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CONTROL OF FLIGHT SAFETY WITH THE USE OF PREFERENCES FUNCTIONS

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Abstract. *On the basis of the "Subjective Entropy Extremization Principle", for a roughly simplified problem setting, of the flight safety control problem (possibly for two aircrafts, or unmanned air vehicles application expediency versus traditional aircraft), it is proposed a mathematical model for the combined technical-economical criterion of the flight safety control (operational effectiveness). The obtained solutions of the formulated variational problems show optimal controlling influence in the view of the canonical distributions of the individual's preferences for both discrete and continuous alternatives. Theoretical speculations are illustrated with the example calculation experiments. The necessary diagrams are plotted.*

Keywords: subjective entropy maximum principle; control of flight safety; unmanned air vehicles application expediency; combined technical-economical criterion of the operational effectiveness; canonical distribution of an individual's preferences; variational problem; controlling function.

Introduction

The problem formulation in the general view and its relation to important scientific and practical tasks refers to the fact that in a variety of safety problems we might see a connection between an objective function and a controlling parameter. Flight safety problems are often imply the so-called "human factor". Preferences functions describe an individual's attitude to the set of considered by him/her alternatives.

Control of flight safety is an important problem which can be solved with the use of the preferences functions.

Thus, the problem formulation in the general view in its relation to the important scientific and practical task of flight safety control is that the criterion of safety has a certain connection to the alternatives and the preferences functions, expressed, in their turn, through effectiveness functions, related to the alternatives, are also the functions of the controlling variable.

Analysis of the latest researches and publications

In the following latest researches and publications it was brought forth the solution to the given problem.

The spectrum for the theoretically considered problem application is so wide that we decide to pay our attention to a flight safety theme with the illustrative depiction to the important issues of alternative types of aircrafts use or even just a few special airplanes.

A. Unmanned Air Vehicles Versus Traditional Aircrafts

Development of unmanned air vehicles (UAV), described in [4], resulted in the fact that: UAVs intend to, and in some areas they really do, compete with the traditional type of aircraft (manned/inhabited); or even more: UAVs applications to accomplish some peculiar missions are beyond the competition comparatively to the traditional aircraft (TAC). It is also important to note that in principle UAVs can be propelled by almost every type of propulsion system [4], [6].

Thus, the problem formulation in the general view in its relation to the important scientific and practical task of expediency of UAVs versus TAC application is that an airline owner needs to have some scientifically proven criteria in order to make a proper decision concerning the usefulness of functioning of that or the other type of the aircraft, i.e. either UAV or TAC [2].

The mentioned above criteria of the UAV or TAC application (operation, use) effectiveness should combine the indexes, on one hand, of technical state: feasibility, ability [4] and [6], airworthiness, flight safety, durability, failure rate, failure intensity, reliability etc.; and on the other hand, of economic advantages and disadvantages [4]: such as profitableness, incomes, costs, expenses, possible losses due to failures that led to air break downs, collisions, air crashes, and so on.

Also, the important human factor is to be evaluated for the both competing types of aircrafts.

Thus, we got the problem formulation in the general view and its relation to the important scientific and practical tasks for comparison of UAV versus TAC [2], also for flight safety of any type of flying object.

B. Criteria

The variety of the criteria makes a separate scientific problem. We will be elaborating the needed criterion on the basis of some appropriate ones. One of such criteria was suggested in [8]. The criterion was the expectation of airline expenditures for a certain designated period of time including possible losses from the unexpected event occurrence – air crash. That complex criterion was considered as the controlled parameter dependently upon the controlling variable of the depth (quality) and scope of diagnostics and maintenance of the aviation engineering. The performed mathematical modeling and calculation experiments discovered theoretical existence of the optimal control of flight safety in the view of the minimization of the airline expenses expectation for the designed period of an aircraft operation. The statistical analysis substantiated the usefulness of the method for choosing the optimal controlling influence in the view of the rated maintenance.

C. Human Factor

The influence of human factor upon flight safety in the framework of subjective analysis was discussed in [5], [11], [12]. There it was suggested to conduct the assessment of human behavior on the basis of the postulated optimality principle. The principle got the name of "Subjective Entropy Extremization Principle" (SEEP) because the postulated objective functional comprised a member in the view of the subjective entropy of the individual's preferences of the achievable for his/her goals alternatives in the given problem-resource situation. The application of the SEEP to economic issues was made in [10]. There it was considered the aspects of human behavior on the basis of variational principle applicably to the problems of light and shadow economic diversion, and in that context to the problems which touching interactions between shadow economic and safety of an active system. A modeling of the optimal internal state shadow taxation conducted in [9] followed the concept of [10] for the case of a continuous alternative.

