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Theoretical modeling of dependability resources of flight crews in commercial aviation

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Abstract. *The paper develops theoretical models of dependability of commercial aviation (CA) flight crews based on the resource method of designing organizational social objects. The aim was to provide an objective description of flight crew activity. Formal models of crew composition were constructed. Definitions of dependability of intense profession members are presented using the example of CA crews. The competitive environment of the open global air transportation market is leveled against the standardization of airline activities and primary object of aviation, i.e. CA pilot and flight crew. Air disasters of the last few decades highlight the primary causes, i.e. professional properties deficiency in pilots and excessive workload of flight crews in CA operations. This situation is caused by not only the pressure of the business environment, but also by the critical insufficiency of scientifically grounded methods of managing flight operations in terms of the human component. The paper developed theoretical models of dependability of flight crews based on classical logic and resource method of designing organizational social objects of the transportation industry (airline). The essence of the problem. In commonly known literature there still is no theoretical framework, formal models that could be used for calculation and management of dependability of activities. Crew resources are researched in terms of dependability and efficiency. In general, crew dependability is understood as the sum of dependabilities of crew members for the completion of the assigned tasks. The dependability depends on the composition of specialized skills and individual qualifications of the crew members. The efficiency is the result of three components: communications, decisions, delegation. These interactions can be formal and informal. The scientific substantiation and definition of the parameters of the crew's assignment in terms of the estimated dependability and efficiency parameters are the solution of the problem. Problem formalization. In order to formalize the problem of objective description of flight crew activity, the crew may be considered as a class of individuals. The logic of classes (sets) uses the class-forming operator C, for "class", predicate of inclusion of individuals into class ∈, a binary predicate, predicate of inclusion of a class into a class. In order for a class to exist it suffices for it to be formed out of the range of values of term t. Class generation principles are expressed in the following axioms: Each element of a class can be chosen regardless of the class formation, the independence principle. A class of individuals exists (does not exist) if it is formed (not formed) in accordance with the definition of class formation and formation axioms. Subsequent statement of the problem must be directed in detail, specific solutions for the development of models suitable for calculation and management of flight operation. Thus, the development of the theoretical essence of the composition and size of crew is a relevant problem and can be solved based on classical logic, managerial control theory, information theory.*

Keywords: *pilot, crew, modeling, class, individual, composition, power of class.*

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Introduction

Essence of the problem. The competitive environment of the open global air transportation market is leveled against the standardization of airline activities and primary object of aviation, i.e. pilot and flight crew of commercial aviation (CA) aircraft (AC). Air disasters of the last few decades highlight the primary causes, i.e. professional properties deficiency in pilots and excessive workload of flight crews in CA operations. This situation is caused by not only the pressure of the business environment, but also by the critical insufficiency of scientifically grounded methods of managing flight operations in terms of the human component.

The Air Code of the Russian Federation provides the following description of flight crew: “The crew of an aircraft consists of a flight crew (the captain, other members of the flight crew) and the cabin crew (operators and stewards). The flight of a civil aircraft shall be prohibited if the number of flight crew members is less than the established minimum” [1]. This description was developed empirically over the course of the the global aviation history. In literary sources known to the author there still is no theoretical framework, formal models that could be used for calculation and management of AC flight operation. The research can start with the examination the problems of identification of the object of activity through logical analysis. In [2], the formal foundations of the CA pilot activity are put together. Observation (measurement, evaluation) in the genus-species classification of the property of an individual’s dependability allows assigning numbers and calculating states. The paper sets forth the results of calculation of states for the purpose of managing AC flight operation: resources of individual dependability (RID), resources of professional dependability (RPD), resources of operational dependability (ROD) [3].

Compared to the results for individuals, the formalization and calculation of the properties of a social group (crew) are undeveloped. Since the 1980s, the aerospace industry has been developing the concept and technologies of cockpit resource management (CRM) [4]. Practically, the technologies are used as a combination of educational programs and training sessions aimed at the development of the skills related to decision, communication and delegation grouped within the concept of efficiency. However, the scientific foundations of the theory and methods of CRM calculation have not been created.

This is the statement of the overall problem, a part of which is structured as follows: 1) establishment of the method; 2) establishment of the terms of objective description of the activity of objects in accordance with the provisions of classical logic; 3) development of terms and definitions; 4) formalization of the problem of calculation of the properties of the flight crew for the purpose of managing AC flight operation.

