FORECASTING AND ESTIMATING THE INTENSITY OF AIRCRAFT FLOWS DURING PEAK HOURS INTO THE AIR TRAFFIC CONTROL SYSTEM

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Annotation. One of the conditions for flight safety in the maintenance of air traffic is a restriction on the intensity of the air flow of aircraft entering the ATC sector, on the route section, at the intersection of routes, at the airfield. Such a restriction is key both in the planning of air traffic and in solving the problem of the organization of airspace. The intensity of the aircraft flow during peak hours is an argument for a large number of indicators of the effectiveness of the organization of airspace in the ATC system, such as the congestion of ATC sectors and the frequency of conflict situations at the points of convergence and intersection of routes. Therefore, the accuracy of the intensity assessment has a direct impact on the accuracy of the assessment of the effectiveness of the organization of airspace.

Keywords: flight safety, efficiency of processes in ATS systems, intensity of aircraft flows, forecasting of intensity of flows, assessment of intensity of flows

Evaluation of the effectiveness of processes in ATS systems can be carried out using a quantitative measure – an efficiency indicator. With a wide variety of processes in ATC systems, it is difficult to establish a single measure of efficiency for the system as a whole, therefore, different indicators and related efficiency measures are used for all processes that are essentially different in their physical nature. Such indicators can be quantitative characteristics (Table 1). When comparing systems and individual processes should have a unified approach to assessing their effectiveness. A simple way to generate indicators is to compare them with the requirements, for example, of that part of the terms of reference directly related to this (evaluated, optimized) process. In most cases, it is possible to write out a number of specific requirements, the fulfillment of which determines the quality of the process. Quantitative characteristics in the air traffic control system

Table 1 Quantitative characteristics in the air traffic control system

Quantitative characteristics of the external environment	Quantitative characteristics of aircraft flows	In-system quantitative characteristics	Performance indicators of the ATC system

•Temperature (t°) •Pressure (P0) •Wind (U, δ,Ubok) •Runway condition (Kcc) •Lvid •*Type of runway •It •Characteristics of dangerous weather events •Characteristics of the ornithological situation	••Interval of motion (τ, I) •Intensity (λ) •Velocity (W) Density (n)	•*Workload () •Driving time () •Runway occupancy (TVPP) •Formed landing interval (x) •Delay time (Δtzad, y) •Frequency (probability) of leaving for the second circle (Ro) •Dispatcher workload (Kzan) •Frequency of the collision Comrade (E)	•Throughput capacity (μ) •Regularity of flights (p) •Indicators of economic efficiency of flights (Q) •Indicators of field safety (P)

The intensity estimate is the average number of aircraft crossing a given boundary.

Disadvantages of the direct method:

1. Large error with a small number of measurements.
2. The difficulty of predicting intensity for years ahead.
3. The inability to account for changes in intensity during observations.

A mathematical model for indirect estimation of the expected intensity of aircraft flows during peak hours. The unevenness of the sun on the day of the month and peak hours.

The intensity estimate is the average number of aircraft crossing a given boundary.

The data is available only for the month as a whole. This method is based on the application of the mathematical model of Kupin Vladimir Vasilyevich:

$$\begin{cases} S = \dfrac{H}{D} \cdot M \\ \lambda = \dfrac{h}{T_{раб}} \cdot S \end{cases}$$

+ (add) M* = (k)l * M

M* - the predicted number of serviced aircraft in the peak month

It is possible to predict the expected M * per month in the ATC zone if we know the coefficient of annual increase in the intensity of flights.

l – forecast period (number of years)

12. Estimation of the average time of aircraft movement in the ATS sector.

Lk the length of the route for the k-th flow of the aircraft.

Wi average speed of each type of aircraft.

$T^{(S)}_{k=}\frac{L(S)k}{L\,k} * T_k$	Calculation of the flight time of the aircraft in the k-th flow of the god sector. All L are measured
$T_{k=}\sum_{k=1}^{m} Cik * Tik$	Calculation of the time that spends EVERYTHING on the flight in the k-th stream, where all types Sun mixed up
$T_{ik}=\frac{Lk}{Wi}$	Calculation of the flight time of the aircraft type in the k-th stream
$C_{ik}=\frac{Mik}{Mk}$	Calculation of the weight coefficient of each k-type in each k-th stream.

