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Multicriterion model of selecting management strategies for UAV[1] design and production

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Abstract: *In this article the mathematical model of the problematic situation of decision making with the group of subjects is examined for the first time. This model is represented in the form of cortege. For the effective and proper selection of the company management strategy the following tasks were preliminarily solved: to find bases for the present-day production efficiency of Unmanned Aerial Vehicles (UAV); to examine forecasts according to basic market indices and investment of means for the development of UAVs into the next decade.*

Keywords: *Multi-criterion model, decision-making, forecasting, efficiency, selection of strategy, Unmanned Aerial Vehicles (UAV).*

Sommario: *In questo articolo viene esaminato anzitutto il modello matematico della situazione problematica per la presa di decisione da parte di un gruppo di soggetti. Il modello è rappresentato nella forma di sequenza. Per un'efficace e adeguata selezione di strategia del management dell'impresa devono essere risolti preliminarmente i seguenti compiti: trovare le basi dell'efficienza della produzione odierna del Veicolo Aereo Automatico (UAV); esaminare le previsioni secondo gli indici di base del mercato e dell'investimento di risorse per la produzione dello UAV nella prossima decade.*

1 UAV — Unmanned Aerial Vehicle www.gov.uk/government/uploads/system/uploads/attachment_data/file/33713/JDN310Amendedweb1June10.pdf *(accessed at 17 November 2014).*

Parole-chiave: *Modello multicriterio, previsione, efficienza, selezione di strategia, Veicolo Aereo Automatico (UAV).*

Introduction

There are many management strategies for high-tech enterprises producing Unmanned Aerial Vehicles (from this point onwards UAVs and management strategies). Yet successful enterprise advancement depends on the efficiency and correctness of strategy choice. Obviously, we consider this matter only if UAV production is profitable. Thus, before stating a final goal for the research and choosing a management strategy, it is necessary to give reasons for the present UAV production efficiency in detail, as well as making forecasts for at least one decade.

Therefore, in this study we need first of all to define and solve the following intertwined issues:

– Proving that UAV production is currently efficient;
– Analysing the forecasts of the major market indices and investments for UAV development for the next decade;
– Finding and if necessary modifying an existing definition of the strategy.

Market overview of major UAV manufacturers

The most important players in the UAV market, especially in the segment of high-altitude long-endurance UAVs (HALE UAVs), are large aircraft corporations possessing the necessary technologies, research departments and established business relations with specific electronics manufacturers (Kalmikov 2016:140-146).

Dozens of companies offering a wide range of UAVs with different applications are represented in this new rapidly expanding market.

At the same time, a new category of long-endurance unmanned vehicle designers is entering the market. These are innovative startups that are now attracting the attention of large Internet companies. In 2014, Google acquired the innovative startup Titan Aerospace, which had designed its own HALE

UAV. With this technology, Google is going to make the Internet available in those parts of the planet where channel wiring and erection of cell towers would be unreasonably expensive (Kalmykov 2016:140-14).

However, the above-mentioned startups have occurred mainly in the civil sector of the HALE UAV market, which is still in its early days. Nevertheless, its range of products has doubled in the last three years. But its development prospects are still too ambiguous. It should also be mentioned that the number of aircraft manufacturers in this market is increasing as is the variety of products, which explains the supply increase. At the same time, a lack of sales and an insufficient number of interested customers explains the low product demand. In the authors' opinion the absence of demand is caused by the following factors:

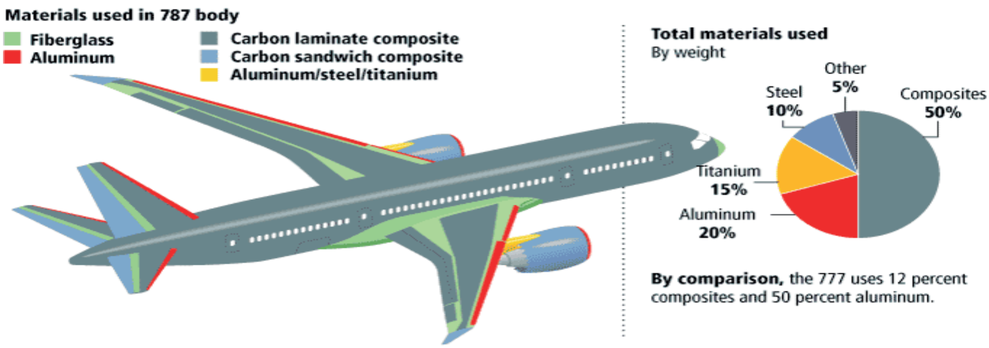
- tough competition from military HALE UAVs as their operational functions allow them to perform all the functions of civil drones;
- a number of construction defects in the majority of modern HALE UAVs;
- the high cost of modern HALE UAV maintenance.

