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SOLVING TECHNOLOGICAL PROBLEMS OF FLIGHT SERVICES AT AIRPORT INVOLVING COMPOSITE MATERIALS

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Inadequate information support and dispatch of the execution of individual operations of the technological process (especially the repair of composite structures) of aircraft preparation for a flight is one of the reasons for delays. In this regard, there is a need to study the management processes of airport services that ensure the performance of individual technological operations in the preparation of aircraft for departure. This problem belongs to the class of multi-criteria problems, which is solved using simulation modelling. The model is represented by an interconnected set of modules, each of which is associated with a separate technological operation of the general technological process, i.e. the technological process is divided into separate technological operations. The links of individual blocks of the model reflect the information and technological links of a real set of technological operations of flight preparation for departure and are represented by the synthesising algorithm of the simulation model.

Keywords: aircraft, flights, simulation modelling, algorithms, composite materials, technological processes

INTRODUCTION

An analysis of statistics on the regularity of aircraft departures at airports demonstrates the fact that the current operational management system for servicing flights at many airports has a number of shortcomings that lead to disruption of the regularity of aircraft departures from the airport [1, 2].

The problem of long aircraft downtime also arises from the repair of non-composite components, modules, parts or structural elements. Composites in many branches [3, 4] and especially in the aerospace industry [5, 6] are widely used due to their incomparable performance with other structural materials. Their repair takes a long time, is expensive, and is also very complex. This happens quite often at airports, causing flight delays.

The main reasons for the imperfection of individual technological operations of the passenger handling process are the following [7]:

- the methods for selecting alternatives for deciding on the use of flight maintenance facilities (MF) within one technological operation,
- the operational control of technological operations,
- the dispatch of the execution of a set of flight handling operations, etc.

Considering the above-mentioned, there is a need to examine the management processes of airport services to achieve the maximum regularity of flights. The task responds to the class of multi-criteria tasks [8, 9]. Solving the mentioned task in the general form using classical analysis methods is almost impossible due to its complexity and the achieved results might be erroneous if the model is simplified. Therefore, we will use simulation modelling as an approach [10, 11]. Simulation modelling is an effective tool for solving multi-criteria tasks related to mass distribution systems.

While developing a simulation model based on decomposition, we will use the modular construction technique [12]. We will divide the technological process of servicing flights into a number of local tasks to solve them separately.

Increasingly more studies are appearing on the use of not only mobile expert systems and the estimation of critical failure rates for a polymer component, or information management technologies. However, the literature barely analyses the monitoring process of repair technologies for structures, or polymer matrix components [13-16] owing to their specificity. Such particular tasks are the technological operations (e.g. the probability of crack development and impact on the service life of polymer matrix components in composite structures – Fig. 1) with detailed algorithms for their construction (referring to the layering of the laminate).

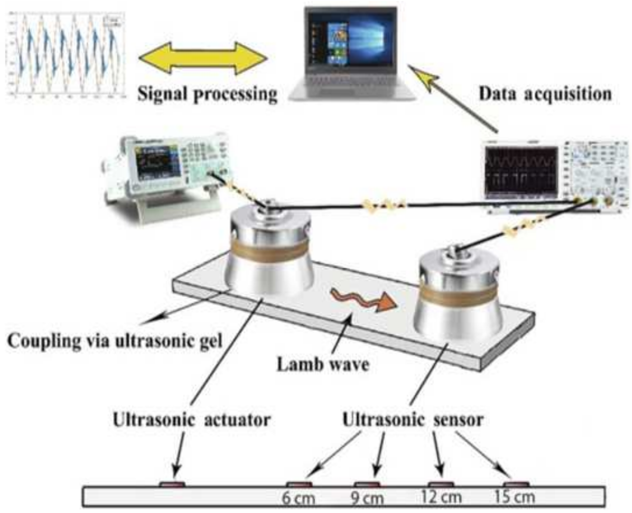

Fig. 1. Diagram of ultrasonic wave propagation test set-up for crack detection in $0_2/90_6$ laminate. Number below each sensor indicates corresponding distance between sensors and ultrasonic actuator [17]

The repair module (bearing in mind the specifics) of the component or structure under investigation for crack propagation and density classification in a polymer matrix composite [17] will use the Lamb wave ultrasonic propagation method, whose performance can however be altered by changing the sequence of ply stacking in the laminate.