N	The expected (average) number of aircraft simultaneously under the control of thedispatcher during rush hour in the entire zone. It's the same workload.
$N^{(s)}$	The expected (average) number of aircraft simultaneously under the control of the dispatcher during peak hours in the bom sector
M	Total number of aircraft per month peak in the zone
M_k	Number of aircraft in the peak month that flew along the route of the k-th stream
T	Average flight time (maintenance). How long will the sun stay in the k-th stream of the new type of sun
i	The number of the ATS sector. Do not confuse the ATS sector with the entire zone.
(S)	Sector - part of the zone
m	Number of flows in the sector. For example there are only 20 threads
n	Total number of types
k	The sequence number of the stream. For example, the 3rd of the 20th
мью	The standard of throughput. Calculated in other sections by different methods
$L_k^{(s)}$	The length of the k-th stream in the S-th sector
C_{ik}	The coefficient of the specific number of the whole type in the A-th stream
W_i	The average speed of the Horn type of aircraft

Estimation of the expected intensity of the flow of aircraft entering the ATS sectors during peak hours.

To assess the effectiveness of the organization of schemes and routes of aircraft movement, as well as the workload of ATC sectors, the values of the expected intensity λk of each k-th aircraft flow according to the list of Table 1 during peak hours are necessary.

$$q_k = \frac{M_k}{M} \quad (3)$$

Estimate the weight coefficients of each sun stream:

Mk - the total number of flights per month peak of all types of aircraft of the k-th stream;

M is the total number of aircraft flights serviced in the analyzed ATC zone during the peak month;

qk is the weight coefficient of the k-th aircraft flow in the analyzed ATC zone.

Then we estimate the expected number of serviced aircraft in the ATC zone per peak day:

$$S = \frac{H}{Д} * M \quad (4)$$

D – number of days in a month (30 days);

H is the coefficient of uneven distribution of the number of aircraft serviced by the day of the month (for the typical variant H = 1,2);

M is the total amount of the number of serviced aircraft in the peak month in the analyzed zone.

To estimate the expected intensity of the total flow of aircraft entering the ATC zone during peak hours, the following formula is used:

$$\lambda = \frac{h}{T_{раб}} S \quad (5)$$

where Trab is the operating time of the ATC Center during which flights are performed in the ATC zone (for a typical Trab variant = 24 hours);

h is the coefficient of uneven distribution of the number of serviced aircraft by the hours of the day (h = 2.15 because S ≥190 aircraft/day).

Now we estimate the expected intensity of each individual aircraft flow during peak hours:

$$\lambda_k = q_k \cdot \lambda \quad (6)$$

Parameter S is the number of aircraft serviced per day, is determined absolutely accurately and therefore the accuracy of the CPSH estimate is entirely determined by the accuracy of the parameter p estimate. If we consider a situation where we can assume that St; " S = const, then we can write an expression for an unbiased estimate of the maximum likelihood of the parameter p [67,109]: n T n T " , = 1./=1 /=1.,=1 p = B = — rist nTS (=i Lip value) (3.12) for the binomial distribution defined, jnTp(p-p) as — -, is asymptotically normal with parameters (0,1). The boundaries of the confidence interval with the confidence coefficient /? the roots of the quadratic equation [108,109] will be: (STn + a2p)x2 -{2STnp + a2p)x + STnp2 =0, (3.21) 114 in which ar is determined from condition (3.16) as a =arg0 (y J , where F(x) = —=e 2dt. 4in o With increasing n, the error in determining the boundaries of the confidence interval of the estimate of p in this way tends to zero. If we denote the roots of equation (3.21) by p and p 2, then for sufficiently large n, the interval p , p 2) and will correspond to the confidence interval within which the true value of the parameter /? will be located with the confidence coefficient p. If p is an estimate of the parameter p, then, based on (2.8) b = p, i.e. the accuracy of the estimate B is determined by the accuracy of the estimate p. Further, if /7, and p2 are respectively the lower and upper bounds of the confidence interval, within which the true value of the parameter / can be found with a certain confidence coefficient (probability)?, then the values Bx = px and b2 = p2 will correspond to the lower and upper bounds of the confidence interval, within which the true value of the parameter B of the mathematical model can be located with the same confidence coefficient (2.6).