Let us consider these factors in detail. At present, the two crucial functions of civil HALE UAVs are Earth surface observation (forest fires, sea and road traffic) and optical and radio-electronic equipment use as telecommunication platforms (known as atmosphere communications satellites). Speaking of Earth surface surveillance, it is worth mentioning that this function is extremely interesting for government bodies as they use military UAVs for this purpose to cut costs. The employment of atmosphere communications satellites is complicated, since their propulsion currently consumes more energy than onboard solar batteries can produce. Furthermore, airfields with trained staff and special operating equipment are at a premium.

Peculiar properties of HALE UAV design

HALE UAV design characteristics, such as the wide use of composite materials, large wingspan and the employment of solar batteries, require the construction of special hangars and maintenance and the employment of particular equipment which significantly increases the operating costs of these aerial vehicles. It should be noted that the recent increase in the number of

UAV parts made of composite materials, especially of carbon fibre-reinforced plastic, has posed a threat to the safety of these unmanned vehicles. Currently, most UAV construction elements made of composite materials are used for the secondary structure and as a rule they are removable, which significantly simplifies their maintenance. Lately there has been an increasing number of aerial vehicles whose primary structure is made of composite materials containing a great number of non-removable connections, which greatly complicates their maintenance. Moreover, in a range of aerial vehicles, the most fragile constituents are made of composite materials. Statistically, approximately 25% of all damage to aircraft fuselages involves components entirely made of carbon and fibreglass.



Picture 1. The percentages of structural materials used in a Boeing 787.

Such composite materials possess low maintainability and reparability indices and high operating costs, due to the cost of labour and, in some cases, of the hand work and special tools required for the improvement and repair of composite components. Quite often the improvement and maintenance of composite materials is actually impossible.

Thus, according to the author, a wide use of composite materials in the construction of UAVs might result in a significant increase in the operating costs of these aerial vehicles (Shevyrenkov 2016:148-157). A competitive analysis of the HALE UAV market, the major trends of HALE UAV design and analyses conducted by leading manufacturers have demonstrated that modern unmanned systems mark a considerable achievement for the aviation industry over the last decade.

These advanced technologies not only explain the HALE UAV market growth rate, but they also create new markets and spheres, and contribute to the efficient growth of national economies thanks to the renewal of manufacturing processes, management methods and labour resources. These technologies are also changing the way military operations are conducted in the 21st century (Preobrazhenskij 2014).

Forecasting HALE UAV market size

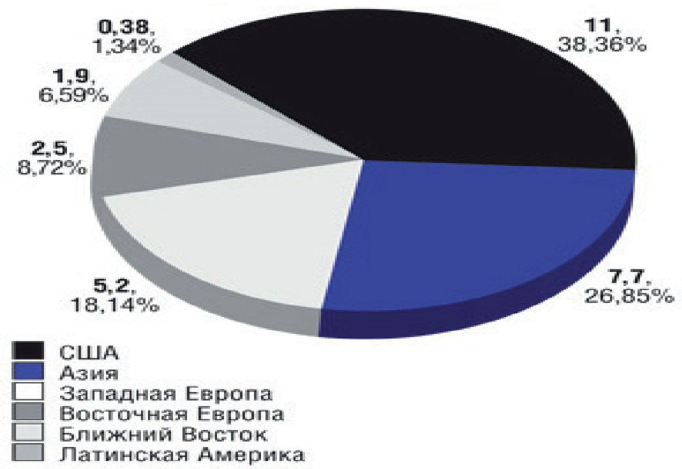
Will the market situation change within a decade and if so in what way?

