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IMPROVING THE SAFETY AND REGULARITY OF AIRLINE FLIGHTS ON BASE OF IMPROVING TECHNICAL OPERATIONS PROCESSES OF AIRCRAFT

Summary of the Doctoral Thesis

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RTU Press
Rīga 2016

Vaivads A. Improving the Safety and Regularity of Airline Flights on Base of Improving Technical Operations Processes of Aircraft. Summary of Doctoral Thesis. Riga: RTU Press, 2016. – 40 p.

Printed according to decision of RTU Aeronautics Institute Promotion Council "RTU P-22" 2016. Decision of 10 March, Munutes No. 1 / 2016

ESF
EIROPAS SOCIĀLAIS FONDS

EIROPAS SAVIENĪBA

This work has been supported by the European Social Fund within the project "Support for implementation of doctoral studies at RTU".

ISBN

DOKTORAL THESIS
PROMOTED FOR RECEIVING DOCTORAL DEGREE IN ENGINEERING SCIENCES IN RIGA TECHNICAL UNIVERSITY

Doctoral thesis for receiving Doctoral degree in engineering sciences is publically defended on 04.07. 2016, at 12-30 Riga Technical University, Faculty of Transport and Mechanical Engineering,1A Lomonosova Street, building k-1, Auditorim 218

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Engineering Sciences, is my own and does not contain any unacknowledged material from any source. I confirm that the present Doctoral Thesis has not been submitted to any other university for the promotion to any other scientific degree.

Andris Vaivads …………………………….(Signature)

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The Doctoral Thesis has been written in English. The Doctoral Thesis comprises an introduction, 4 chapters, conclusions, bibliography with 98 reference sources and 5 appendices. It has been illustrated by 19 figures and 27 tables. The total volume of the present Doctoral Thesis is 122 pages.

CONTENT

GENERAL DESCRIPTION OF THE PRESENT RESEARCH

Topicality of the Research

Safety and regularity of flight are an important indicator of the quality performance of an airline operations are safety and regularity of flight. Delays in arrival and departure of flights where the carrier involves in additional costs associated with penalties for passengers, shippers and consignees, as well as the airport if flight delays are caused by the airline. These entail direct and indirect losses and consequently it reduces operation productivity and capital productivity of the airline. From time to time each airline has some probability to have flight delays due to different unexpected situations (failures to comply with company procedures). Flight delays have both economic and social consequences. Unexpected conditions cause flight delays and lead to aviolation of regularity. Flight delays will increase aircraft time on the ground and thus will have impact on the next scheduled flights and coordinated work of the production units of the airline and in some cases other airlines. They also have an important social influence. Therefore, to ensure the quality of functioning of the airlines and enhance competitiveness appropriate structure of the organization is required, which would be the most effective. The growing number of passengers can be guaranteed only by high safety, regularity, punctuality and service culture. In the current market, the cost of the provided services is also having big impact. For the aircrafts, aircraft maintenance is considered one of the major components of operations. The process of aircraft maintenance has a significant impact on the security level and intensity of operations, reduces costs and generally the cost of air travel. Therefore, one of the major topics in civil aviation is the issue of efficiency of aircraft maintenance. Over the years this problem has become more complicated because of the complexity of different aircraft types, the increase in the usage of the aircrafts, operation of the combination of the old and new types of aircraft. At the same, time each airline is aiming to reduce aircraft time spent on the ground in order to increase the time of their effective application. This can lead to reduction of the quality of aircraft maintenance, which entails an increase in the failures of the aircrafts and their systems, increasing costs and reducing the level of safety and regularity. Preparation of the aircraft for the flights involves different departments and services of the airline and airport. The analysis of their performed work shows that a significant place is taken by the procedures which are required for operative solutions, especially in non-standard and emergency situations. Non-effective solutions during working conditions and work with existing technologies will inevitably lead to violation of organizational and technological regulations and reduce their work quality. Therefore, development and implementation in real life at the a particular airline of scientific methods to ensuring internal communication services involved in the processes of aircraft maintenance can increase their efficiency, which will lead to improving efficiency of the movement of ground-based services, which consequently can reduce financial, material and human resource losses and improve profitability and efficiency of the airline.

This determines relevance of the chosen theme of the dissertation. In this dissertation we study the problem of improving safety, efficiency and maintenance of a stable and steady position of an airline in air transport services market by improving the production processes and reducing the losses due to technical condition of the aircraft.

