УДК 004.772 DOI:10.31673/2412-4338.2021.033745

Abdalla A. *Flying Academy of the National Aviation University, Kropyvnytskyi*

DEVELOPMENT OF A METHOD OF QUANTITATIVE ASSESSMENT OF THE FLIGHT SAFETY CURRENT LEVEL DURING THE FORMATION OF AIRCRAFT FLOWS IN THE AREA OF RESPONSIBILITY

Abstract: *Flight safety is the most important operational and technical characteristic of the air transport system, which is influenced by many factors, unstable and random in nature, which, as a rule, are interconnected with each other. The management of any property of a complex dynamic system, including the safety property of an operated air transport system, provides, as a mandatory procedure, a quantitative assessment (measurement) of the current value of the parameters by which control is carried out, since, in accordance with the basic postulate of management, to control is possible only by what is measurable. During the operation of the aircraft, information is accumulated about the state of the automatic exchange, as about the object of study. In this case, to some extent, the uncertainty in the knowledge about the object is eliminated. The main reason for uncertainty is the randomness of phenomena and processes. Obviously, there are no phenomena or events in which there are no elements of chance. No matter how accurately and carefully the operating conditions of the aircraft are recorded, it is impossible to ensure that with repeated (continued) observations, the results completely and exactly coincide. Random deviations inevitably accompany any natural phenomenon. Unlike common practice random elements cannot be neglected, especially since the result of operation depends on a large number of factors and even more combinations of them. It is necessary to study random phenomena, investigate patterns and find out the causes of random occurrences in a regular phenomenon. Finding any stable patterns is usually very difficult. However, if we consider a sequence of a large number of observations, then some rather interesting properties are revealed: individual (separate) observations are unpredictable, and the average results show stability or a pronounced trend of change (pattern of change) characteristic of dynamic systems.*

Keywords: *method, flight safety, aircraft, airport, system.*

Абдалла А. *Льотна академія Національного авіаційного університету, Кропивницький*

РОЗРОБКА МЕТОДУ КІЛЬКІСНОГО ОЦІНЮВАННЯ ПОТОЧНОГО РІВНЯ БЕЗПЕКИ ПОЛЬОТІВ ПІД ЧАС ФОРМУВАННЯ ПОТОКІВ ЛІТАКІВ У ЗОНІ ВІДПОВІДАЛЬНОСТІ АЕРОПОРТУ

Анотація: *Безпека польотів є найважливішою експлуатаційно-технічною характеристикою повітряно-транспортної системи, на яку впливає багато факторів, нестабільних і випадкових за характером, які, як правило, взаємопов'язані один з одним. Управління будь-якою властивістю складної динамічної системи, у тому числі властивістю безпеки експлуатованої повітряної транспортної системи, передбачає, як обов'язкову процедуру, кількісну оцінку (вимір) поточного значення параметрів, за якими здійснюється контроль, оскільки , згідно з основним постулатом менеджменту, контролювати можна лише тим, що вимірюється. Під час експлуатації літального апарату накопичується інформація про стан автоматичного обміну, як про об'єкт дослідження. У цьому випадку певною мірою усувається невизначеність у знаннях про об’єкт. Основною причиною невизначеності є випадковість явищ і процесів. Очевидно, що немає явищ чи подій, у яких не було б елементів випадковості. Як би точно і ретельно не фіксувалися умови експлуатації літального апарата, неможливо домогтися, щоб при повторних (продовжуваних) спостереженнях результати повністю і точно збігалися. Випадкові відхилення неминуче супроводжують будь-яке природне явище. На відміну від звичайної практики, випадковими елементами нехтувати не можна, тим більше, що результат операції залежить від великої кількості факторів і ще більшої кількості їх комбінацій. Необхідно вивчати випадкові явища, досліджувати закономірності та з'ясовувати причини випадкових появ у регулярному явищі. Знайти будь-які стабільні закономірності зазвичай дуже важко. Однак, якщо розглядати послідовність великої кількості спостережень, то виявляються досить цікаві властивості: окремі (окремі) спостереження непередбачувані, а середні* *результати демонструють стабільність або виражену тенденцію змін (шаблон змін), характерний для динамічних. системи.*