The forecasts are quite optimistic. For example, the American consulting company Forecast International predicts that the UAV world market volume will amount to 67.3 billion USD in a decade (2014-2023) (Aviation daily 2014). According to the forecasts of the same company, within this period, the UAV sales volume in the Asian region might reach 18 billion USD, of which 13 billion USD in the Chinese market, pointing to a sharp growth in that country's potential in the unmanned technology sector. Western Europe accounts for 5.2 billion USD (18.14%), while Eastern Europe including Russia accounts for 2.5 billion USD (8.72%). A competitive analysis of the HALE UAV market, the major trends of HALE UAV design and analyses conducted by leading manufacturers have demonstrated that modern unmanned systems are one of the most important achievements for the aviation industry over the last decade. The R&D investments in drone systems by 2023 are estimated at 28.68 billion USD, where the share of the USA is 11 billion USD, i.e. 38.36 % of world expenditure.

Major study trends in the USA are currently related to unmanned aerial systems based on long-endurance UAVs. These include the development of conceptual alternatives to unmanned aerial systems (conceptual R&D) and the development of technologies required for unmanned aviation industry design (technological research and process development).

By 2023 a significant increase in the share of the Asian regions should have taken place, as the same forecast foresees the R&D financing of unmanned aerial vehicles at about 7.7 billion USD (26.85%).

The diagram in picture 2 shows the UAV investment forecast for 2023.



Picture 2. UAV investment forecast for 2023 by country (billion USD, %) (Aviation Daily 2014).

To allay doubts concerning such significant forecasts and other optimistic estimates of important indices, it is crucial to identify the customers of this forecast and ascertain to what extent they are interested in the development of this market. This will serve to counteract the suspicion that the forecast may be an attempt to apply information speculation to drive further development of the UAV world market within the next decade. This is common practice when using forecasting techniques. *This work is aimed at* developing a model for selecting the best management strategies based on the solution of previously formulated tasks for high-tech enterprises producing UAVs.

The development of the multi-criterion model

Before concentrating on this model let us define the major notion. Within the framework of this material taking the representation of such a basic notion as strategy analysed in the work (Litvak 2000: 392) we will extend this notion in some ways by means of a link with the strategic scenario forecast. We thus consider the strategy as a sequence that includes the following:

- long-term strategic goals defining the enterprise operation and based on strategic scenario forecasts;
- technologies (including IT) which enable us to achieve strategic goals;
- resources that will be used while pursuing the strategic goals;
- the management system that ensures the achievement of the strategic goals, mainly labour resources.

At the same time, we agree that the management strategy of high-tech enterprises producing a certain product frequently depends on product type and class. That means a reasonable choice of UAV type may define the success of the management strategy. Naturally, it is necessary to set the fundamental criteria used for selecting the best option.

It is our belief that the criteria to be taken into account include:

- UAV flight altitude;
- UAV flight duration;
- the profit from the UAV appliance;
- the efficiency of the UAV design and appliance;
- the technological level of industrial development of the producing country;
- UAV type and function.

In this case, the meaning of the above-mentioned criteria must be put into words – since the criteria may vary according to the situation in which they have to be expressed.

So, for instance, next to the UAV altitude we might find the expressions ‘up to 60 metres’, ‘up to 900m’ or ‘up to 1500m’.

UAV types have names, such as ‘atmosphere satellite’ and so on. Such a UAV is able to fly non-stop at an altitude of 20km for several months or even years.

The characterisation of criteria can be achieved through a classification like the UAV classification of the UK Ministry of Defence.

UNMANNED AIRCRAFT CLASSIFICATION TABLE						
Class	**Category**	**Normal Employment**	**Normal Operating Altitude**	**Normal Mission Radius**	**Civil Category (UK CAA)**	**Example platform**
Class I <150 kg	MICRO <2kg	Tactical Platoon Sect. Individual (single operator)	Up to 200ft AGL	5km (LOS)	Weight Classification Group 1 (WCG) Small Unmanned Aircraft (<20kg)	Black Widow
	MINI 2-20 kg	Tactical Sub-Unit (manual launch)	Up tp 3000' AGL	25 km (LOS)		Scan Eagle, Skylark, Raven DH3
	SMALL > 20kg	Tactical Unit (employs launch system)	Up to 5000' AGL	50 km (LOS)	WCG 2 Light UAV (20><150kg)	Luna, Helmes 90
Class II 150-600kg	TACTICAL	Tactical Formation	Up to 10000' AGL	200 km (LOS)	WCG 3 UAV (>150kg)	Sperwer, Iview 250, Hermes 450, Aerostar, Watchkeeper
Class III > 600 kg	MALE	Operational/ Theatre	Up to 45000' AGL	Unlimited (BLOS)		Predator A&B, Heron, Hermes 900
	HALE	Strategic/ National	Up to 65000' AGL	Unlimited (BLOS)		Global Hawk
	Strike/ Combat	Strategic/ National	Up to 65000 AGL	Unlimited (BLOS)		