Aim of Dissertation

a) To improve efficiency of aircraft operational costs and increase potential utilization by minimizing the time spent by aircraft during various conditions on the ground.

b) Development of process models of the aircraft during aircraft maintenance in airlines on the ground and in flight by keeping and maintaining the necessary level of reliability and technical condition to ensure a high level of safety and regularity during increased usage of the aircraft by keeping at the minimum labor and maintenance costs.

Tasks of the Research

a) Development of mathematical models of minimization of the temporary expenditures of the location of aircraft in different conditions on the ground and possible conditions in flight during technical failures and their identification.

b) Development of the optimum system for control of the preparation of an aircraft for departure with delays due to technical reasons.

c) Development of procedures and algorithms of operational process management of aircraft maintenance on the basis of the developed models.
d) Applying and testing of the procedures in one of the airlines.

Methods of the Research

General and special scientific cognition methods used in research process, such as analysis, synthesis, evaluation expertise, methods of observation, comparison, economic analysis methods and systems analysis.

Theoretical and methodological basis for problems solving are:

a) Fundamental research works on the theory of management, decision-making and management systems effectiveness, marketing methods, logistics, analysis and synthesis methods, economic and mathematical models;
b) Structure, functioning and technical maintenance basis for aircraft systematic analysis;
c) Semiotic and mathematical modeling of basic maintenance technological processes;
d) Research recommendations of ICAO documents, IATA, EASA, statistics and documents of CAA and A/S airBaltic used as the information base.

Scientific Novelty

a) Mathematical models have been developed to minimize time spent by aircraft on the ground in different conditions based on which processes of aircraft maintenance in the airline in different combinations have been modeled. Models have been tested and adopted for aircraft maintenance processes of B737 in an airline.
b) Mathematical model for identification of conditions of aircraft in flight during components failure has been developed. Based on this the level of severity of failures of different functional systems and their components and their interrelation with the level of flight safety have been determined. The model was tested based on reliability data of AVRO-RJ70 aircrafts during operations at airBaltic for the period 1995-2005.
c) Mathematical model of the management system of preparation an aircraft for the flight has been developed. The model was tested at Line maintenance organization with respect to distribution of aviation technical personnel. It was used in solving technical problems

which reduced expenses for aircraft maintenance by reducing flight delays due to technical reasons.

Research Results

a) The developed mathematical models of minimization of spending during location of the aircraft in different conditions on the ground make it possible to simulate the processes of aircraft maintenance on certain aircrafts in the airline in different variations.
b) The models are used in connection with the processes of aircraft maintenance of 13 aircrafts B -737 of a real airline. As a result, the types of distributions of the real condition of aircraft as the random variable of $x_r = \{x_r\}$ and their statistical characteristics have been obtained, which gives the possibility to perform the planned work to keep the required level of planning of the necessary resources for maintenance.
c) By using the semiotic models of the condition of aircraft in flight and multilevel structure the mathematical model of the interrelation of the failures of the aircraft components and conditions of aircraft in flight has been developed.
d) On its basis, the procedures of management of the technical conditions of the aircraft during operation and evaluation of conditions of the aircraft in case of failures of aircraft components in flight have been developed.
e) The developed method has been tested based on statistics of the technical failures of aircraft AVRO-RJ70 during operation at airBaltic for the period of 1995-2005.
f) The mathematical model of the optimum organizational structure of control system of maintenance with the preparation of aircraft for the flight has been developed.
g) Procedure has been tested in the airline maintenance organization in the area of distribution of maintenance personnel and tasks performed by them between different levels of control in case if aircraft failure is due to technical reasons. By doing this it was possible to decrease the company’s economic losses due to flight delays.

Practical Significance of the Research

The application of the developed models in the real life of the airline maintenance organization attested their effectiveness:

a) The number of nonconformities related to maintenance staff during aircraft maintenance has been substantially reduced.

b) The effectiveness of different levels of the system of control of aircraft maintenance processes has become more clear and transparent.

c) Due to improvement of the technological process of aircraft maintenance and increase in the qualification of maintenance personal labor requirement has decreased.

d) The reliability of the functional systems and their components has increased.

e) Possibility to perform additional flight if needed has been obtained.

Defended Theses

The author of the work defends:

1. Mathematical models of technical operation processes for a particular aircraft fleet and airline maintenance.
2. Mathematical model “aircraft state” in flight and assessment of the aircraft in case of failure.
3. Mathematical model of optimal control system of aircraft preparation for flight in case of delay due to technical reasons.
4. The principles of organization of aircraft maintenance in unforeseen circumstances.