D. Control in Active Systems

Papers [1], [3], [7] were dedicated to the actual problems of control in active systems. In [1] it was considered the elements of artificial intellect in control of optimality. Papers [3], [7] dealt with mathematical modeling for: a horizontal flight for the maximal distance [3]; and the flight safety support through the maintenance strategies [7] in active systems.

All the initial ideas of [1] – [12] have been laid down into the basement of the presented problem solution.

Outlining the previously unsolved parts of the general problem

Accordingly to the analysis of the resent researches and publications, particularly [1] – [12], the presented material of the paper is dedicated to the dilemma of different aircrafts (for instance, UAV versus TAC) functional expediency because it still looks like the unsolved part of the general problem of flight safety and the airline holder's rational choice in a situation of operational multi-alternativeness with respect to his/her optimal individual preferences distributions on conditions of possible conflictable operation at the control of the flight safety.

Formulation of the paper's material objectives (problem setting)

This paper is intended to make an attempt to find the individual preferences distributions which allow choosing the scientifically substantiated alternative as a kind of the flight safety control.

Consideration of the research's main material with the complete substantiation of the achieved scientific results

For the roughly simplified but acceptably correct problem setting we take the criterion for making a decision about expediency of that or another flight safety control on the alternative basis (different aircrafts, UAV versus TAC, for example, application) in the view that follows [8]:

$$\operatorname{Exp}[R] = C_o + \left(\frac{V_r(V_s)}{\lambda(V_s)} + \Delta r \right) \left(1 - \exp\left[-\lambda(V_s) t_k \right] \right). \quad (1)$$

where $\operatorname{Exp}[R]$ is expectation of an airline expenditures R for a certain designated period of time t_k;

C_o is cost of the airplane;

$V_r(V_s)$ are operational expenses as a function of the special rated procedures for the flight safety support (rated maintenance) V_s;

$\lambda(V_s)$ is failure intensity;

Δr is onetime unexpected although possible losses due to the air crash happening.

For the operational expenses we accept the model of [8]:

$$V_r(V_s) = V_e + V_t + V_s. \quad (2)$$

where V_e are operating cost including all related payments likewise amortization and so on;

V_t are money spent for paying taxes.

The failure intensity, parameter of the failures flow, is modeled by the relation from [7], [8]:

$$\lambda(V_s) = \lambda_{\min} + \frac{\lambda_0 - \lambda_{\min}}{1 + \alpha V_s}. \quad (3)$$

where $\lambda_{\min}$ is minimal achievable failure intensity of randomly occurring air crashing events, herein we imply that this minimal failure intensity cannot be lowered by increasing the rated maintenance at the contemporary level of the aviation engineering technologies development;

λ_0 is initial, without the especially directed controlling influence in the view of the rated maintenance V_s, failure intensity of the air crashing events, herein we imply that this intensity has a finite value, i.e. $\lambda_0 \neq \infty$, because regalement (prescribed by regulations, rules, and guidance) maintenance is not included into V_s;

α is effectiveness of the especial flight safety supporting maintenance.

A. Discrete Alternatives

Then, instead of the methods of [8] for finding the extreme of the controlled complex flight safety criterion (1) separately with respect to each alternative "1" and "2" (it can be different aircrafts or competing types of aircrafts, for example, UAV versus TAC), we apply SEEP of subjective analysis [5], [10] – [12] in the framework of the postulated optimization concept in the view of the functional

$$\begin{aligned}\Phi_{\pi}^{\left(1 \succ\!/\!\prec 2\right)} &= -\left\{\pi_1[\cdot]\ln\pi_1[\cdot] + \pi_2[\cdot]\ln\pi_2[\cdot]\right\} \\ &-\beta\left\{\begin{aligned}&\pi_1\left[\mathrm{Exp}_1\left[R_1\left(V_s\right)\right]\right]\mathrm{Exp}_1\left[R_1\left(V_s\right)\right] \\ &+\pi_2\left[\mathrm{Exp}_2\left[R_2\left(V_s\right)\right]\right]\mathrm{Exp}_2\left[R_2\left(V_s\right)\right]\end{aligned}\right\} \\ &+\gamma\left\{\pi_1[\cdot] + \pi_2[\cdot] - 1\right\},\end{aligned} \tag{4}$$

where $\pi_1[\cdot] = \pi_1\left[\mathrm{Exp}_1\left[R_1\left(V_s\right)\right]\right]$ and correspondingly $\pi_2[\cdot] = \pi_2\left[\mathrm{Exp}_2\left[R_2\left(V_s\right)\right]\right]$ □□□ individual preferences functions of their arguments (controlling functions) distributed on the first and second flight safety alternatives (TAC and UAV) respectively;