Thus, the resulting simulation model is presented in the form of a set of modules with detailed algorithms for their construction, which is the basis for the development of automated control programs. The article presents the results of the development of an approach to solving the multi-criteria problem of improving the operational management of technological processes of flight service at the airport. For this purpose, the technological process of aircraft preparation for departure was divided into a number of local tasks (modules). An appropriate algorithm was developed for each of them, on the basis of which a computer program was created. The methodology of the mathematical modelling of one of the modules – the selection of a parking space for an aircraft arriving at the airport – is presented.

OPERATIONAL PLANNING OF TECHNOLOGICAL PROCESSES AT THE AIRPORT

The operational management of airport activities can be considered to be a solution to a number of complex management tasks related to commercial activities, aircraft technical maintenance, the operation of special vehicles, logistics, the supply of fuel and lubricants, aircraft traffic control, airfield service, weather support, the dispatch of airport operations, etc. [18]. The basis for the operational activities of airport services is the daily flight plan (DFP), which is a set of planned initial, final and transit flights passing through the airport [19]. According to IATA recommendations, a modern flight support strategy should be based on the use of strategic flight schedules in airport operations, which contain the planned date and time of flight arrival and departure 6 months prior to the flight day [20]. Nevertheless, they do not provide information about possible flight delays and cancellations on the day of performance. Aircraft flight delays lead to unavoidable consequences such as an unpleasant passenger experience, and economic losses estimated at $50 billion in the global economy in 2019 [21]. At present, the main way of delivering the DFP to the performers is automated, although there are airports where this procedure remains traditional (manual). In any case, the main disadvantage of the existing operational planning system is that the set of strategies for the use of flight facilities (FF) is based on a lack of coordination of work on the part of production and dispatch services (PDS). One of the most important phases of airport operational management, which affects flight delays, is the operational planning of the technological processes of aircraft preparation for a flight (e.g. repair of non-composite components or structures).

TECHNOLOGICAL PROCESS OF AIRCRAFT PREPARATION FOR A FLIGHT

The technological process of aircraft preparation for a flight for the most general case – a transit flight – includes the following main technological operations: landing of the aircraft; towing of the aircraft to the parking place; disembarkation of passengers from the aircraft; delivery of passengers to the terminal building; unloading-loading of mail, unloading of baggage, unloading-loading of cargo, refuelling, aircraft maintenance; registration of passengers and baggage: accumulation of passengers and inspection of baggage; loading of on-board food; loading of baggage; delivery of passengers to the aircraft; boarding of passengers; towing of the aircraft; starting of engines; take-off of the aircraft (end of flight service – Fig. 2). Inadequate information support and dispatch of individual operations of the technological process of aircraft preparation for a flight are among the reasons for flight delays. The analysis of the statistics of aircraft departure delays at airports has shown that one of the significant causes of delays is the deviation of the time of execution of certain technological operations of aircraft preparation for a flight to the established standards [22].

In this regard, there is a need to study the management processes of airport services that ensure the execution of certain technological operations in the preparation of aircraft for departure. This problem belongs to the class of multicriteria problems [23]. The solution to such problems by methods of classical analysis is practically impossible because of the need to search for extreme values over discrete multisets, the presence of nondifferentiable functions, and the presence of constraints. If we simplify the model by introducing significant assumptions, we can obtain results that are very sensitive to errors [24].

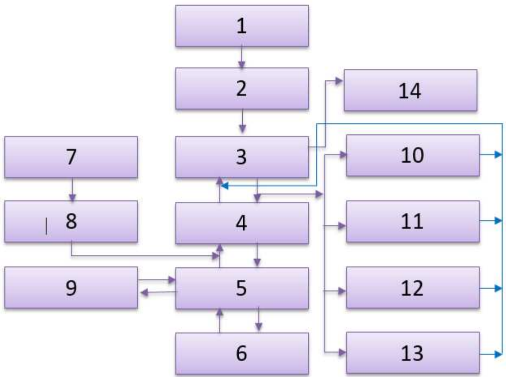

Fig. 2. Diagram of technological process of servicing transit flight: 1 – aircraft parking determination, 2 – aircraft technician, 3 – tractor, 4 – gangway, 5 – passenger boarding, 6 – bus, 7 – passenger registration, 8 – storage, 9 – tanker, 10 – cargo, 11 – mail, 12 – catering, 13 – luggage, 14 – starting engines

APPROACH TO MODELLING TECHNOLOGICAL PROCESS OF AIRCRAFT PREPARATION FOR DEPARTURE AT AIRPORT AS A MULTI-CRITERIA PROBLEM

Analysis of possibility of solving general problem using existing methods

When solving multi-criteria problems, two approaches of criteria ranking are most commonly used:

1. **Expert method.** As a result, the ranks of criteria that characterise the quality of operational management in preparing an aircraft for a flight are established:
   a. regularity criterion
   b. criterion of costs, characterising the number of resources required
   c. criterion of strategy of their use
   d. social criterion.

