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V. O. Tychonova
Student of the Faculty of Transport, Management and Logistics,
National Aviation University
D. V. Medynskyi
Assistant of the Faculty of Transport, Management and Logistics,
National Aviation University

STATEMENT OF THE PROBLEM OF OPTIMIZATION OF PRODUCTION MANAGEMENT IN CASE OF ACCUMULATION OF DELAYED AIRCRAFT

It should be noted, when adopting the economic criterion, the task of determining the absolute amount of costs is not set. The only interesting thing is the change in costs while changing the delayed aircraft queue management parameters. Thus, when solving the problem, it is sufficient to know the relative values, which makes it possible to avoid taking into account only the most significant factors in operational management [1]. Taking into account these circumstances, the mathematical formulation of the problem of determining the optimal release queue for delayed flights with a cluster of aircraft takes the following form:

there is a set of delayed flights

$$M = \{S_1, \dots S_i, \dots S_m\} \tag{1}$$

it is necessary to minimize the objective function

$$\sum_{i=1}^{m} U_1\,(m, z_1) \to min \tag{2}$$

under the restrictions

$$\begin{cases} \tau_i \geq \tau_{normal} \\ Q_j \leq Q_{normal} \end{cases} \tag{3}$$

$$t_{fl.s} = t_{sc.s} \forall\, S \not\subset M \tag{4}$$

$$\begin{cases} t_{fli} \leq t_{cli} - t_{fi}\,, \\ t_{fli} < t_{tri} - t_{fi}\,, \\ t_{fli} \geq t_{opi} - t_{fi}\,, \end{cases} \tag{5}$$

where z_i - delay of the i-flight, $z_i = t_{fli} - t_{sci}$;
t_{fi}- flight time on the i-route;
t_{cli}- closing time of the i-destination airport;
t_{fli} - actual departure time of the aircraft;
t_{sci}- scheduled departure time of the aircraft;
$U_i\ (z_i)$- costs due to delays z_ii-flight;
m - total number of delayed flights at the time of opening of the airport;
τ_{normal} - standard time of pre-flight service;
τ_i-actual time of pre-flight service of the i-flight;
Q_{normal} -standard capacity of this airport;
Q_j- airport capacity at any of the j-moments of release of delayed flights;
t_{tri}-end of working hours of the transit and "foreign" aircraftcrews;
t_{opi}- opening time of the i-destination airport.

Inequality (3) reflects the safety requirements, equation (4) - the requirement of regular release of flights [2] that have not been delayed yet, the system (5) allows you to take into account the restrictions imposed by the situation at the destination airports and the flight time standards of the crews.

To predict future losses, you must have analytical dependence of costs by length of delay, since each service queue and production of the aircraft has its own delay [3].

To obtain the dependence of costs on the duration of the delay, it is necessary to analyze the terms of the costs for the delay of each flight.

The most significant components of cost are:

-cost of downtime of the aircraft;

-the cost of compensation to passengers;

-refund of tickets;

- loss of the operator due to the subsequent late return of the aircraft caused by the delay in departure.

The cost of U_{ci} downtime of the aircraft which is scheduled for the i-flight can be determined by the formula:

$$U_{ci} = C_{ci} Z_{ci}, \tag{6}$$

where C_{ci} - is the cost of the unit of downtime of the aircraft of this type on which the flight is performed [4].

Loss of time for passengers on the i-flight:

$$U_{ni} = C_n N_{ci} \tag{7}$$

where C_n - is the average cost of compensation for moral damage to passengers per unit of downtime. In performed work[100], it is proposed to take the $C_n$which equals to 0.5 c.u./person per hour. N_i - the number of passengers in i-flight.

Losses caused by ticket refunds:

$$U_{wi} = \begin{cases} 0, z_i < z_{0i}, \\ C_{wi} N_i k_{oi}(z_i - z_{0i}), z_i > z_{0i} \end{cases}, \tag{8}$$

whereU_{wi}- is the ticket price for the i-flight;
k_{oi} - is the coefficient that characterizes the intensity of ticket delivery, its value is due to the length of the air route, the presence and frequency of movement of competing modes of transport to the destination;
z_{oi} - the initial period of time during which there is no refund of tickets when a flight is delayed.