β and γ are structural parameters, they can be considered in different situations as Lagrange coefficients, weight coefficients or endogenous parameters that represent some certain properties of the individual's psych;

for the discrete set of the two given alternatives, i.e., for instance, either UAV or TAC.

The first member in (4) is the subjective entropy of the individual preferences with respect to the first and second (TAC and UAV) alternatives correspondingly. The second member in (4) is the cognitive function. The third member in (4) represents by itself the normalizing condition.

From the necessary conditions for extremum we obtain the so-called canonical distributions of the preferences [5], [10] – [12]:

$$\pi_1\left(V_s\right) = \frac{e^{-\beta\mathrm{Exp}_1\left[R_1\left(V_s\right)\right]}}{e^{-\beta\mathrm{Exp}_1\left[R_1\left(V_s\right)\right]} + e^{-\beta\mathrm{Exp}_2\left[R_2\left(V_s\right)\right]}}, \tag{5}$$

$$\pi_2\left(V_s\right) = \frac{e^{-\beta\mathrm{Exp}_2\left[R_2\left(V_s\right)\right]}}{e^{-\beta\mathrm{Exp}_1\left[R_1\left(V_s\right)\right]} + e^{-\beta\mathrm{Exp}_2\left[R_2\left(V_s\right)\right]}}. \tag{6}$$

B. Continuous Alternatives

For the continuous alternatives of V_s in the chosen alternatives of flight safety (types of aircrafts) we use the integral style objective functional, of the kind of (4) with the corresponding corrections [5], [10] – [12] in the manner of [9]:

$$\begin{aligned}\Phi_{\pi}^{\left(V_s|1\right)} &= \int_{V_{s0}}^{V_{s1}}\left\{\begin{aligned}&-\pi^{(1)}\left(V_s\right)\ln\pi^{(1)}\left(V_s\right) \\ &-\beta\pi^{(1)}\left(V_s\right)\mathrm{Exp}_1\left[R_1\left(V_s\right)\right]\end{aligned}\right\}dV_s \\ &+\gamma\left[\int_{V_{s0}}^{V_{s1}}\pi^{(1)}\left(V_s\right)dV_s - 1\right],\end{aligned} \tag{7}$$

$$\begin{aligned}\Phi_{\pi}^{\left(V_s|2\right)} &= \int_{V_{s0}}^{V_{s1}}\left\{\begin{aligned}&-\pi^{(2)}\left(V_s\right)\ln\pi^{(2)}\left(V_s\right) \\ &-\beta\pi^{(2)}\left(V_s\right)\mathrm{Exp}_2\left[R_2\left(V_s\right)\right]\end{aligned}\right\}dV_s \\ &+\gamma\left[\int_{V_{s0}}^{V_{s1}}\pi^{(2)}\left(V_s\right)dV_s - 1\right],\end{aligned} \tag{8}$$

where $\pi^{(1)}$ and $\pi^{(2)}$ are individual preferences functions of the continuous alternatives on condition the corresponding discrete alternative is considered.

The integral members in (7) and (8) are interpreted in the same meanings as those in (4).

The necessary conditions for extremum of (7) and (8) yield the canonical distributions for the continuous alternatives likewise in [5], [9], [11], [12]:

$$\pi^{(1)}\left(V_s\right) = \frac{e^{-\beta\mathrm{Exp}_1\left[R_1\left(V_s\right)\right]}}{\int_{V_{s0}}^{V_{s1}} e^{-\beta\mathrm{Exp}_1\left[R_1\left(V_s\right)\right]}dV_s}, \tag{9}$$

$$\pi^{(2)}\left(V_s\right) = \frac{e^{-\beta\mathrm{Exp}_2\left[R_2\left(V_s\right)\right]}}{\int_{V_{s0}}^{V_{s1}} e^{-\beta\mathrm{Exp}_2\left[R_2\left(V_s\right)\right]}dV_s}. \tag{10}$$

C. Examples

Let us conduct a series of calculation experiments by the elaborated methods (1) – (10) with the set of the two discrete alternatives: flight safety criteria "1" and "2" (UAV and TAC); and at the each of these discrete alternatives there is the corresponding continuous alternative – the value of the related rated maintenance.