Table 1 — Unmanned Aircraft Classification Guide

In the case of long-term goals, the technologies and the management system that guarantee the achievement of the strategic goals will coincide. In terms of financial and human resources, there are more options. When choosing management strategies, decision-makers have to simultaneously take into account various factors, impacts, threats and distant consequences. Besides, as a rule analysts have various preferences and their targets and correspondingly their tasks do not always go together. Taking this into account, analysts who make a decision choosing a certain management strategy need to consider multi-criterion phenomena. One of the methods allowing the selection of the most efficient management strategy in problematic situations is the "multi-criterion model". As opposed to the majority of methods used by experts, multi-criterion analysis contains clearly identifiable prerequisites and appropriate assumptions. In this research work, we take into account linear or simultaneous management strategy characteristics. These characteristics are those for which:

- there is a direct and inverse relationship between the characteristic itself and the level of satisfaction of the UAV customer;
- there is a linear order relation on the set of partial criteria and in cases when the score grade is pointed their number is strictly greater than two;
- the range of any subtest is determined by setting the goal.

It is these partial criteria that are used in the multi-criterion model, as only through them is the level of goal achievement modelled by the increase/decrease of the functions, which are often called "subtests" and, in our case, "characteristics".

Demonstration of the model

Taking into consideration what has been mentioned above, let us analyse a multi-criterion model of a problematic decision-making situation involving a group of customers. Only a multicriterion model can reasonably enable the customer group to select the most efficient management strategies by taking into account several criteria.

In general terms such a model can be illustrated as follows:

$< V_j, S_i, X, K, P, I, S >$, where

1. $\{V_j\}$ is the management strategies set ($j = 1 \div Y, Y \geq 2$);
2. $\{S_i\}$ is the set of possible customers involved in choosing the management strategy ($i = 1 \div I, I \geq 2$);
3. $\{X\}$ is the set of characteristics of the management strategy:
4. $K = (K_1, K_2 \ldots K_T)$ is a vector test ($t = 1 \div T, T \geq 2$);
5. is the binary relations of preference (P) and indifference (I) of the individuals participating in making the decision, fixed at the set of management strategies, vector grades and characteristics (criteria);
6. (S) is the set of possible solutions.

We will explain the entity of the elements of the suggested model.

<u>In terms of point 2,</u> the customers $\{S_i\}$ participating in the process of decision-making are quite numerous and of various categories. In the context of the model analysed by us, besides decision-makers, there is also the category including the customers interested in the product. It is their preferences that must be taken into consideration when selecting the most effective management strategies.

As we mentioned above, participating customers and their interests do not coincide. Some of them represent their own interests, others are representatives, mediators or management agents of other entities.

It is important to note that the notion of "goal" changes significantly depending on the status of the customers participating in the process of decision-making, just as it changes, for instance, if we compare a member of a managerial board with the managerial board itself as a small group (Vartanyan and Sidelnikov 2005: 114-119).

It is our belief that if customers are authorised to make decisions in terms of a management strategy, then they should possess opportunities to implement it and be responsible for its consequences. At the same time they rely on their preferences and the goal of each customer, to their mind, is the achievement of the best decision.

<u>In terms of point 3</u>, in this research we consider only linear characteristics. We call these characteristics criteria.

Thus, the degree of goal achievement can be given by the tendency to increase/decrease special functions, quite often called subtest; sometimes efficiency or quality indices (K_t). The level of goal achievement in subjects and entities is determined by the corresponding score grade[2] of the given criterion.