The valuesk_{oi} and z_{oi} can be determined by accumulating and processing data on the time of delivery of tickets for a particular flight or by an expert surveyby the relevant airport specialists [5].

The amount of economic losses due to the subsequent late return of the aircraftis advisable to calculate only for those aircraft that will once again be involved in the current SPP.

It can be decomposed into two components:

- compensation for moral damage to passengers of the subsequent flight of this aircraft ;
- refund of tickets to these passengers.

In this case, the formula for determining losses from a late return of the aircraft takes the form:

$$U_{nwi} = \begin{cases} C_{ni} N_i' z_i', z_i' < z_{0i}', \\ C_n N_i' z_i' + C_{wi} N_i' k_{0i}'(z_i - z_{0i}), z_i' > z_{0i} \end{cases}, \tag{9}$$

where N_i', z_i', z_{0i}',C_{wi}, k_{0i}' - are the corresponding parameters of the subsequent flight for this aircraft.

Initially, the hypothesis was accepted that the delay in the release of a flight leads to an increase in the duration of its stay at the release airport [6]. In this regard, the average length of aircraft stay*(θ)* at the destination airport upon arrival the delay we can imagine:

$$\theta = A(S) Z_n + B(S), \tag{10}$$

where $B(S)$ - the average duration of the training aircraft at arrival without delay;
$A(S)$-coefficient of increase of the length of training;
Z_n - delay in arrival to the airport;
S - duration of the stay of aircraft at the airport of destination according to schedule.

Processing of statistical data on the service time of aircraft that arrived late using the least squares method allowed us to obtain an equation of the form:

at *S=70 min.* $\theta = 0.0066\, Z_n + 78.6$ (min);
at *S=75 min.* $\theta = 0.0045\, Z_n + 86.1$ (min);
at *S=80 min.* $\theta = 0.0046\, Z_n + 83.4$ (min).

The coefficient of increase in the average duration of aircraft training, depending on $S - A(S)$, has a very small value. Taking into account the values of time allowances for departure, it can be concluded that the duration of the flight that started with a delay will be almost equal to the duration of the flight performed according to the schedule.

In this case, the mathematical expectation of the delay of the next scheduled flight will be equal to:

$$z_i' = \begin{cases} z_i - T_{pl}, z_i > T_{pl} \\ 0, z_i < T_{pl} \end{cases}, \tag{11}$$

where T_{pl}- is the planned downtime of this basic aircraft between the performed and subsequent flight, according to the flight connection schedule.

Substituting (11) in (9), we get:

$$U_{nwi} = \begin{cases} 0, z_i > T_{pl}, \\ C_{ni}N_i'(z_i - T_{pl}), z_i > T_{pl}, z_i - T_{pl} \le z_{0i} \\ C_{ni}N_i'(z_i - T_{pl}) + C_{wi}N_i'k_{0i}'(z_i - T_{pl} - z_0'), z_i > T_{pl}, z_i - T_{pl} > z_{0i} \end{cases}, \tag{12}$$

In this case, the total losses for the base aircraft will be equal to:

$$U_i = \begin{cases} U_{ci}+U_{ni}, z_i \le z_{0i}, z_i \le T_{pl}, z_i - T_{pl} \le z_{0i}' \\ U_{ci}+U_{ni}+U_{wi}, z_i > z_{0i}, z_i \le T_{pl}, z_i - T_{pl} \le z_{0i}' \\ U_{ci}+U_{ni}+U_{wi}+U_{nvi}, z_i > z_{0i}, z_i > T_{pl}, z_i - T_{pl} \le z_{0i}' \\ U_{ci}+U_{ni}+U_{wi}+U_{nvwi}, z_i > z_{0i}, z_i > T_{pl}, z_i - T_{pl} > z_{0i}' \end{cases} \tag{13}$$

To determine the order of release of delayed flights, it is necessary to proceed from minimizing the total losses from delays in the service queue.