Definition of the terms of description of the objective scope

The logical analysis of subject field terms is motivated by the following. In engineering, the “commonly accepted” and “commonly known” concepts, definitions and terms are not really such, as they have not been submitted to humanities and logical research. According to A.A. Zinoviev “... in general, it is impossible to judge the applicability of formal constructs in the research of some subject field, if there is no prior knowledge of it, if it is not studied to some extent at the descriptive level” [7, p. 7]. For that very reason we deem it essential to determine the subject field of the social groups theory and social science terms examined below.

Let us determine the objective meaning of the terms “class”, “composition”, “individual”. The problem may be considered within the concept theory (a division of logic) [11, 12, 13], the class (sets) logic [7]. We believe that identifying the meaning of identical terms, they must be researched simultaneously in all the above theories. In the concept theory, each concept has a content (set of diverse attributes) and size (number of identical elements). The law of reverse genus-species relations established: the richer is the content, the smaller is the size and vice versa. The concept of “individual” has a large content and is generic for such concepts as “class”, “composition” that have large sizes.

In the class logic [7] a social group is regarded as a class of individuals. The class-forming operator C is used, for “class”, predicate of inclusion of individuals into class $\in$, a binary predicate, predicate of inclusion of a class into a class. Class formation is defined as follows.

D 1. To form (and select) a class of individuals is to construct the term “class of individuals from range *t*, where *t* is the given term and *t* is a subject” [7, p. 176].

The definition of class formation contains notation C*t*, where C is the class-forming operator. Individuals from range *t* are elements of C*t*. In order for a class to exist it suffices for it to be formed out the range of values of term *t*. The range of values *t* (pilot) is the individual whose range of values (purpose) is defined by the ability to control an AC in a three-dimensional airspace.

A 1. The term “individual” (pilot) and term “class” (crew) are terms [“individual” · “crew”], i.e. an object denoted by each of the terms, of which the meaning is known.

Class formation principles are expressed in the following axioms:

A 2. Each element of a class can be chosen regardless of the class formation, the principle of independence of elements from class.

That means that each and every pilot can be included in any class (crew). In a particular case, an individual is identical to a class, if the crew consists of one individual.

A 3. Regarding any individual it can be established whether he/she is an element of a given class, the principle of certainty.

The certainty is defined by the existence of education, qualification, experience and pilot's permission to fly.

D 2. A class of individuals exists (does not exist) if it is formed (not formed) in accordance with the definition of class formation and formation axioms.

Let us consider the primary terms of the class theory: power, composition.

D 3. **Power of class.** "The power of a class is the number of its elements. The existing (possible) power of a class is the number of existing (possible) individuals that are its elements" [7, p. 187].

Out of this definition follows the conclusion regarding the identity of two logical concepts (power ≡ size): power is a concept of class logic, size is a term of concept theory.

D 4. **Composition of class.** "Determining the composition of a class means determining what individuals are included in it. Determining the existing (potential) composition of a class means determining what individuals that are its elements exist (are possible)" [7, p. 187].

As we can see, in the definition with the wording "... determining, what..." there are no attributes (content) of the "composition" concept. Therefore, the concept of "content" has a wider generic scope that is to be divided into specific concepts.

It must be determined, what competences, training, qualifications of AC crew members are included in the class. From the history of aviation it is known that the highest competences are defined for and concentrated in the profession of pilot. With the automation of the modern commercial aviation, the professions of navigator, flight engineer, radio operator, etc. disappeared from the crew. The diversity (intensity) of the pilot's functions causes the reduction of the power (size) of the class, i.e. the number of crew members. Here we can clearly see the effect of the law of the genus-species relations. Let us complement the definition of the "composition of class": determining the composition of a class (crew) means determining the attributes of diversity of the content (intensity) an individual (pilot) must be included in the class. Thus, in the class logic, the key terms are the composition and power of class. In the concept theory those are the content and scope of a concept. Additionally, let us also examine the dictionary definitions of the term "composition".

D 5. Composition is an object (set) that includes a set of parts (elements, components), as well as the description of the quality, quantity and other characteristics of the parts of such object (set) [8].

D 6. The set of parts, elements that make a whole [9].

The dictionary definitions also indicate that "composition" is and abstract umbrella term, i.e. it has a large scope and can therefore be used as a generic term. According to the inverse relation law of the scope and content of a term, the following structure of the terms can be defined:

$$(N)\ \text{composition}:\ \mathrm{C}\{\text{content}(\text{intensity})\}\ 1\,/\,/\ V\,\{\text{power},\ \text{size}(\textit{number})\}, \quad (1)$$

where (*N*) is the introduced notation of composition (of a class, crew), C is the diversity of attributes (intensity) of each and every out of the *i*-th individuals of the class, *V* is the size, power, i.e. the number of individuals in the class, (·) is read like operator *and*.

