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PLANNING ALGORITHMS OF TECHNOLOGICAL PROCESSES OF PREPARATION FOR DEPARTURE AIRCRAFTS

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The problem of planning of technological processes of preflight service of aircrafts is considered. It is proved that planning of technological processes of preflight service of aircrafts in the conditions of limitation of resources demands the decision of two problems: planning of complexes of works as a whole and variations of terms of performance of separate works within their reserve of time. For the named problems necessary conditions and functional dependences are formalized, algorithms of their decision are resulted.

Розглянуто задачу планування технологічних процесів передполітного обслуговування літальних апаратів. Доведено, що планування технологічних процесів передполітного обслуговування літальних апаратів в умовах обмеженості ресурсів вимагає розв’язання двох задач: планування комплексів робіт в цілому та варіювання строків виконання окремих робіт у межах їх резерву часу. Для розв’язання цих задач формалізовано необхідні умови та функціональні залежності. Наведено алгоритми розв’язання задач.

Рассмотрена задача планирования технологических процессов предполетного обслуживания летательных аппаратов. Доказано, что планирование технологических процессов предполетного обслуживания летательных аппаратов в условиях ограниченности ресурсов требует решения двух задач: планирования комплексов работ в целом и варьирования сроков выполнения отдельных работ в пределах их резерва времени. Для решения этих задач формализованы необходимые условия и функциональные зависимости. Приведены алгоритмы решения задач.

Statement of purpose

The problem of planning of technological processes of preflight service dares in situations, when there is a necessity of preparation of group of aircrafts to start during the set moments of time. Preflight services of everyone aircraft are regulated to the typical technological schedules depending on type of aircraft and a kind of its preparation (preflight preparation, preparation for a repeated start, etc.).

Formally technological schedule of preparation aircrafts to start is represented the network model displaying sequence of performance of a certain set of operations.

Any limitation of the resources necessary for performance of technological operations, provided by schedules of preparation aircrafts to start (technical positions on which separate works are performed, direct executors of works and etc.), does a problem of planning of processes of preflight service aircrafts not trivial and multiple, that demands automation of its decision.

The analysis of a condition of a problem

The problem of automation of planning of land service of aircrafts is deeply enough investigated [1–3]. However, the specificity inherent in technological processes of preflight preparation of aircrafts demands working out of special methods, which differ from applied, for example, in civil aviation.

For some half-open interval of time $[t_0, t_1)$ the set I of board numbers of aircrafts, which are necessary for preparing for start, and the moments of time t_i^B of end of preflight service of each of them is set; $t_i^B \in [t_0, t_1)$; $i \in I$. For each aircraft the kind of preflight preparation defining network model of corresponding technological process is specified. Each technological operation provided by network model, the category of its potential executors (experts) is compared.

It is necessary to define terms of performance of works on preparation for start of each i-th aircraft, $i \in I$, in the conditions of limitation of structure of technical positions and direct executors of works.

The considered period of time $[t_0, t_1)$ breaks as λ equals half-open intervals Δt_k, $k = \overline{1, \lambda}$, renumbered by numbers of a natural number, since 1, and standard units of time playing a role. The length of such pieces should be multiple to standard durations of performance of works and technological intervals between them.

Based on real technological schedules of preparation aircrafts to start, length of pieces it is possible to choose equal 30 seconds. Thus time characteristics of technological process of preparation aircrafts to start are defined by number of the half-open interval k_i^H, corresponding to the moment of the beginning of performance of works on i-th aircraft, $i \in I$.

The initial data for the problem decision are:

1) the initial moment of time, associable with the beginning of performance of works on preparation aircrafts to start and set by number k_0 of a half-open interval;

2) set I of board numbers aircrafts, which are necessary for preparing for start;

3) numbers of half-open intervals k_i^B in which it is necessary to finish preparation each i-th aircraft to start; $i \in I$;

4) set J_i of the professional categories participating (according to corresponding technological schedule) in the course of preparation i-th aircraft to start;

5) the technological schedule of preparation i-th aircraft to start, set by set of step-functions:

$$\Phi_i = \{\varphi_{ij}(k); \quad j \in J_i; \quad k = \overline{1, \lambda_i}\},$$

where λ_i is quantity of half-open intervals in time period during which according to the technological schedule preparation i-th SBA to start is carried out;

$\varphi_{ij}(k)$ is the step-function, which values characterize quantity of experts of j-th category necessary for performance of works on preparation i-th aircraft to start on k-th interval under the account.