The calculation of total U_{0i} losses for the i-flight must be carried out from the moment of departure, since the company bears losses even when the airport is closed, and this phenomenon cannot be ignored [7].

If graphically represent the economic losses of U_{nwi}, as a function of time delay (Fig. 1.1), we obtain a polyline with three points bending at $z_i = z_{0i}, z_i = T_{pl}, z_i - T_{pl} = z_{0i}'$. First bending due to commencement of delivery of tickets by passengers, the second delay subsequent scheduled docking flight in result of a late return to base; the latter curve is due to the surrender of tickets bypassengers subsequent flight. As shown in figure 1., each flight will have its own polyline curve.

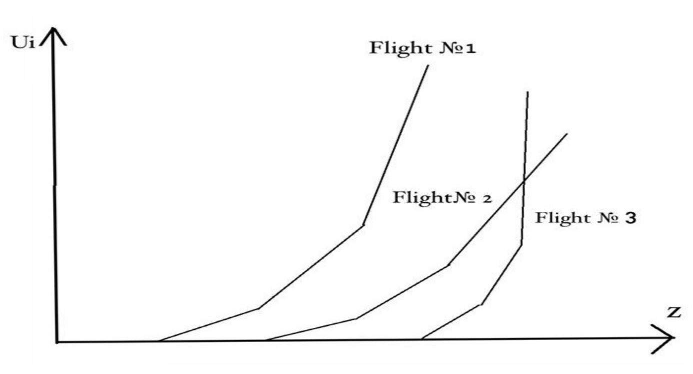

Fig. 1. Dependence of cost losses on the duration of flight delays: z - duration of flight delay, U_i - economic losses.

During the period when the airport is closed and departures are not carried out, the losses of U_{Hi} (damage that the company bears) are unmanageable and unavoidable. Delayed flight release management begins when the first of the delayed flights is prepared. From this point on, losses become manageable. Service for the first of the delayed flights may start earlier, later, or coincide with the opening of the airport [8].

To get a really optimal order, you need to separate losses that can be managed against unavoidable losses. With the growth of delay z, in accordance with the formula (13), the intensity of losses for the i-flight changes. Controlled losses must have the intensity of growth inherent in the i-flight, as illustrated in Fig.2. Based on the above, controlled losses can be determined by the formula:

$$U_i(z) = U_{0i}(z_i) - U_{Hi}(z_i - t_0), \tag{14}$$

where t_0-delay at the time of release of the first of the delayed flights; $U_{0i}(z_i)$- losses since the airport closed, $U_{Hi}(z_i - t_0)$ - losses from the delay of the i-flight at the time of the start of preparation for the flight of the first of the delayed flights.

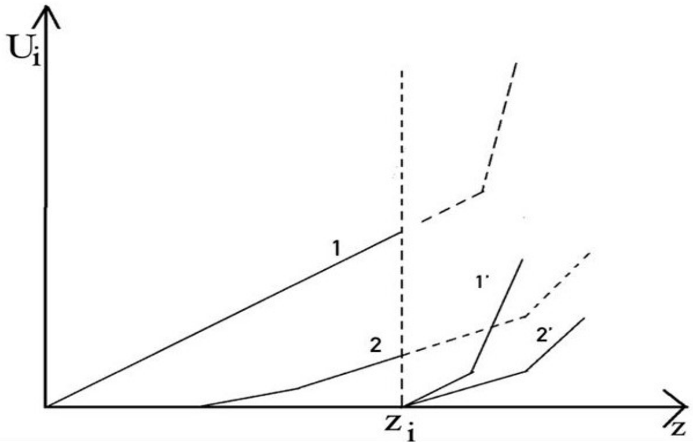

Fig. 2. Dependence of controlled and unavoidable losses on the time of flight release:1, 2-unavoidable losses of the 1st and 2nd flights; 1', 2 ' - controlled losses of the 1st and 2nd flights.

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