Example 1. For the first alternative (for example, TAC), with the supposed data: $t_k = 100$; $\Delta r = 5 \cdot 10^6$; $\alpha = 0.8$; $\lambda_0 = 1 \cdot 10^{-4}$; $\lambda_{\min} = 1 \cdot 10^{-5}$; $V_t = 20$; $V_e = 80$; $C_o = 1 \cdot 10^6$; $V_{s0} = 0$; $V_{s1} = 100$; $\beta = 2 \cdot 10^{-4}$; the results of modeling, for expositional conveniences in the appropriate scales, are illustrated in Fig. 1.

For the second flight safety alternative (UAV) we assume the difference in its data in the comparison to the previous aircraft (TAC): $\Delta r_2 = 2\cdot 10^6$; $C_o = 1.005\cdot 10^6$; for the second alternative's (UAV's) operational expenses instead of (2) we accept the model

$$V_r(V_s) = k_e(V_e + V_t) + V_s, \qquad (11)$$

where k_e is coefficient which make allowance for the differences in operating costs of the competing aircrafts; $k_e = 0.9$.

The results of modeling, in the corresponding scales, are shown in Fig. 1.

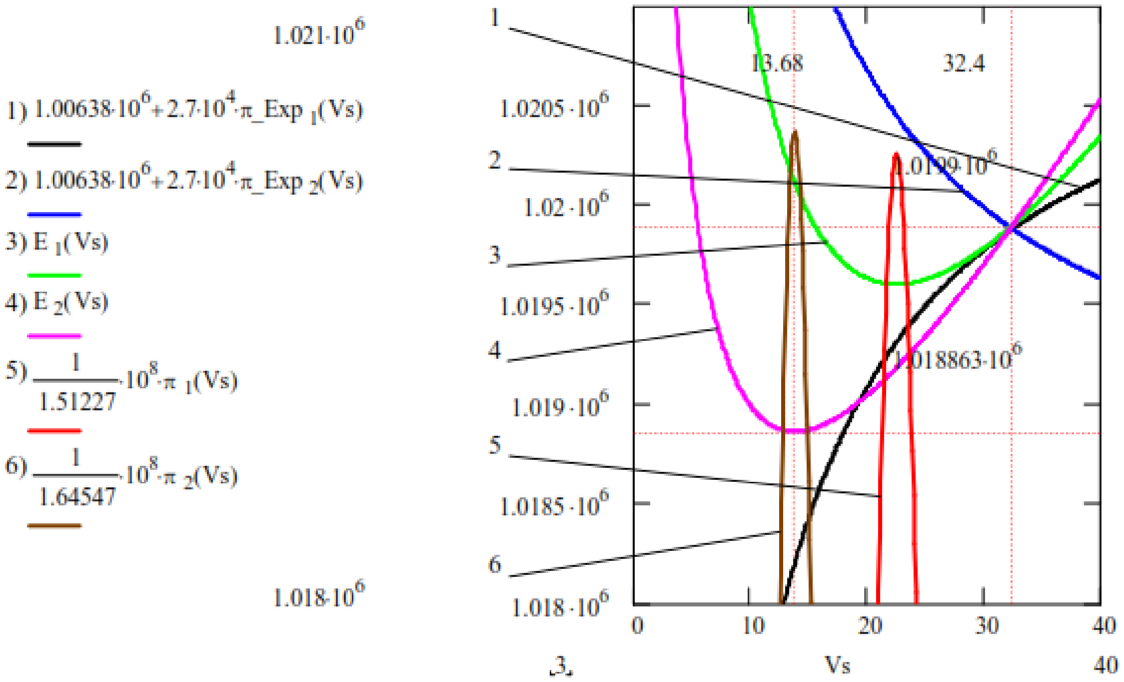

Fig. 1. Criteria of flight safety and corresponding preferences of the related alternatives

In Fig. 1 it is depicted

$\pi\_\text{Exp}_1(\text{Vs})$ – for $\pi_1[\cdot]$; $\pi\_\text{Exp}_2(\text{Vs})$ – $\pi_2[\cdot]$; $\text{E}_1(\text{Vs})$ – $\text{Exp}_1[R_1(V_s)]$; $\text{E}_2(\text{Vs})$ – $\text{Exp}_2[R_2(V_s)]$; $\pi_1(\text{Vs})$ – $\pi^{(1)}(V_s)$; $\pi_2(\text{Vs})$ – for $\pi^{(2)}(V_s)$.