   As is known, the application of the expert method is a rather complicated procedure requiring labour-intensive preparation and the accuracy of the obtained results depends on many conditions and circumstances [25], and obviously, to solve the investigated problem in which the result is estimated in several minutes is not the best option.
2. **Synthesis of a global criterion** that is some function of the local criteria [26] when applying it [27, 28], it is necessary to construct a global scalar criterion as a sum of local ones taken with their weighting coefficients (scalarisation, convolution of criteria). The effectiveness of the method depends on the degree of objectivity and accuracy of these constants. There are other approaches to solving the organisational and technological problems of airport operation in the time-of-day interval mentioned in the literature as well:

– application of network models to study the issues of operational aircraft technical maintenance [29],
– solving a general problem by methods of the theory of schedules [30].

Nonetheless, their application does not lack the disadvantages described above.

Based on the above, we will use the methodology of simulation modelling as an approach. For its application, we will combine all the indicators characterizing the technological process into blocks. Each block represents a grouping of homogeneous variables of the technological process:

– input variables
– constants
– controllable parameters
– output parameters.

Let us divide the technological process of aircraft preparation for a flight into a number of local tasks and solve them separately. Such individual tasks will be the technological operations shown in Figure 3.

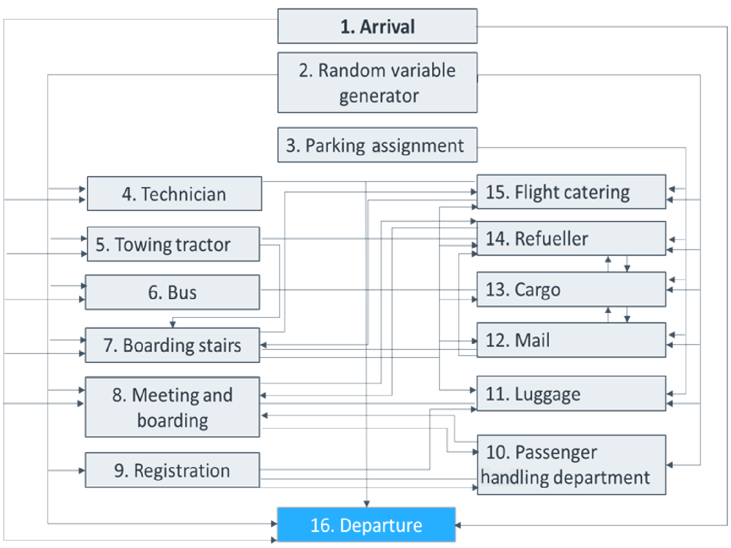

Fig. 3. Scheme of information connections between blocks in simulation model

When developing a simulation model based on division, we will use the modular construction methodology. By combining the indicators characterising the technological process with technological operations, we obtain a set of blocks (modules – Table 1), each of which is described by a certain set of variables presented in groups. Each block solves certain tasks. The formalised description of each block by an admissible input and a known internal state allows us to obtain calculated data on the output.

Based on the condition that the service of an individual flight is performed in strict accordance with the order of technological operations included in the technological process, we obtain the scheme of information links between the blocks of the simulation model in Figure 3. In accordance with this scheme, the "Arrival" block (1) forms the initial data for the model operation based on the schedule of aircraft movement at the airport and flight service facilities, taking into account the aircraft types. In the "Parking assignment" block (3) the task of aircraft arrangement after their arrival is solved. The tasks of determining the number of necessary facilities for servicing other technological operations, their operation schedule, etc. are solved by blocks 4-14, "Departure" blocks (24, 25) simulate the time of engine start and generate the protocol of the airport model: flight departure delays, regularity values achieved at different threshold values, the table of local delays of technological operations, etc. are calculated.

For illustration, here is the developed algorithm of the "Parking assignment" block.

DETERMINATION OF PARKING AREAS FOR AIRCRAFT ARRIVING AT THE AIRPORT

General approach

All the aircraft arriving at and departing from the airport during the day, according to the DFP, are serviced at designated areas of the airport, called parking areas. At most Class I airports, the parking areas are arranged in groups to accommodate aircraft of the same type. During normal airport operations, each arriving aircraft is placed in a free parking area according to its type. When solving this problem within the framework of the general flight service management model to obtain integral characteristics of apron parking utilisation, cases when aircraft can move from one apron parking lot to another in the course of service are not considered. Then, considering only those aprons where short-term servicing is performed, we introduce the following designations:

TN_r – time of occupying the parking lot by flight r;
TK_r – moment of time of leaving the parking lot by flight r.