There are other definitions of criterion features. These are such features of evaluated objects or options of the choice that characterise the measure of correlation of the object (the option of the choice) to the defined purpose (goal) (Glotov and Pavelev 1984). It goes without saying that the authors automatically switch from multi-criterion selection to criterion importance theory, and this choice must be further explained (Saltikov 2010: 16-41). The feasibility of this choice of methods, which are described in research studies by V.V. Podinovsky, is dealt with in works by S.A. Saltykov (Saltikov 2010: 16-41; Saltikov 2011: 5-29).

If there is a dependence relation between characteristics which can be described (for instance, a linear or inverse proportion), then it must be taken into consideration when selecting the important characteristics. This will make it possible to process quantitative information about the importance of criteria so that it can be correctly used in the further set of different methods of analysis of multi-criterion tasks. Usually, quantitative information about criterion importance is obtained by collecting the opinions of all participating subjects by means of specific questions, such as: why is criterion Ki more important than criterion Kj? The general summary of the methods and methodologies of defining quantitative grades of criterion importance is analysed in the work (Anohin, Glotov, Pavelev and Cherkashin 1997:3-35).

<u>In terms of point 4</u>, we believe that in our case it is not possible to choose generalised (integrated) criteria, since the assumptions related to the uniformity of increase/decrease in decision-making preferences from zero up to maximum K_t* are quite often doubtful. We agree with the position of many multi-criterion decision-making specialists that, in general, it is impossible to suggest how to choose general criteria to analyse multi-criterion decision-making tasks (Podinovskij and Nogin 1982: 254; Podinovskij 2007: 64).

2 In this passage the notion of the score grade possesses a general sense that is different from the sense of the term introduced by I. Pfantsagelem in his work on social-economic measurements (Podinovskij 1978: 48-82).

We see criterion K_t as a single-valued transformation[3], determined at $\{V\}$ and taking its value from the set X_i (in the literature on multi-criterion tasks this transformation is usually determined as a function), where $\{V\}$ is the set of possible management strategies where the partial order relation was determined. {X} is the set that carries an optional characteristic, where the relation of the linear order is determined and gradation is pointed out. This set is determined by each subject when choosing the goal. At the same time, the mark can be a number (for instance, it is an annual return for the firm) or on a scale which can be expressed verbally or by symbols.

Any one of the criteria K_t characterises each of the management strategies. They must be clearly described so that their meaning can be understood by the experts and by all subjects involved in decision-making.

The specific character of our task lies in the fact that the applied general criteria K_t in a general case are not homogeneous. Their range of values not only lacks a general scale but also similar scale gradation may illustrate a different level of preference for each of the criteria. So, for example, such verbal marks as "superb" may have different meanings according to the criteria.

Thus, it is generally necessary to use a special section of the importance theory initially analysed by V.V. Podinovsky in his study (1978: 48-82). In this case, non-homogeneous criteria need to be transformed into homogeneous ones, bringing them to unified criteria measured quite often with an ordinal scale.

The gradation of this scale possesses a general interpretation in terms of preferences for all criteria. It is important to keep in mind that the values of criteria are difficult to measure even with an ordinal scale.[4]

Having received the values of each linear characteristic based on the analysed model from the experts or a decision-maker, we will ignore the management strategies, considered inappropriate by Edgeworth-Pareto (Noghin 2006: 554-562).

According to point 5, to achieve a certain goal the subject is forced to set it in partially uncertain conditions. This means one must be able to choose

3 This transformation is not one-to-one, as there will be such values of a score grade which are applied to different management strategies.

4 In this passage we see the notion of a scale as introduced by I. Pfantsagelem (1976) in his work on social-economic measurements.

given a set of alternatives defined by the task and set preference relation (identifying the best) and equivalence relations (identifying similarity). At the set of criteria the importance relation is established. It is significant to take into consideration a different type of preference relation of subjects at this set of characteristics (or criteria), directly or indirectly influencing the choice of the management strategy.