Example 2. From the example 1 it might seem that the lower the optional $V_{s_{\text{opt}}}$ the better. Now, we are modeling the following situation: the first alternative is the same as before, therefore it is characterized by the same expectation of its own expenses as that one of the example 1; for some other, alternative airplane, though equivalent in mission, (UAV, for instance) the differences from the second alternative (UAV) of the first example: $\Delta r_2 = 1.5\cdot 10^6$; $C_o = 1.00297\cdot 10^6$; for the new alternative's (UAV's) failure intensity instead of (3) we implement the model discussed in [7]

$$\lambda(V_s) = \lambda_0 - (\lambda_0 - \lambda_{\min})\left(1 - e^{-\alpha V_s}\right), \qquad (12)$$

$\alpha = 0.05$.

The results of modeling, in the corresponding scales, are shown in fig. 2.

Now, from the diagrams plotted in Fig. 2 it is visible that the relatively higher optimal rated maintenance of $V_{s_{\text{opt}}}\big|_2 = 38.07$ is the rightly preferred alternative.

D. The Researches Results

From the diagrams presented in fig. 1 it can be noticed that at the given problem setting and presumed data at the rated maintenance values $V_s > 32.4$ the first alternative (TAC) is more preferable than the second one (UAV). It is because of the values of the first and second (TAC's and UAV's) flight safety criteria, that is for the expectations of the airline's, operating the two alternative airplanes, losses: $\text{Exp}_1[R_1(V_s)] < \text{Exp}_2[R_2(V_s)]$.

It is important that the values of the related controlling functions (preferences functions) provide evidence of that fact: $\pi_1[\cdot] > \pi_2[\cdot]$.

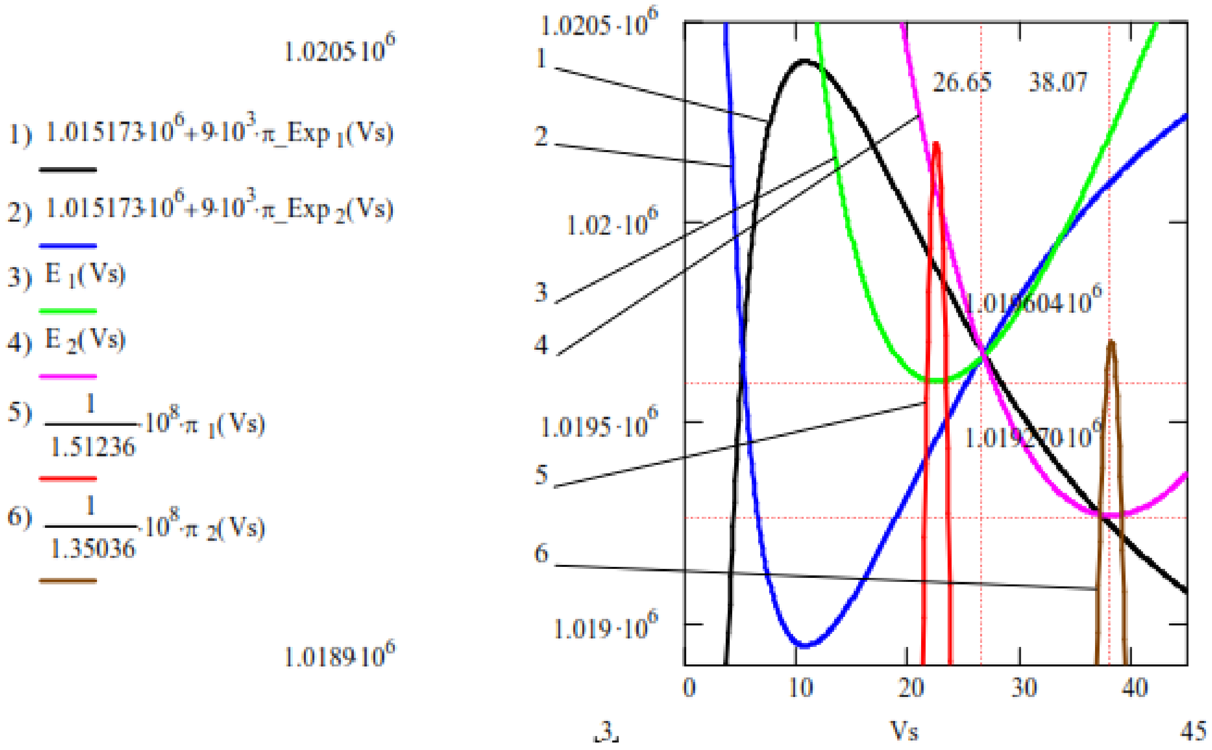

Fig. 2. Criteria of flight safety and corresponding preferences of the related alternatives