Approval of Research Results

International scientific conferences:

Basic provisions of the thesis presented at international scientific conferences held in Poland, Lithuania, Russia and Latvia:

1) Conference on scientific aspects concerning operation of manned and unmanned aerial vehicles. Deblin, Poland May 20-22, 2015, “Reducing the risk of layovers for technical reasons on the basis of improving the organization of aircraft maintenance”, A. Vaivads.

2) 11th International Conference Vilnius, 15-17 October 2014, “Streamline the system of a maintenance management of aircraft in the airline”, A. Vaivads.
3) International Scientific Conference ENGINEERING AND TRANSPORT SERVICES – 2014 RIA, Riga, Latvia 24-25. 07.2014, “Improving safety and regularity of flights in airline company based on aircraft' technical operation processes improvements”, A. Vaivads, A. Paničs, V. Šestakovs.
4) International Scientific Conference ENGINEERING AND TRANSPORT SERVICES - 2014 RIA, Riga, Latvia 24-25. 07.2014, „Связь профессионально важных качеств авиационно-технического персонала и безопасности полетов”, O. Gorbachev, A. Vaivads, V. Shestakov.
5) 4th International Conference on Scientific Aspects of Unmanned Aerial Vehicle, Kielce, Poland, May 5-7, 2010, “Оценка уровня безопасности полетов при отказах авиационной техники”, A. Vaivads, V. Shestakov, L.Vinogradov.
6) 4th International Conference on Scientific Aspects of Unmanned Aerial Vehicle, Kielce, Poland, May 5-7, 2010, “Search and Emergency – Rescue Organization and Realization at Aviation Accidents in the Airport Responsibility Area”, A. Vaivads, V.Shestakov, L. Vinogradov.
7) Riga Technical University 49th International Scientific Conference, Latvia, Riga, October 13-15, 2009. „Pilota kļūdas analīze”, A. Vaivads, N. Dreimanis, V. Šestakovs.
8) Riga Technical University 49th International Scientific Conference, Latvia, Riga, October 13-15, 2009, „Gaisa kuģu lidojumu drošības aviātehnikās atteikumos ietekme”, A. Vaivads.
9) International Scientific Conference “Civil Aviation on the Current Stage of Development Science, Technology and Society - Moscow, MGTU CA, April 22-23, 2008, “*Quality* management system”, A. Vaivads.
10) Riga Technical University 49th International Scientific Conference, Latvia, Riga, October 13-15, 2009. „Pilota kļūdas analīze”, A. Vaivads, N. Dreimanis, V. Šestakovs.

Research results have been published in:

1) Ruta Bogdane, Andris Vaivads, Dejan Dencic Evaluation of Management System Effectiveness in the Preparation of the Aircraft for Flight in Faulty Conditions.//Transport and Aerospace Engineering.-2015.- Volume 2, Issue 1, -13-18 p. ISSN (Online) 2255-9876, DOI: 10.1515/tae-2015-0002.

2) Vaivads A, Gorbačovs O, Šestakovs V. Связь профессионально важных качеств авиационно-технического персонала и безопасности полетов. // Proceedings of the International Scientific Conference "ENGINEERING AND TRANSPORT SERVICES - 2014".-.2014. Riga, Latvia , -12-19 p.- –ISBN 978-9984-9996-5-4.

3) Vaivads A, Shestakov V. Streamline the system of a maintenance management of aircraft in the airline.// Eleventh International Conference 15-17 October 2014, Vilnius, Lithuania. -32-33.

4) Vaivads A., Paničs A., Šestakovs V. Improving Safety and Regularity of Flights in Airline Company based on Aircraft Technical Operation Processes Improvements.// Proceedings of the International Scientific Conference ENGINEERING AND TRANSPORT SERVICES – 2014. Riga, Latvia.-2014, - 5-12 p. –ISBN 978-9984-9996-5-4.

5) Vaivads A., Shestakov V., Vinogradov L. Оценка уровня безопасности полетов при отказах авиационной техники. //RTU 4th International Conference on Scientific Aspects of Unmanned Aerial Vehicle, Kielce, Poland, May 5-7, 2010, - 602-609 pp. -ISBN 978-83-88592-70-6.

6) Vaivads A., Shestakov V., L.Vinogradov Search and Emergency – Recue Organization and Realization at Aviation Accidents in the Airport Responsibility Area. // RTU 4th International Conference on Scientific Aspects of Unmanned Aerial Vehicle, Kielce, Poland, May 5-7, 2010, - 616-619 pp.- ISBN 978-83-88592-70-6.