6) the description of an available manpower (presence of experts of j-th category), represented by set of step-functions

$$F = \{ f_j(k); \quad j \in J; \quad k = \overline{1, \lambda}\},$$

where J are set of the professional categories necessary for performance of the task on preparation all specified aircrafts to start:

$$J = \bigcup_{i \in I} J_i;$$

$f_j(k)$ is the step-function, which values characterize quantity of experts of j-th category, which can be involved in performance of works on preparation specified aircrafts to start on k-th interval of the considered (planned) period of time.

It is supposed that $(\forall i \in I)(\lambda_i \le \lambda)$ as otherwise the task a priori cannot be executed in target dates.

Planning of technological processes of preparation for start of group of aircrafts provides the decision of two primary goals:

– planning of performance of complexes of works on preflight service of group of aircrafts as a whole;

– a variation of terms of performance of separate works within their reserve of time.

Algorithm of the decision of a problem of planning of complexes of works

Preliminary the set I of board numbers of aircrafts, which are necessary for preparing for tart, is ordered in process of increase of the set moments of time t_i^B:

$$t^B_{i_m} \le t^B_{i_{m-1}} \le \ldots \le t^B_{i_\mu} \le \ldots \le t^B_{i_2} \le t^B_{i_1},$$

where m is quantity of such aircraft: $m = |I|$.

To avoid two-level indexation, we will consider that board numbers of specified aircrafts are initially ordered in process of increase of the moments of time of their start. It does not influence in any way program realization of algorithm and results of calculations, but will allow to present the given sequence and the further constructions in more simple form:

$$t^B_m \le t^B_{m-1} \le \ldots \le t^B_i \le \ldots \le t^B_2 \le t^B_1 .$$

Further in a cycle on parameter $i = \overline{1, m}$ following operations are carried out.

1. Gets out next (not considered still) aircraft with a board number $i; 1 \le i \le m$. On a board number i and a current condition of aircraft is defined a kind of the technological schedule Φ_i of its preparation for start.

2. Number of a half-open interval k^B_i to which possesses set time of end of its preparation for start is fixed: $t^B_i \in \Delta t_{k^B_i}$.

3. The subset J_i of the professional categories necessary for performance of works on preparation i-th aircraft to start is defined.

4. The subset of the step-functions describing presence of executors of works (experts), necessary for preparation i-th aircraft for start is formed.

5. In the second (internal) cycle on parameter $j \in J_i$ subtraction of step-functions is consistently made:

$$\delta_{ij}(k) = f^{(i)}_j(k) - \varphi_{ij}(k - k^B_i + \lambda_i);$$

$$k = \overline{k^B_i - \lambda_i + 1, k^B_i},$$

where $\delta_{ij}(k)$ is the step-function, defined in a range of values of discrete argument k from $k^B_i - \lambda_i + 1$ to k^B_i inclusive and characterizing difference between available and necessary (for performance of works on preparation i-th aircraft to start) quantity of experts of j-th category;

$f^{(i)}_j(k)$ is the step-function defined in a range of values of discrete argument k from 1 to λ inclusive and characterizing quantity of experts of j-th category, remained not involved in process of preparation aircrafts to start after consideration of all aircrafts previous of i-th.

By consideration of the first under the account aircraft

$$f^{(1)}_j(k) = f_j(k)$$

for all $j \in J_1$; $k = \overline{1, \lambda}$.

For performance of operation of subtraction of step-functions the third (built in) cycle on parameter k is organized. However, unlike the traditional scheme of the organization of cycles the given cycle provides change of values of parameter k from the top border of a range k^B_i to the bottom border $k^B_i - \lambda_i + 1$ inclusive with negative step -1 (that is, towards decrease of values of a loop variable).

Such approach is caused by that at the given statement of a problem is logical and expedient to make a start from set time of the termination of performance of works on preparation aircrafts to start, instead of from possible (and while uncertain) time of the beginning of this process.

6. For each value of the parameter k changed from k^B_i to $k^B_i - \lambda_i + 1$, the condition is consistently checked:

$$\delta_{ij}(k) \ge 0. \qquad (1)$$

If the condition (1) is carried out for everything $k \in \{k^B_i - \lambda_i + 1, \ldots, k^B_i\}$ after end of all iterations of the third (built in) cycle step function is formed:

$$f^{(i+1)}_j(k) = \begin{cases} f^{(i)}_j(k) - \delta_{ij}(k) \\ \quad \text{for} \quad k \in \{k^B_i - \lambda_i + 1, \ldots, k^B_i\} \\ f^{(i)}_j(k) \\ \quad \text{for} \quad k \in \{1, \ldots, \lambda\} \setminus \{k^B_i - \lambda_i + 1, \ldots, k^B_i\} \end{cases},$$

then the second (internal) cycle for the following parameter $j \in J_i$ is realized.