***Ключові слова**: метод, безпека польотів, літак, аеропорт, система.*

Абдалла А. *Летная академия Национального авиационного университета, Кропивницкий*

РАЗРАБОТКА МЕТОДА КОЛИЧЕСТВЕННОГО ОЦЕНИВАНИЯ ТЕКУЩЕГО УРОВНЯ БЕЗОПАСНОСТИ ПОЛЕТОВ ПРИ ФОРМИРОВАНИИ ПОТОКОВ САМОЛЕТОВ В ЗОНЕ ОТВЕТСТВЕННОСТИ АЭРОПОРТА

***Аннотация:** Безопасность полетов является важнейшей эксплуатационно-технической характеристикой воздушно-транспортной системы, на которую влияют многие факторы, нестабильные и случайные по характеру, которые, как правило, взаимосвязаны друг с другом. Управление любым свойством сложной динамической системы, в том числе свойством безопасности эксплуатируемой воздушной транспортной системы, предусматривает, как обязательную процедуру, количественную оценку (измерение) текущего значения параметров, за которыми осуществляется контроль, поскольку, согласно основному постулату менеджмента, контролировать можно только тем, что измеряется. При эксплуатации летательного аппарата накапливается информация о состоянии автоматического обмена как об объекте исследования. В этом случае в определенной степени устраняется неопределенность в знаниях об объекте. Основной причиной неопределенности является случайность явлений и процессов. Очевидно, что нет явлений или событий, в которых не было бы элементов случайности. Как бы точно и тщательно ни фиксировались условия эксплуатации летательного аппарата, невозможно добиться, чтобы при повторных (продолжающихся) наблюдениях результаты полностью и точно совпадали. Случайные отклонения неизбежно сопутствуют любому природному явлению. В отличие от обычной практики, случайными элементами пренебрегать нельзя, тем более что результат операции зависит от большого количества факторов и еще большего количества их комбинаций. Необходимо изучать случайные явления, исследовать закономерности и выяснять причины случайных появлений в регулярном явлении. Найти любые стабильные закономерности обычно очень затруднительно. Однако, если рассматривать последовательность большого количества наблюдений, то обнаруживаются достаточно интересные свойства: отдельные (отдельные) наблюдения непредсказуемы, а средние результаты демонстрируют стабильность или выраженную тенденцию изменений (шаблон изменений), характерный для динамических. системы.*

***Ключевые слова**: метод, безопасность полетов, самолет, аэропорт, система.*

1. Introduction

Randomness is a type of uncertainty that obeys some regularity, which is expressed by a probability distribution. Knowing the probability distribution, we can determine:

- in what interval are the values of a random variable;
- what is the most likely value;
- what is the scattering of realized;
- what is the relation between different implementations/

In order to determine the law or density of distribution, information about the object of study is required. Measurements of random variables and processes in the field of are essentially a measurement of an output parameter that characterizes certain properties of the evaluated object. Based on such measurements, the issues of restoring the type and parameters of the distribution law, calculating regression and correlation coefficients, restoring spectral densities, etc. are solved.

Features of the results of monitoring [1]:

- large dimension of the array of initial data,
- diversity of initial and required data,
- noisy data (the observed value differs from the true value). The statistical properties of interference may not depend on the quantity being measured,
- deviations from assumptions, distortion of results,
- the presence of missing values (part of the observations are not brought to the estimated or

expected sign or aviation event due to the rare occurrence of characteristic events),

- changing in space and time the properties of the automatic telephone exchange and operating conditions (the influence of many factors that cause uncertainty and non-stationarity). Variability of parameters.

The task of obtaining a reliable estimate of the parameters is complicated by the presence of an inevitable random error and a systematic dynamic error, primarily due to ongoing changes in the operated automatic telephone exchange, both as a result of possible natural progress or regression, and as a result of targeted actions to minimize the risk of accidents within the system [2].

2. Analysis of literature and problem statement

The problem formulated is proposed to be solved through a probabilistic approach to both single-parameter and multi-parameter (integral or cumulative), both direct and indirect assessment of the level, both in the airline [3], and in the department or aviation industries on a national (regional) scale.