A successful solution of multi-criterion tasks is not feasible without using data about the preferences of those individuals who make the decisions. At the same time, one of the most important resources of such data is the information about the relative importance of the criteria. The information about subjects' indifference or preference in terms of criteria will help us further compare vector marks, which characterise the management strategies. For a further conscious selection of the best management strategies, it is essential to find additional information about the preferences of the decision-makers. Such information will include data about the relative importance of linear characteristics (or criteria) and information about scales as well. And this, in turn, is related to the significance of sorting out the key problem of substitution in the theory of decision-making. This means the problem of comparison based on the preference of losing according to some criteria and winning with others. To implement this, it is important to analyse the set of characteristics (or criteria) and transform it into sorting (collecting elements ordered according to preference). High-quality information about the preferences at the set of criteria establishes the preference relation in the set of vector marks characterising management strategies. Combining these relations and the Edgeworth-Pareto relation it is feasible to compare vector marks of management strategies correctly according to preference using all the information. For clarity it is essential to use explanatory chains.

To clarify let us analyse the following example from the study (Podinovskij and Nogin 1982: 254). Let it be that in a double-criterion task the first criterion is preferable to the second one, i.e. K1≥K2. Then if we have the vector values (5.3) and (3.5) it is possible to write down that (5.3) $P^{1\geq 2}$ (3.5), as the first criterion is more important than the second one. In addition to that, since vector value (3.5) is preferable to (2.4) according to Pareto we can write down the following: (3.5) P^0 (2.4). If the transitive closure of the two given relations of preference (P^Ω) is not empty, then it is possible to construct an explanatory chain with 2 links: valid correlations (5.3) $P^{1\geq2}$ (3.5) and (3.5) P^{0}(2.4). Joining them together we will obtain (5.3) P^{Ω} (2.4). (This makes it clear that each following further statement will be correct neither at (5.3) $P^{1\geq2}$ (2.4) nor at (5.3) P^{0} (2.4)).[5] Constructing such chains makes it possible to explain to decision-makers why one should prefer one project over another.

In case there is incomplete information about preferences in this model, it sounds practical to use the notion of l-domination. This notion is a generalisation of the notion of undominated object (in our case, the management strategy). This is under the condition specified by the task, as we do not simply choose one of the best strategies but we select the l-best ones (Podinovskij 2007:64).

In terms of point 6, the decision is analysed as a responsible subject's exclusion of less efficient management strategies from their set, in conditions of partial uncertainty based on vector criteria and existing data related to indifference or preferences of individuals, making decisions on the set of criteria.

When choosing the management strategy, we take into account that different characteristics (X) possess different decision-making potential.

In terms of exclusion of a management strategy, the decision is made by a group of individuals by using the models of a problematic situation of decision-making. The decision is made by comparing the management strategies taking into account their vector marks of characteristics.

At the same time, it is necessary to take into consideration the specifics of decision-making by a collective subject (top management or outside specialised expert institutions) (Vartanyan 2006:288). There are advantages and disadvantages in collective-subject decision-making (Sidelnikov 2007: 348) For example, groups usually tend to make riskier decisions than individuals, as the responsibility of each member for implementation decreases in time. It can take much time, but if the decisions are predictable then resources are wasted. In terms of advantages, to attract specialists to the process of decision-making the following examples can be listed: a more far-sighted view of the problem and its thorough analysis; during the discussion the establishment of the task can be clarified and uncertainty may decrease in terms of possible options.

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5 We proceed from the assumption that in this case the hypothesis about the transitivity of priorities given at the unity of the two given preference relations is correct.

If there is a correlation between the characteristics and this correlation can be described (for instance, it is a linear and inverse proportion) it must be taken into account while selecting the characteristics in terms of importance level. This will allow us to organise the quantitative information about the importance of the criteria so that later on it will be possible to use it correctly in the structuring of different methods of analysis of multi-criterion tasks. Usually, quantitative information is obtained on the basis of the answers of all participants or on the basis of specially created questions, e.g.: why is criterion Ki is more important than criterion Kj? The general overview of methods and methodologies to identify the quantitative marks of criterion importance is dealt with the work (Anohin, Glotov, Pavelev and Cherkasim 1997: 3-35).

Conclusion

For the first time in this paper the mathematical method is overviewed as a tuple of steps in problematic decision-making situations.

Simultaneously, the notion of management strategy, development and HALE UAV production is introduced, enabling us to explore this theme effectively.

The mathematical model of the problematic decision-making situation within a group of subjects is intended for the effective selection of strategy control, development and production of UAVs by highly technological production companies.

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