If the second (internal) cycle is realized for everything $j \in J_i$ transition to the first (external) cycle for the following parameter $i \in I$ is carried out.

If the first cycle is realized for everything $i \in I$ the conclusion of results of the decision of a problem then computing process comes to the end is carried out.

7. If for any value of parameter k the condition (1) is not carried out, it means that on k-th interval of time the necessary quantity of experts of j-th category exceeds available.

In this case following actions are carried out.

The four of target messages is fixed and brought in a special file:

$$\{i', j', k', \delta_{i'j'}(k')\},$$

where i' is board number of aircraft considered at present time;

j' is considered professional category;

k' is number of an interval of time, on which $\delta_{i'j'}(k') < 0$.

This information subsequently (if it will appear what to carry out the put task in target dates it is impossible, and it will be necessary to specify the reason of it) it can be demanded for formation of the target message under the form: «At scheduling on preparation i'-th aircraft to start on an interval of time $\Delta t_{k'}$ shortage of experts of j'-th category in quantity $\delta_{i'j'}(k')$ of the person was found out». Here $\Delta t_{k'}$ – an interval of time corresponding to k' half-open interval.

Number of a half-open interval k_i^B in which it was supposed to finish preparation i-th aircraft to start, decreases on 1 then the second is repeatedly realized (internal, built in) a cycle, since point 5.

The logic of the given action is that. If because of limitation of number of experts it is not possible to prepare aircraft for a start precisely by set time, it is possible to try to begin spadework before the maximum term to avoid "peak" employment of technicians.

Reduction of value k_i^B on 1 can repeatedly be made. The fourth (built in) cycle on the parameter k' which values can change in limits from k_i^B to with λ_i step -1 is for this purpose organized.

The further reduction of value k_i^B is inadmissible, as it will lead to an exit of the moment of the beginning of performance of works on preparation for start i-th aircraft for the bottom border of the considered (planned) period of time.

The first (maximum) value k' of a loop variable at which the condition (1) is satisfied, can be demanded at a conclusion of results of calculations. Therefore it is necessary for fixing in the form of parameter k_i^C to which before the first realization of the fourth (internal, built in) a cycle it is appropriated maximum of possible values: $k_i^C = k_i^B$. If for the minimum value of a loop variable $k' = \lambda_i$ the condition (1) is not carried out, on the screen the message on impossibility of performance of the task with instructions of the reasons is deduced. On it computing process comes to the end. The offered numbering of cycles not absolutely corresponds to logic of algorithm. After all in situations when $\delta_{ij}(k) < 0$, the next value of parameter k_i^C which then acts as the top border of a range of values of parameter k' at first is fixed. Therefore it turns out that the third cycle (on k or k') is built in the fourth (on k_i^C).

Computing process comes to the end in two cases:

– after a binding of technological schedules of preparation of all aircrafts specified in the task, by real time within the set period (positive result);

– after an establishment of the fact of impossibility of performance of works on preparation for start of one of aircraft, specified in the task, within the set period of time (negative result).

The positive result is characterized by following mathematical objects:

– set of numbers of half-open intervals of time $\{k_i^C; i \in I\}$ to which should possess the moments of the termination of performance of works on preparation aircrafts to start;

– a set of step-functions

$$F^{(m)} = \{ f_j^{(m)}(k);\ j \in J;\ k = \overline{1,\lambda}\},$$

where $f_j^{(m)}(k)$ – the step function defined in a range of values of discrete argument k from 1 to λ inclusive and characterizing quantity of experts of j-th category, remained not involved in technological processes of preparation for start of all aircrafts specified in the task.

The set $\{k_i^C; i \in I\}$ allows defining numbers k_i^H of half-open intervals to which should possess the moments t_i^H of the beginning of performance of works on preparation of everyone aircraft to start:

$$k_i^H = k_i^C - \lambda_i + 1;\ t_i^H \in \Delta t_{k_i^H}.$$

On values t_i^H; $i \in I$ and on the basis of technological schedules time parameters of each separate work are calculated.

On the basis of set $F^{(m)}$ is defined set

$$G = \{g_j(k);\ j \in J;\ k = \overline{1,\lambda}\}$$

of step-functions, each of which is defined in a range of values of discrete argument k from 1 to λ inclusive and characterizes quantity of experts of j-th category which should be involved in performance of works on preparation aircrafts to start:

$$g_j(k) = f_j(k) - f_j^{(m)}(k);\ j \in J;\ k = \overline{1,\lambda}.$$

At reception of negative result on the screen the message on impossibility to plan performance of works on preparation for start of all specified in the task aircrafts in the set terms, and also the information concretizing the reasons of such conclusion (listed in point 7 of the given algorithm) is deduced.