The duration of occupancy time j of the aircraft parking area by flight r will be equal to the short-term parking time at the airport.

$$T_r^j = TK_r^j - TN_r^j \tag{1}$$

The above ratio will also be true when one aircraft parked at a parking area performs two different flights (usually one of which is the initial flight and the other is the final flight), provided for in one daily flight plan or in the daily flight plans of consecutive days.

For this purpose, it is enough to introduce a fictitious moment of time of leaving the parking lot by flight r, equal to the time of occupying this parking lot by the next flight $r + I$

$$TK_r^j = TN_{r+1}^j \tag{2}$$

In the event of a "failure", when the number of aircraft received in a relatively limited period of time exceeds the airport's capacity to accommodate aircraft in accordance with the organization of normal operations, it is allowed to accommodate aircraft in parking areas in groups that do not correspond to their types (if these parking areas are of sufficient size) or in a reserve zone. The reserve zone should be defined as a part of the airport area that allows the accommodation and servicing of aircraft. The parking areas in the reserve zone will be considered unfixed, i.e. the location of aircraft here will be determined by the order of their arrival in this zone and the specific situation that caused the necessity to fill it in.

Methodology for solving the parking lot selection problem

Problem Statement. Let each flight served during a day at an airport be characterised by the following: r – flight number; TC_r – type of aircraft performing flight r; TN^j_r TK^j_r – time of occupying and moment of time of leaving parking area j by the aircraft performing flight r.

Each parking lot is characterised by the following:
j – number of the parking spot; TC_j – type of aircraft (identified by board number) positioned in parking spot j.

It is necessary to assign the aircraft occupied on each flight to parking areas in such a way that the airport's total costs for servicing flights during the day are minimised. The problem is solved based on the assumption that the daily flight plan is made taking into account the availability of parking facilities.

When solving the problem at the planning stage, it is impossible to accurately calculate the costs of servicing flights in accordance with the parking assignment made as these costs will depend on the organisation of individual servicing operations, which in turn, is determined by the parking assignment made. Therefore, an approximate estimate of costs is used depending on the amount of work performed in servicing flight r and the "convenience" of their performance when aircraft of this area are positioned in parking area j.

The total cost of servicing flight r at parking lot j shall be specified as f_{rj}. These costs can be divided into two groups, the first of which depends on the number of the parking area – a_j, the second – on the flight number – b_r;

$$f_{rj} = a_j + b_r \quad (3)$$

Under this condition, inseparable costs C_{rj} are omitted, i.e.

$$f_{rj} = a_j + b_r + C_{rj} \quad (4)$$

The mathematical model of the problem formulated above has the following form:

$$\sum_{r=1}^{N} \sum_{j=1}^{KI^3} f_{rj}\,(x) * x_{rj} \rightarrow min \quad (5)$$

where

$$f_{rj}(x) = \begin{cases} 0, \text{if } x_{rj} = 0 \\ a_j + b_r + C_{rj}, X_{rj} > 0 \end{cases} \quad (6)$$

moreover

$$\sum_{rj} x_{rj} = N, X_{rj} \geq 0, X_{rj} = 0\ V\ 1 \quad (7)$$

then

$$\sum_j x_{rj} = 1, \sum_j x_{rj} = m_j \quad (8)$$

where m_j is the multiplicity of utilisation of the parking lot.

The condition of positioning aircraft of a certain type in the parking lots assigned for this type is as follows:

$$X_{rj} = \begin{cases} 0, \text{if } TC_r - Z_{TC} \neq 0 \\ 1, \text{if } TC_r - Z_{TC} = 0 \end{cases} \quad (9)$$

where: TC_r – aircraft type indicator; Z_{tc} – indicator of the parking area assigned to a particular type of aircraft.