However, at V_s<32.4 it is vice versa the second alternative (UAV) is more preferable than the first one (TAC). $\text{Exp}_1\left[R_1(V_s)\right] > \text{Exp}_2\left[R_2(V_s)\right]$, $\pi_1[\cdot] < \pi_2[\cdot]$. Moreover, the second (UAV's) criterion has the lowest value at V_s = 13.68: $\text{Exp}_2\big|_{V_s=13.68}$ $\approx 1.0189\cdot10^6$.

Therefore, this particular dilemma has an appropriate solution: the preferred discrete alternative is the second alternative (UAV); and then, the optimal value of the continuous alternative, in this second discrete alternative (the UAV's) rated maintenance, is $V_{s_{\text{opt}}}\Big|_2 = 13.68$. The manifestation of that is the maximal value of $\pi^{(2)}(V_s)$ in the continuous alternative distribution of the second discrete alternative.

The example 2 proves the convenience of the controlling functions in a case when a relatively higher controlling influence is more preferable. The value $V_{s_{\text{opt}}}\Big|_2 = 38.07$ is the appropriate solution as that follows from the diagrams shown in Fig. 2.

Although further researches are necessary in order to determine the best controlling influence.

Conclusions on the presented research

From the presented theoretical methods (1) – (12) illustrated with the examples we conclude that flight safety control (expediency of UAV versus TAC application) is successfully substantiated with the use of the controlling functions in the view of the individual preferences functions obtained on the basis of SEEP.

Prospects of further studying in the specified direction

The further researches are worth of the prospects from the attempts in studying situations when it is not necessarily the lower the optional $V_{s_{\text{opt}}}$ the better, as that follows from the example 2; as well as discovering the common preferences distribution for a few continuous alternatives.

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А. В. Гончаренко. Керування безпекою польотів із використанням функцій переваг

Запропоновано математичну модель для комбінованого техніко-економічного критерію керування безпекою польотів (експлуатаційною ефективністю) на основі «Принципу екстремізації суб'єктивної ентропії», для грубо спрощеної постановки задачі, проблеми керування безпекою польотів (можливо для двох літаків, або доцільності застосування безпілотних літальних апаратів порівняно до традиційних літаків). Отримані розв'язки формульованої варіаційної задачі показують оптимальний керуючий вплив у вигляді канонічних розподілів індивідуальних переваг, як для дискретних, так і безперервних альтернатив. Теоретичні міркування проілюстровано прикладами розрахункових експериментів. Побудовано необхідні діаграми.

Ключові слова: принцип максимуму суб'єктивної ентропії; керування безпекою польотів; доцільність застосування безпілотних літальних апаратів; комбінований техніко-економічний критерій експлуатаційної ефективності; канонічний розподіл індивідуальних переваг; варіаційна задача; керуюча функція.

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А. В. Гончаренко. Управление безопасностью полетов с использованием функций предпочтений

Предложена математическая модель для комбинированного технико-экономического критерия управления безопасностью полетов (эксплуатационной эффективностью) на основе «Принципа экстремизации субъективной энтропии», для грубо упрощенной постановки задачи, проблемы управления безопасностью полетов (возможно для двух самолетов, или целесообразности применения беспилотных летательных аппаратов по сравнению с традиционными самолетами). Полученные решения сформулированной вариационной задачи показывают оптимальное управляющее воздействие в виде канонических распределений индивидуальных предпочтений, как для дискретных, так и непрерывных альтернатив. Теоретические соображения проиллюстрированы примерами расчетных экспериментов. Построены необходимые диаграммы.

Ключевые слова: принцип максимума субъективной энтропии, управление безопасностью полетов, целесообразность применения беспилотных летательных аппаратов, комбинированный технико-экономический критерий эксплуатационной эффективности, каноническое распределение индивидуальных предпочтений, вариационная задача, управляющая функция.

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