The composition of a class is defined in terms of the time {past ↔ present (now) ↔ future} of observation of the following binary antonymic relations of terms:

a. existing	a'. potential
b. permanent	b'. variable
c. limited	c'. unlimited
d. finite	d'. infinite
e. known	e'. unknown
f. definite	f'. indefinite

These relations and the number of their mutual combinations create the *multiaspect* context of the problem:

$$(N):\ \mathrm{C}\left(\overline{a,n}\right)\cdot\left\{1\,/\,V\left\{\overline{a',n'}\right\}\right\}, \quad (2)$$

where the symbols make the above conventional notations.

The existing class may be defined in such a way as to include only those individuals that are placed in time {past ↔ present}. A finite numbers class my be infinite in terms of professions. A class restricted in professions can be defined unrestricted in terms of the number of individuals. We may avoid restricting the number of individuals, but in the {present ↔ future} future new elements will not appear. Although exceptions should be kept in mind and taken into consideration, when the inverse relation law C: 1/*V* does not work in the concept theory (for discordant concepts). That is the cause of the extreme complexity of problem definition and solution using only the classical logic tools. Nevertheless, the proposed problem structure can be used in further research. The identification and formalization of relations can probably be continued using pseudophysical logic.

For the purpose of solving the problem by expert (heuristic) method we create a convolution: the set of existing professions of crew member individuals are *known* and *finite* in terms of power (content, professions) and size (number).

This statement is empirical, based on historical experience of aviation, as well as crew composition in terms of professions and number.

Development of terms and definitions of CA AC flight crew dependability

The definition will be based on the previous terminology work subject to the mentioned limitations and assumptions. The following definitions are established.

D 7. Composition N is the class defined by the assignment of power and size:

$$N : \{C \cdot 1 / V\}.$$

D 8. Crew (social group), the controlling subject of vehicle $(Cr) \geq 1; \overline{1,\ n}$.

D 9. AC cockpit crew, the controlling subject that performs activities in accordance with the AC flight purpose.

D 10. The ability to control an aircraft in a three-dimensional airspace is called the crew's resource of purpose.

The essence of the category of purpose can be easily understood by comparing the movement of an aircraft in a three-dimensional (X, Y, Z) space and the movement on a plane (X, Y) by a car.

D 11. Dependability is the set of properties and states of the object within the metric of the standard activity space.

D 12. The crew dependability is defined as the set of properties and states of the member individuals for the purpose of completing the purpose (flight).

Problem of calculation of flight crew dependability

Let us form the content of the problem of calculation of CA AC flight crew dependability. Let us use the above terms, definitions, work formalizations [10] in the context of the problems considered in this paper.

D 13. Dependability calculation is defined as the observation (measurement, evaluation) of the properties and states of the flight crew, performance of standard operational procedures (SOP) within the specified parameters and indicators corresponding to safe and efficient execution of flights.

Conditions of restrictions: number of members (V) and professions (C) of crew members is known and finite;

N_0 is the existing final crew composition;

N is the target state of the crew as the result of the control task solution;

N' is the set of ways of establishing the target state, ground set of the crew $N \subseteq N'$, $N_0 \subseteq N'$;

$\Phi = (N, N_0)$ is the functional that associates the initial and final states, dependability of control;

$|N|$ is the standard crew composition;

$|N| > |N_0|$ is the extended crew composition: double, enhanced, with inspectors, trainees onboard;

$|N| < |N_0|$ is the reduced composition of crew: absence of navigator, radio operator, other specialists;

$|N| \neq |N_0|$ is the replacement of crew composition: quantitative (replacement of the aircraft captain (ACC) or copilot) and/or specialized (inclusion of navigator authorized to act as radio operator).

The problem of definition of crew composition with no initial composition $N_0 = \varnothing$ has the following form:

$$\Phi(N, \varnothing) \to \max_{N \in 2^{N'}},$$

where $N \in 2^{N'}$ is the first defined crew composition: ACC, copilot.

The problem of possible modification of composition in case of fixed initial composition N_0 has the following form:

$$\Phi(N, N_0) \to \max_{N \in 2^{N'}},$$

where $N \in 2^{N'}$ is the possible crew composition; example: ACC (replacement), copilot; ACC, copilot (replacement).

The problem of extended crew composition under initial number n and m additional members has the following form:

$$\Phi(N, N_0) \to \max_{N \in 2^{N'} : N_0 \ \ N,\ |N| \leq n+m},$$

where $N \in 2^{N'}$ is the defined composition, $N_0 \subseteq N$, if $|N| \leq n + m$ is the extended composition; example: addition of one trainee and one inspector.