Quantitative assessment of the level is traditionally performed according to generally accepted standardized indicators (statistical and probabilistic) [4-6], using mostly methods known to specialists [7]:

- calculated - when assessing the level, as a rule - for the group of factors "aircraft" at the stage of development and certification of the type of aircraft;

- statistical - in a posteriori estimation and forecasting of the level based on the results of tests and operation;

- expert - with a priori assessment and prediction of the level according to the conclusion of specialists.

Estimates of indicators, obtained initially by calculation methods, are a posteriori refined as information on the results of tests and operation is accumulated. By the end of the operation of the type of aircraft, the estimates of indicators are approaching their true values.

The task of a priori estimation of the level, like most tasks related to the assessment of the risks of accidents and disasters, is generally incorrect, since it is characterized by:

- high level of uncertainty and variability of parameters reflecting the current and prospective levels;

- lack of reliable objective information and initial statistical data;

- dynamism and multifactorial dependence of the level.

Due to the unequal conditions in which observations are carried out (due to the changing conditions of aircraft flight operation, regional, intradepartmental and corporate features, ...), the available data, according to the theory of measurements, are unequal series of conditionally equal observations [8].

If a certain parameter (for example, the frequency or statistical probability of an aviation event of a fixed severity) is estimated from multiple observations made over a long period of flight operation (for example, for several years under different operating conditions), then it should be taken into account that the change and the conditions of its operation can cause significant systematic and random changes in both the mathematical expectation of the estimated parameter and its dispersion [9]. To take into account the noted changes, observations are carried out in several series, between which and within which qualitative transformations of the operated automatic telephone exchange are possible. If there is insufficient information about the object under study, information about the functioning of analogue objects is used.

Formulation of the problem. This paper proposes an approach to this paper proposes an approach to development of a method of quantitative assessment of the flight safety current level during the formation of aircraft flows in the area of responsibility.

3. The aim of the study

The aim of the study is to develop of a method of quantitative assessment of the flight safety current level during the formation of aircraft flows in the area of responsibility.

4. Airline safety survey by incident frequency

Within the framework of the SMS of an aircraft operator, the main (but not the only) indicator is "the number of incidents per 100,000 flights or hours" [10], i.e. the frequency or statistical probability of an in-flight incident [11-14]. This indicator is subject to direct quantitative assessment both in a planned manner for a certain period of flight work (month, quarter, year), and as incidents occur.

In the case of an airline's transition from the concept of "accident prevention through the reduction of the number of incidents" to the concept of "incident prevention through the reduction of the number of incident precursors", the considered indicator can also be extended to the precursors of incidents, provided that such category of aviation events is clearly and unambiguously defined, if not on the state, then at the corporate level.

However, the indicator "the number of incidents per 100,000 flights or hours" cannot be of general use within a state, since the level for a state (region) is set and estimated by the relative number of accidents with human casualties, i.e. the relative number of disasters. Therefore, this indicator should determine, control and adjust the acceptable level within the state, as well as the established and current level in airlines.

The absence of "infinity" type uncertainties in the indicator values obtained from the results of cumulative observations leaves the possibility of using the apparatus of probability theory and mathematical statistics in the processing and analysis of observation results.

The experience of current (monthly) measurement of BP characteristics and trend analysis, including using the method of quantitative assessment of indicators of the current level [15], showed the expediency of improving the previously developed methodology in order to expand its analytical functions.