One of the main tasks of the rational division of airspace is to compare alternative options in order to choose the best one. Such a comparison can be made using the indicator /, reflecting the principle of equal strength [19,23,62,71,73]: I=Nmax-Nmin, (4.48) where N Min and N min are the maximum and minimum values of the ATC sector congestion indicators of the considered variant of airspace division. The best option is considered to be the division of airspace in which the indicator / takes a minimum value. The indicator of the workload of each ATC sector is determined according to the expression (1.1): t k = \ where t is the number of route sections in the ATC sector; Lic, Tic are the corresponding values of the intensity of aircraft flows and the average passage time by each aircraft of the k-th section of the i-th ATC sector. In practice, we have to deal with estimates of N (the indicator of the workload of ATC sectors, the accuracy of which depends on the accuracy of estimates of the Xic intensity of aircraft flows during peak hours.

In this case, it is necessary to have an idea of the accuracy with which they are determined, on which the probabilities of true and false solutions depend, i.e. the probability that the choice of the best option is carried out correctly (rist) and the probability that the option chosen as the best one is not actually such (RST), where/?isya,+ p,=1 [112].

Using such numerical characteristics of a random variable as variance and standard deviation as indicators of estimation accuracy, the following expressions can be obtained: D[lj]=D[NJmax\D[-\.Njmin]=D[NJmax (-l)2 D[Njmin\D[Njmax\D[Njmin].

These expressions are derived based on the assumption that the random variables N max and Nmin are independent and uncorrelated. In the process of comparing the options for dividing the airspace, there may be situations when there are several alternative options with similar values of the estimates of the corresponding indicators / . Then, if the accuracy of their determination is not high enough, there may be an overlap of confidence intervals of estimates / and the decision on finding the best option for dividing the airspace will become difficult.

Such a problem can be solved by using an indirect method of estimating the intensity of aircraft flows during peak hours, which allows to significantly increase the accuracy of the assessment of indicators / and thereby provide the opportunity to compare alternative options for dividing the airspace to choose the best one.

As an example, we can consider the process of solving the problem of rational division of the airspace of the responsibility zone of the Krasnoyarsk RC EC ATM. As a result of studies conducted in 1999, it was recommended to divide the specified zone into two sectors. In comparison with the existing organization of airspace, the proposed one provides a more uniform distribution of congestion, taking into account restrictions on permissible values of intensity and congestion.

In the process of solving the task of the OSMD PVVS, it is necessary to analyze the intensity of the main flows of incoming and departing aircraft of the ATC zone under study. Such an analysis is performed according to the schedule of aircraft movement, according to the ADP reports of the airfield in question, or according to the results of the forecast of air traffic volumes. With the existing methodology, the analysis is carried out with reference to the selected corresponding points and broken down by aircraft types for a specific, sufficiently long period of time (year, season or month). All the initial data obtained are summarized in a data recording table for analyzing the intensity of aircraft flows .

Since, in its essence, an indirect method of assessing the intensity — this is a method that allows you to determine the values of the intensity of aircraft flows at the studied peak time interval by the intensity values for longer time intervals, and in the process of analyzing the intensity of the main flows of aircraft when designing the OSMD PVVS, there is already information about the monthly (M) or annual (D) value of the intensity of aircraft flows, it may be appropriate to form a method for analyzing the intensity of aircraft flows during peak hours, allowing the use of these known MiG values.

If we take into account that the number of serviced aircraft in each stream varies from day to day and from month to month, it seems natural to be tied to a specific type of day and a specific type of months. In this case, you will need to use the concepts of peak day and peak month.

Based on the above, for practical application, we can propose the following methodology for preparing initial data to assess the effectiveness of the designed variants of the OSMD PVVS. 1. In the process of analyzing the intensity of the main flows of aircraft in the corresponding column of the data recording table of the intensity of the main flows of aircraft (see Table.26) along with the annual number of incoming and departing aircraft by streams, their number observed in the peak month (Mpic) for each stream is also indicated.

Conclusion. To analyze the real flows of aircraft in the ATC system , a mathematical model of indirect estimation of the intensity of aircraft flows in hours has been developed peak, parametric identification of which is performed by the proposed method of two-level piecewise linear approximation using the maximum likelihood method. Maximum likelihood estimates (6) for the analyzed Poisson and binomial distribution laws turned out to be the same. Moreover, for the proposed mathematical model, it was possible to prove the non-bias of the obtained estimate

even for an arbitrary distribution law of a random value of the number of aircraft during peak hours, if the reference points for piecewise linear approximation are chosen in the way proposed in the dissertation work. This made it possible to expand the application of the proposed method of estimation in the case of intensity analysis at maximum peak hours.

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