Algorithm of a variation of terms of performance of works

The problem of a variation of terms of performance of separate works dares after on some k-th half-open interval of time shortage of experts of j-th category necessary for performance of works on preparation for start i-th aircraft is found out. The fact of shortage of experts is reflected by condition default: $\delta_{ij}(k) \geq 0$.

Let R – set of works which should be executed in the course of preparation of group of aircrafts to start, k_r^H and k_r^K – numbers of half-open intervals to which possess the moments of time of the beginning and the termination of performance of r-th work, $r \in R$, a_r – quantity of the half-open intervals characterizing standard duration of performance of r-th work, b_r – quantity of the half-open intervals defining a reserve of time of r-th work.

The algorithm of a variation of terms of performance of works provides consecutive performance of following actions.

Definition of a subset of the works $R_j(k)$, which are carried out in the course of preparation i-th aircraft to start by experts of j-th category on k-th interval of time:

$$R_j(k) = \{r \in R_j : k_r^H \leq k \leq k_r^K\},$$

where R_j is set of works, which should be carried out in the course of preparation i-th aircraft to start experts of j-th category.

Allocation in $R_j(k)$ subsets of the works $R_j^C(k)$, which terms of performance can be shifted (at the expense of an available reserve) along time axis to the left so that these works came to the end on $(k-1)$-th interval:

$$R_j^C(k) = \{r \in R_j(k) : b_r \geq k_r^K - k + 1\}.$$

Check of potential possibility to eliminate deficiency of experts of j-th category on k-th interval of time by change of terms of performance of works.

If $\left| R_j^C(k) \right| < \left| \delta_{ij}(k) \right|$, such possibility does not exist.

In this case realization of the given algorithm stops.

Otherwise the following point of algorithm is carried out.

The choice of the works, which terms of performance are subject to change.

If $\left| R_j^C(k) \right| = \left| \delta_{ij}(k) \right|$, (to shift to the left along time axis) terms of performance of all works $r \in R_j^C(k)$ are subject to change.

If $\left| R_j^C(k) \right| > \left| \delta_{ij}(k) \right|$, those get out of a subset $R_j^C(k)$ such works $\left| \delta_{ij}(k) \right|$, which to the greatest degree satisfy to the set criterion.

Possible criteria of a choice of works for the subsequent shift (to the left along time axis):

– a minimum of size of shift:

$$\min\{k_r^K - k + 1 \mid r \in R_j^C(k)\} ;$$

– a maximum of a reserve of time:

$$\max\{b_r \mid r \in R_j^C(k)\} ;$$

– a maximum of a reserve of an operating time which remains after change of terms of its performance:

$$\max\{b_r - (k_r^K - k + 1) \mid r \in R_j^C(k)\} .$$

Updating of terms of performance of works

$$r \in \overline{R}_j^C(k) : \ k_r^H = k - a_r ;$$

$$k_r^K = k - 1 ; \ r \in \overline{R}_j^C(k) .$$

Updating of values of a reserve of time of the works, which terms of performance are changed:

$$b_r := b_r - (k_r^K - k + 1) \ ; \ r \in \overline{R}_j^C(k) .$$

Updating of values of a reserve of time of the works previous in the network schedule works $r \in \overline{R}_j^C(k)$, which terms of performance are changed.

On it process of the decision of a problem of a variation of terms of performance of works comes to the end.

Conclusion

It is proved that planning of technological processes of preparation for start of group of aircrafts generally consists of two stages.

On the first of them planning of performance of complexes of works on preflight service of group of aircrafts as a whole is carried out. Terms of the beginning and the termination of performance of all necessary technological operations are as a result established. At the second stage realized in case of deficiency of resources, demanded for timely end of preflight preparation of group of aircrafts to start, is carried out procedure of a variation of terms of performance of separate works within their reserve of time. The considered problems belong to the class of problems of decision-making and, hence, have optimizing character.

Computing experiments have proved that the resulted algorithms allow finding close enough to optimum admissible decisions of the considered problems in all cases, when such decisions objectively exist. However multiple character of a problem of planning of technological processes of preparation for a start of group of aircrafts basing gives the grounds to consider expedient continuation of researches in a direction of working out of the mathematical models focused on application to the decision of listed problems of effective optimizing algorithms, realizing strategy of the directed search of variants.

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