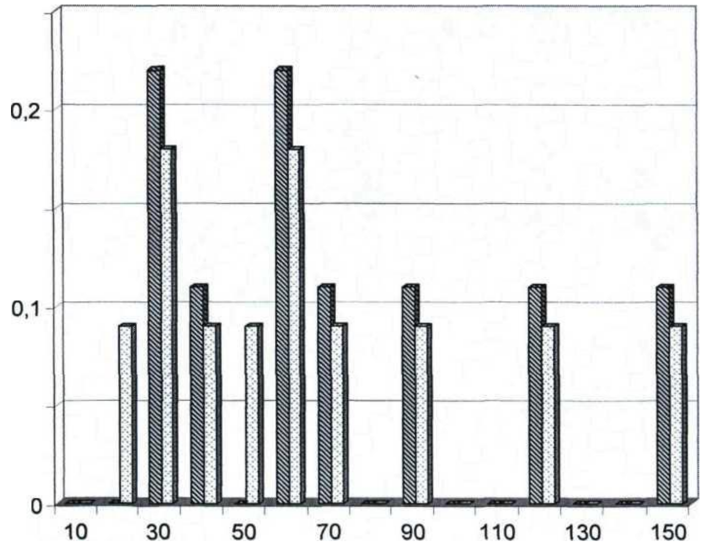
If during the estimated period (for example, a month) in N flights an aviation event (for example, an incident) was observed n times, then the frequency of this being is defined as an estimate of the mathematical expectation of the probability of its occurrence (table 1).

Table 1.

Trust probability	U
0.8	1.282
0.85	1.439
0.9	1.643
0.95	1,960
0.99	2.576
0.999	3.290

Long-term monthly monitoring of indicators allows expanding statistical analysis to spectral analysis with the construction of a histogram of the distribution frequencies of incident probability estimates (Fig. 1).

According to the histogram, the most probable value of the estimated parameter is determined, corresponding to the achieved level. Figure 1 shows an example of a real bimodal distribution of incident probability estimates where the estimated air transport system is characterized by an equal probability of both a frequency of 30 incidents per 100,000 flights (which is quite consistent with the ICAO level of 46 incidents per 100,000 flights) and 60 incidents. per 100,000 flights (which clearly does not correspond to the given level).



Number of incidents per 100,000 flights

Figure 1. Histogram of the relative frequencies of the incident probability distribution in the observed period of operation of the air transport system

The given methodological approach extends to the assessment of indicators of direct measurement. When indirectly measuring indicators, for example, when estimating the probability of a catastrophe for the entire set of aviation events that have taken place [8], the accuracy and reliability of the estimates obtained is determined by the method of indirect measurements.

The most common approach to assessing the level of an aircraft operator's safety level is through an average value, using a sequence of current values of the "number of incidents per 100,000 hours" indicator. In the general case, there are values of some indicator obtained from the facts of aviation events for equal periods of time.

To assess the current level in a state (region), ICAO recommends using the five-year moving average method [14].

A simple moving average t, at some discrete moment (determined by averaging the past current values of the indicator y, over a certain number of observation periods n (smoothing factor) up to the current moment.

A simple moving average is used in the case of stationarity of the series, as the simplest ("traditional") method of short-term forecasting, while it is assumed that the calculated value of m reflects the expected value of the indicator in the future, i.e. is considered a prediction [4].

In table 2 shows the values for smoothing coefficients from 2 to 5.

Table 2.

Smoothing factor (n)	Square deviation (5 „)
2	2557
3	1749
4	2039
5	2293

From the data of Table 2 it can be seen that for the annual sample of K_i in a large airline, the moving average has the smallest deviation with a smoothing coefficient n = 3.

It should be noted that the simple moving average method in the task of monitoring and identifying trends in the dynamics of the level has a significant drawback, which consists in the inevitable delay of the average values of the indicator relative to its current values - for any smoothing coefficient n. In some cases, smoothing (filtering) using simple moving average turns out to be so significant that the development trend is manifested only in the most general form, and individual factual data important for analysis disappear as a result of smoothing (averaging) fluctuations or bends in the trend [5]. Moreover, as the practice of statistical evaluation shows, after smoothing, some fluctuations can change their sign, i.e. instead of a convex section on the trend, a concave section on the line of a simple moving average is obtained, and vice versa.

So, for example, in the case of a one-time significant jump in the level, the indicator of a simple moving average will be equally "noisy" during n time periods of the smoothing interval (in the variant recommended by ICAO - 5 years). Therefore, when assessing the level (frequency of rare events), it is more acceptable to use the weighted moving average indicator, in which more recent data are taken into account with more weight than old ones.

Estimation of the degree of deviation of the values of the linearly weighted moving average V,. from the values of the indicator y_1 for the year (for a certain period) with a given smoothing coefficient n = 2...5, performed by the least squares method.

The evaluation results are given in table 3.