The problem of reduced crew composition under initial number n and m reduced members is formulated by the search for the set $\Delta^- \subseteq 2^{N_0}$ that maximizes the dependability (under the condition $\Delta^+ = \varnothing$) and has the following form:

$$\Phi(N, N_0) \to \max_{N = N_0 \setminus \Delta^-,\ |\Delta^-| \geq m},$$

where $N = N_0 \setminus \Delta^-,\ |\Delta^-| \geq m$ is the description of conditions; example: requirement to replace the ACC with flight instructor and exclusion of one of the specialists (radio operator, navigator, loadmaster).

The problem of replacement of crew members under initial number n and m replaced members that maximizes the dependability has the following form:

$$\Phi(N, N_0) \to \max_{N = 2^{N'},\ |\Delta^-| = \Delta^+ = m},$$

where $N = 2^{N'}, |\Delta^-| = \Delta^+ = m$ is the description of the cindition; example: replacement by a more experienced crew member.

In this class of problems the variables not described above are not taken into consideration. The main limiting factor of formalization is the introduction of simplification: N_0 is the existing defined crew composition instead of: N_0 is the existing defined quantitative $\{V : 1, 2, \ldots, n\}$, $v_i \in V$ and specialized $(C : a, b, \ldots, k)$, $c_i \in C$ crew composition consisting of n individuals of k professions, $|N_0| = n,\ k$.

Additionally, the above binary (probably, unary) relations of class composition terms are not formalized. In whole, it can be said that formal constructions can be used for calculation of crew composition and subsequent development of automated control software.

Example of calculation of pilot and flight crew dependability

Let us give an example of calculation of pilot and flight crew dependability based on two selected indicators that are associated with the states of the dependability property. The states are evaluated using a nominal scale and

Table 2. Pilot dependability evaluation metric

Indicators	States (indicator values)		
	Green	Yellow	Red
	1	2	3
Age	40 years	30 years	65 years
Flight hours	10 000 hours	3000 hours	20 000 hours
Evaluation	complete	acceptable	inadequate

an ordinal scale of three-level risk matrix: "red-yellow-green". Example: let three pilots aged 40, 30 and 65 have 10 000, 3000 and 20 000 flight hours respectively (Table 2).

Compliance with purpose is evaluated as follows: the 40-year-old pilot complies with the assignment in terms of two indicators, the 30-year-old pilot acceptably complies in terms of the same two indicators. The age indicator "65 years old" is called "critical state" (CS) that is sufficiently easily predicted and calculated. Therefore, despite the "green" level of risk per another indicator, i.e. 20 000 flight hours, the general score of the 65-year-old pilot is "non-compliant". This example of evaluation of two indicators is a simple demonstration of the resource method of calculation of object states in risk matrices. The complete structure consists of 43 indicators and is a scientifically substantiated standard activity space [3].

The problem of calculation of the dependability of a flight crew of one pilot is identical to the calculation of an individual's dependability. The calculation of the dependability of a flight crew of *n* individuals is based on the premise that not a single indicator of not a single crew member (except the trainees) must be outside the "acceptable" score.

Conclusion

The problem and task of identifying the object of individual and social group through the example of CA objects is considered in terms of purpose and dependability of activity. The concept of "purpose" can be considered generic with a large scope that is difficult to use "directly" in the observation of properties and states of objects. Observation is possible if the scope of the concept is divided into specific concepts, i.e. efficiency, safety, dependability that have smaller scopes, but larger content (attributes). Thus the object of activity is identified.

In terms of assignment the objects "individual" and "group" are identical. In terms of dependability they are different. In the simplest case the dependability of a group is the sum of the properties of individuals. The dependability of an AC crew members is identified based on the differences between special knowledge and skills for controlling AC functional systems. The growth of technology dependability and automation lead to the universalization of knowledge and skills within the single profession of pilot.

The proposed definitions and models of AC flight crew are the initial formal tools that allow controlling the crew composition. As its is shown, the number of combinations of time-to-space relations constitutes a long list of relevant problems that require a formal description.

This paper proposes the terminology related to the object of dependability of CA AC flight crew. We assume that the definition of the terms "dependability" and "crew composition" completely comply with logical provisions. The property (purpose) of an object can be observed (measured, evaluated) in terms of the states of a previously developed standard space of dependability.

The objective meaning of the term "dependability" is the static characteristic of the subject of activity that can be structured in order to evaluate states and calculations. The formalized mathematical description of efficiency is even more complicated compared to the above stated problem of calculation of CA AC flight crew dependability. In [1], mathematical models of efficiency – decisions, communications and delegations of powers, as well as crew member responsibilities – are set forth.

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