The solution to such a nonlinear integer problem can be obtained by discrete programming methods. However, one can assume that $C_{rj} \ll f_{rj}$ and disregard them. Such a division allows one, firstly, to organise the parking lots by ascending costs a_j, i.e. to consider that

$$a_1 \leq a_2 \leq \cdots \leq a_m \quad (10)$$

and secondly, to state that the optimal parking assignment does not directly depend on the costs of b_r.

$$F = \sum_r \sum_j f_{rj} x_{rj} = \sum_r \sum_j (a_j + b_j) x_{rj} =$$
$$= \sum_j a_j \sum_r x_{rj} + \sum_r b_r \sum_j x_{rj} = \quad (11)$$
$$\sum_j a_j m_j + \sum_r b_r = \sum_{j=1}^{m} a_j m_j + \overline{B}$$

where $\overline{B}$ is a constant value that does not depend on the parking lot assignment plan. On this basis, we propose a heuristic algorithm to obtain an acceptable solution (Fig. 4). As the calculations show, the deviation from the optimum when using this algorithm is no more than 10 % [24].

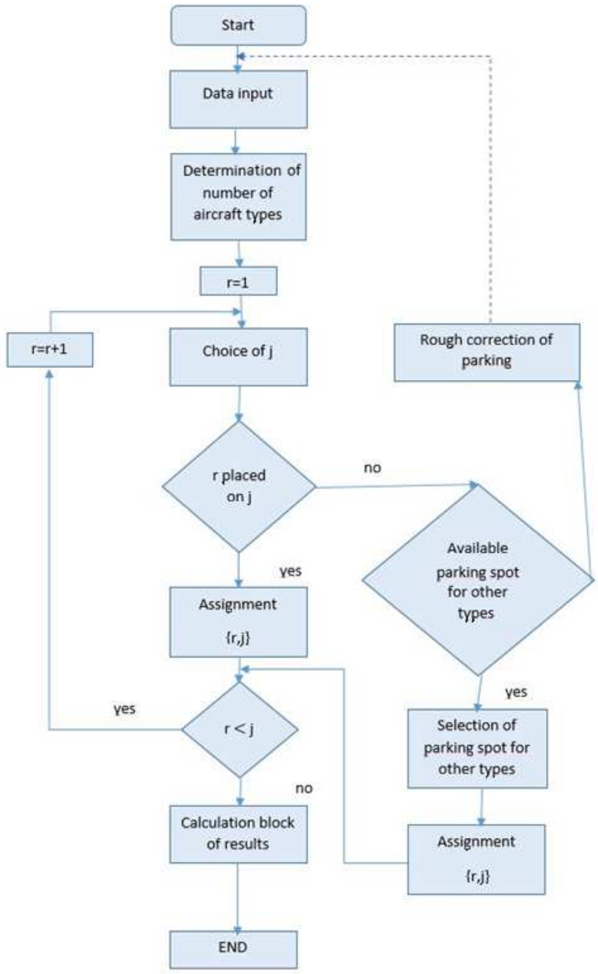

Fig. 4. Block diagram of algorithm of module for solving parking lot selection problem

Thus, the solution to the described problem in the normal operation of the airport is reduced to determining the parking place for the aircraft to be accepted in the group of parking places corresponding to its type. In a "failure" situation, the solution to the problem results in finding a parking place among all the available ones (suitable for positioning in accordance with the type), or indicating the need to fill the reserve zone, or calculating the time of delays in receiving flights at the airport due to the lack of parking places.

The authors have also developed algorithms for other blocks of the simulation model, which are not presented in the current article owing to the large volume.

CONCLUSIONS

1. The present article introduces an approach to the study of a multicriteria problem, which is the preparation of aircraft for departure at an airport. The application of exact methods in solving such problems is difficult because it entails the introduction of significant assumptions that do not allow the construction of mathematical models adequate enough to the

actual reality. Bearing in mind that repairs are carried out on a large number of components, subassemblies or structures made of polymer matrix components (composites), the models implemented by the algorithms may not be acceptable for real-time systems as the required counted time may significantly exceed the required system response time.

2. It is advisable to solve this problem with the help of simulation modelling, which makes it possible to reproduce real processes of passenger service technology (and repairs not only to composite structures) under different strategies of using the means of service, to assess the efficiency of their use under different strategies and options for organising technological processes at the airport, to identify the impact of different solutions on the value of the selected criteria. The proposed simulation model is an interconnected set of modules, each of which is associated with a separate technological operation of the overall technological process, i.e. there is a division of the technological process into separate technological operations. The links of individual blocks of the model reflect the information and technological links of a real set of technological operations of flight preparation for departure and are represented by the synthesising algorithm of the simulation model.
3. When developing algorithms for individual technological operations of the process of aircraft preparation for departure, it is proposed to use heuristic methods that significantly simplify their application in automated airport management systems without reducing the compliance of the model with the execution of real tasks of technological operations.

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