Table 3.

Smoothing factor	Square deviation
2	777
3	1445
4	1607
5	1794

Comparative analysis of the data given in table 2 and table 3 shows that for any smoothing coefficient, the dynamics of the time series is best reflected by the weighted moving average.

The calculation of the moving average is a simple and accessible operation for the aircraft operator, which, however, transforms the dynamic series to a greater extent than it seems at first glance [9]: if before smoothing the levels of the series were independent, then after this transformation, successive calculated levels (in within the smoothing interval) are somewhat dependent on each other. In turn, the relationship of levels can, when smoothing out significant random fluctuations, lead to an undesirable effect. The resulting trend is characterized by periodicity (insignificant cyclicity of development compared to the initial random fluctuations), while in reality it was not (the Slutsky effect) [10].

In order to increase the reliability of estimating the level, taking into account the requirements of the Global Plan for [5], it is advisable to supplement the Method for monitoring indicators in an airline [1], as well as the procedure for forming an acceptable level of in commercial aviation, by smoothing the current values parameters according to the method of linearly weighted moving average.

Thus, assessing the current level using the linearly weighted moving average method should be preferred both at the corporate and state (regional) levels.

The stated methodological approach applies to indicators that reflect the frequency of aviation events, but does not apply to indicators such as "aircraft event flight" and "number of flights performed per aviation event", since in the absence of these events at least at one time stage of observation, there is uncertainty type "infinity", which significantly complicates or excludes the use of the apparatus of probability theory and mathematical statistics.

In modern conditions, characterized by an increase in the fleet of aircraft and an increase in the number of types of aircraft in operation, the problem of training flight personnel with the required qualifications has become aggravated in the leading airlines.

Naturally, for any airline, intensive growth, accompanied by the development of new types of aircraft for the airline, new routes and airfields, is a well-known accident risk factor mainly in terms of the “Human Factor”, and out of almost 80% of accidents and disasters, on average, 25- 30% [2].

(According to other data, the share of erroneous actions of flight personnel among the causes of accidents reaches 70% or more [3]). Internationally, it is recognized that at least three of four incidents are the result of errors admitted by apparently healthy individuals with proper qualifications [6].

In the context of crisis phenomena, the problem in commercial aviation is exacerbated by the forced desire of operators to achieve maximum efficiency in the flight operation of air transport. An obligatory, but the most difficult condition for the prevention of accidents is the training of pilots of the appropriate professional level while reducing the time and costs associated with training, commissioning, professional growth, including admission to flights on new types of aircraft, when appointing aircraft commanders, instructors, etc. To some extent, the solution of commercial problems periodically conflicts with the provision of the required level of BP, since the risk of an aviation event increases as a result of insufficient professional training, which causes flight parameters to go beyond operational limits.

When determining the professional level of a pilot (the degree of his compliance with the required level of safety in terms of the “Crew” factor), a specific decision is made on the basis of a subjective assessment of the degree of readiness of the pilot for solo flights (or for instructor work). The use of the functionality of on-board means of recording flight information, hardware and software for processing, including express analysis, contributes to an increase in the objectivity of assessing the quality of piloting in each individual flight. It is natural to determine the achieved professional level based on the total number of flights performed, which differ from one another in the degree of complexity and, consequently, in the degree of potential success (danger), i.e. an appropriate database should be maintained.

When quantifying and predicting the level in a corporate SMS, the greatest difficulty is estimating the probability of an accident by the “Crew” group of factors due to the significant dependence of this parameter on the functional reliability of pilots, i.e. on the quality of piloting. One of the most significant characteristics of piloting quality is the probability of piloting without going beyond the operating limits.

Flight parameters that are subject to operational restrictions are obligatorily recorded in the onboard data storage devices. The subject to processing and analysis in at least 90% of flights. Modern hardware and software for processing makes it possible to accumulate in the database the extreme values of flight parameters obtained by express analysis, including those for which operational restrictions have been introduced. Thus, it seems possible to estimate the probability of piloting parameters going beyond the operational limits - based on the total number of flights performed by each aircraft commander (pilot).

