasoning rules for *Training* local model.

Rule	*Pause*	*Simulator*	*Checkride*	*Training*
4	*Low*	*Average*	*Low*	*High*
6	*Low*	*Average*	*High*	*High*
7	*Low*	*High*	*Low*	*Average*
17	*Average*	*High*	*Average*	*Average*
21	*High*	*Low*	*High*	*Low*
25	*High*	*High*	*Low*	*Low*

6 THE RESULTS DISCUSSION

The example results of fuzzy inference system simulation for linguistic variable *Training* estimation, obtained with a computational tool created in SciLab 5.4 environment are shown on Figure 4.

In the case of *Training* and *Simulator* relationship (Fig. 4a) we can see in the results that the pilots with relatively short break from the last flights (up to 20 days) may extend the time between simulator trainings up to 6–7 months. The more frequent simulator trainings don't improve the *Training* value, which equals to 4.3 (the *high* linguistic value). For pilots with longer break from last flight (40 days and more) the simulator trainings should be organized more often (after about 3 months). The longer break results with the drop of *Training* value even to 0.8 (the *low* linguistic value). The observation is similar to intuitional approach but the model results give us quantitative assessment. The above experiment result can be treated as the element of the model validation process.

On the other hand the *Training* and *Checkride* relationship analyses (Fig. 4b) reveal a little amazing results. The simulation experiments results show, the *Checkride* in most cases doesn't influence the *Training* at all. This concerns the cases when the break from the last simulator training is longer than 1.5 month for any value of break in flights practicing. The only case (showed on Fig. 4b) the *Checkride* influence on the *Training* value, exists when a pilot has long break in flying (60 days or more) and the time from the last simulator training is shorter than 1 month. Then the checkride makes sense, but only if the break from the last one is more than 18 months. The observation is interesting because it indicates the checkride every 6 or 12 months (as requested by the regulations) may be needless because it doesn't improve the *Training* variable. In case the check-rides are to be continued they should be scheduled maximum every

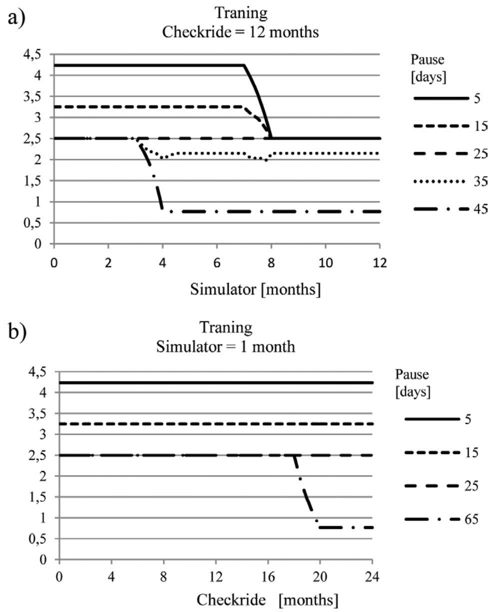

Figure 4. *Training* correlation with: a) *Simulator,* b) *Checkride.*

16–17 months. However further verification of the model, system and the results should be continued.

7 SUMMARY

The flight operators crew resources management is one of the most important factors that influence the air transport safety. The proper crew selection process is one of the key elements. The crew should have optimal performance that among the others mirrors their competency, motivation, communication skills or situational awareness. Those features are not constant and depend on many different factors such as current crew predisposition to perform the safe flight. The crew selection and assessment process in the context of flight safety is significantly difficult due to the imprecise, uncertain and incomplete information. In such a case the expert systems based on the fuzzy sets theory can become the meaningful and helpful assistance. The presented example of the fuzzy inference system assures the possibility of the presented approach utilization in flight operator assistance by crew reliability improvement.

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