5. Conclusions

Thus, it is possible to draw the following conclusions:

1) the air transport system, as a control object, corresponds to all the signs of a complex dynamic system, the assessment of the state of which requires a systematic approach.

2) a dynamic and multifactorial property, is evaluated by relative indicators characterizing it with a high level of uncertainty and variability, which have deterministic and stochastic components.

3) the assessment of the level in addition to the random component of the error, contains a systematic dynamic error due to ongoing changes, both as a result of regular changes and as a result of targeted actions to minimize the risk of an accident.

4) the greatest reliability of estimating the current level using the moving average technique is achieved by using a linearly weighted moving average.

5) the smoothing coefficient is subject to optimization taking into account the scale of the estimated system. For large airlines, when assessing on a monthly basis by the frequency of incidents, the coefficient $n = 3$ is optimal.

6) to assess the degree of compliance / non-compliance with an acceptable level, the most common and accessible indicator is the assessment of the frequency (probability) of accidents,

calculated from the totality of aviation events that have taken place, starting from incidents, taking into account their causal factors.

7) during evaluating indicators, the reliability and accuracy of the values obtained are subject to calculation.

Список використаної літератури

1. Ruban I., Smelyakov K., Bolohova N. "Method of neural network recognition of ground-based air objects". Proceedings of 2018 IEEE 9th International Conference on Dependable Systems, Services and Technologies, DESSERT 2018. P. 589 – 592.

2. Sumtsov D., Osiievskyi S., Lebediev V. "Development of a method for the experimental estimation of multimedia data flow rate in a computer network". Eastern-European Journal of Enterprise Technologies, Volume 2, Issue 2-92, 2018. P. 56 – 64.

3. Mistry D., Modi P., Deokule K., Patel A., Patki H., Abuzaghleh O. "Network traffic measurement and analysis". 2016 IEEE Long Island Systems, Applications and Technology Conference (LISAT).

4. Tkachov V., Tokariev V., Radchenko V., Lebediev V. "The Problem of Big Data Transmission in the Mobile "Multi-Copter – Sensor Network" System". Control, Navigation and Communication Systems. 2017, Issue 2. P. 154 – 157.

5. Pavlenko M., Timochko A., Korolyuk N., Gusak M. "Hybrid model of knowledge for situation recognition in airspace". Automatic Control and Computer Sciences, Volume 48, Issue 5, 2014. P. 257 – 263.

6. Gonzales R.C., Woods R.E. "Digital image processing" Prentice Inc. Upper Saddle River, New Jersey, 2002. 779 p.

7. Прэтт У. Цифровая обработка изображений: в 2 т.; пер. с англ. Москва: Мир, 1985. 736 с.

8. Миано Дж. Форматы и алгоритмы сжатия изображений в действии: пер. с англ. Москва: Триумф, 2003. 336 с.

9. Захарченко М.В., Гаджиєв М.М., Басов В.Є., Мартинова О.М. та ін. Системи передавання даних. Т.1: Завадостійке кодування: підручник. Одеса: Фенікс, 2009. 406 с.

10. Korchynskii V.V., Kildishev V.I., Osadchuk E.A. "The increase of transmission protection based on multiplexing of timer signal constructions". Наукові праці ОНАЗ, Одеса: ОНАЗ, 2018. №1. С. 93 – 97.

11. Barabash O., Dakhno N., Shevchenko H., Sobchuk V. "Integro-Differential Models of Decision Support Systems for Controlling Unmanned Aerial Vehicles on the Basis of Modified Gradient Method". 2018 IEEE 5th International Conference on Methods and Systems of Navigation and Motion Control (MSNMC). 16-18 October, National Aviation University, 2018. Kyiv, Ukraine. P. 94 – 97.

12. Обідін Д.М., Барабаш О.В. Ознаки та критерії функціональної стійкості інтелектуалізованої системи автоматичного управління польотом літака. Системи озброєння і військова техніка. 2012. № 1 (29). С. 133 – 136.

13. Tuyrin V., Barabash O., Openko P., Sachuk I., Dudush A. "Informational Support System for Technical State Control of Military Equipment". Proceedings of 2017 IEEE 4th International Conference "Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD)", October 17-19, 2017, Kyiv, Ukraine. P. 242 – 244.

14. Захарченко Н.В., Гордейчук В.В., Севастеев Е.А. Увеличение информационной емкости найквистового элемента при передаче двусимвольных ансамблей таймерными сигналами. Сучасні інформаційні технології у сфері безпеки та оборони. № 2(26). 2016. С. 21 – 26.

15. Tyurin, V., Martyniuk, O., Mirnenko, V., Open'ko, P., Korenivska, I. "General Approach to Counter Unmanned Aerial Vehicles". 2019 IEEE 5th International Conference Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD). 2019. P. 75 – 78.

References

1. Ruban I., Smelyakov K., Bolohova N. (2018), "Method of neural network recognition of ground-based air objects". Proceedings of 2018 IEEE 9th International Conference on Dependable Systems, Services and Technologies, DESSERT 2018. P. 589 – 592.

2. Sumtsov D., Osiievskyi S., Lebediev V. (2018), "Development of a method for the experimental estimation of multimedia data flow rate in a computer network". Eastern-European Journal of Enterprise Technologies, Volume 2, Issue 2-92. P. 56 – 64.

3. Mistry D., Modi P., Deokule K., Patel A., Patki H., Abuzaghleh O. (2016), "Network traffic measurement and analysis". 2016 IEEE Long Island Systems, Applications and Technology Conference (LISAT).

4. Tkachov V., Tokariev V., Radchenko V., Lebediev V. (2017), "The Problem of Big Data Transmission in the Mobile "Multi-Copter – Sensor Network" System". Control, Navigation and Communication Systems, Issue 2. P. 154 – 157.

5. Pavlenko M., Timochko A., Korolyuk N., Gusak M. (2014), "Hybrid model of knowledge for situation recognition in airspace". Automatic Control and Computer Sciences, Volume 48, Issue 5. P. 257 – 263.

6. Gonzales R.C., Woods R.E. (2002), "Digital image processing" Prentice Inc. Upper Saddle River, New Jersey, 779 p.

7. Prett U. (1985), "Digital Image Processing": 2 volums. Moskva: Mir, 736 p.

8. Miano Dzh. (2003), "Image compression formats and algorithms in action", Moskva, Triumf, 336 p.

9. Zakharchenko M.V. Hadzhyyev M.M., Basov V.Y., Martynova O.M. (2009), "Data transmission systems" Vol.1. "Noise-tolerant coding". Odesa, Feniks, 406 p.

10. Korchynskii V.V., Kildishev V.I., Osadchuk E.A. (2018), "The increase of transmission protection based on multiplexing of timer signal constructions". Collection of scientific works ONAZ, Odesa, № 1. P. 93 – 97.

11. Barabash O., Dakhno N., Shevchenko H., Sobchuk V. (2018), "Integro-Differential Models of Decision Support Systems for Controlling Unmanned Aerial Vehicles on the Basis of Modified Gradient Method". 2018 IEEE 5th International Conference on Methods and Systems of Navigation and Motion Control (MSNMC). 16-18 October, National Aviation University, 2018. Kyiv, Ukraine. P. 94 – 97.

12. Obidin D.M., Barabash O.V. (2012), "Signs and criteria of functional stability of the intellectualized system of automatic flight control". Weapons systems and military equipment: Scientific Journal, 1 (29). P. 133 – 136.

13. Tuyrin V., Barabash O., Openko P., Sachuk I., Dudush A. (2017), "Informational Support System for Technical State Control of Military Equipment". Proceedings of 2017 IEEE 4th International Conference "Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD)", October 17-19, 2017, Kyiv, Ukraine, National Aviation University. P. 242 – 244.

14. Zakharchenko N.V., Hordeychuk V.V., Sevasteev E.A. (2016), "Increasing the information capacity of the Nyquist element when transmitting two-symbol ensembles with timer signals" Modern Information Technologies in the Sphere of Security and Defence, 2 (26). P. 21 – 26.

15. Tyurin, V., Martyniuk, O., Mirnenko, V., Open'ko, P., Korenivska, I. (2019), "General Approach to Counter Unmanned Aerial Vehicles". 2019 IEEE 5th International Conference Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD). P. 75 – 78.