7) Vaivads A. Quality management system. // International Scientific Conference Civil Aviation on the Current Stage of Development Science, Technology and Society - Moscow, MGTU CA, April 22-23, 2008 p.78-80.

8) Vaivads A. Gaisa kuģu lidojumu drošības aviātehnikās atteikumos ietekme.// 49th International Scientific Conference, Latvia, Riga, October 13-15, 2009. - p. 23-27.

The Structure of the Doctoral Thesis

The Doctoral Thesis contains the Announcement Introduction, 4 Chapters, Conclusion, 4 appendices, 18 figures, 15 tables, and 96 entries in the bibliography. The volume of the Thesis is 141 pages.

Chapters 1 - Analysis of theory and practice of aircraft maintenance organization. The first chapter presents an analysis of the current condition of the theory and practice of organization of technical operation of aircrafts.

Chapters 2 – Development of the mathematical models of the processes of the aircraft maintenance in airline. The chapter covers the development of mathematical models of technical operations in regard to a particular aircraft fleet and specific types of aircraft maintenance in the airline.

Chapters 3 – Development of the mathematical model which characterizes the condition of aircraft in flight. In the third chapter the model of the conditions of aircraft in flight and management of the technical condition of the aircraft during aircraft maintenance and methods of evaluations due to failure aviation equipment in flight are developed.

Chapters 4 – Development of the mathematical model of the optimum system for control of the preparation of aircraft for the flight. In the fourth chapter on the basis of the results received in the previous chapters a model of optimal process control system preparation of the aircraft for the flight with delays due to technical reasons is developed.

Appendices. Appendices contain statistical data used in the modeling process of aircraft maintenance methods and their implementation in the airline.

THE SCOPE OF RESEARCH

Chapter 1. Analysis of theory and practice of aircraft maintenance organization

This chapter introduces the role and importance of airline aircraft maintenance in ensuring safety and regularity at high competitive economic results of its activity. These issues have always been of utmost importance for civil aviation airlines. Currently, these issues have become even more topical. This is primarily due to the fact that airlines have to survive in the tough competition in the current market. The process of preparing the airplane for the next flight is a strictly regulated sequence of operations combined under a single term called “Ground Handling” and “Pre-Flight and Departure Inspections”. Failure on any of the operations can lead to flight delay. The current level of flight and ground operations of aircraft provides high regularity of operations in all regions of the globe. For the punctuality level the target of 90% is normally set and regularity indicator of departures – 99%. However, aircraft operators differ by ownership, performance of aircraft used, air traffic flow, and so on. And these circumstances explain big variation in performance indicators of the airlines, primarily safety and regularity of flights. Reasons for departure delays of the flights may be different and some of them are related to technical reasons. As show by analyses, all technical reasons can be divided in two groups. The first is related to the reliability of aircraft and methods of ensuring airworthiness and the second is connected to the organizational issues of the maintenance management. The ratio of these reasons varies for different airlines but acting together they lead to the fact that at the moment in the majority of airlines in there is no unified method for elimination of failures and malfunctions of aircraft which can provide high dispatch reliability – the reliability of flight schedules. Our analysis leads to the conclusion that for the individual airline in today's conditions the problems of efficiency modeling development of the processes of management control systems in the aircraft maintenance organizations remain insufficiently studied, in particular the systems of preparing aircraft for the flight and especially during aircraft failure situations. Such important condition for the effectiveness of process management as an organizational-technological definition of aircraft technical operation process is also underrepresented. To solve this radical problem the airline may follow the path of a comprehensive approach, i.e. to introduce scientific methods of aircraft technical operation processes management organization into practice for an individual airline. These issues are addressed in subsequent chapters of this dissertation. Technical operations are a complex dynamic process including but not limited to preparation of the aircraft for the flight, management of the functional systems, selection and maintenance of the most advantageous modes of engines operation in flight, aircraft maintenance and repair on the ground. The questions of operational management of production processes are reviewed in many papers by Russian and Western authors. Some of them are based on the principle of optimal management strategies while others on the principle of the separation of planning and management. M.J. Kroes, Harry Kinnison, Tariq Siddiqui, Manoj S. Patankar, Dale Crane, A. Volkov, V. Zabaluev, I.S. Golubev, A. Kondratyev, V. Kulik, V. Kurilo, V. Novikov, E. Pinaem, A.Sarkisyan A. Chervonyi and others dedicated their works to the development of scientific bases of production management in civil aviation and the use of socio-economic models in the management of aviation enterprise. Practical methods for implementation of the results in this area allowed getting a fairly complete picture of the effectiveness of maintenance and repair systems of civil aircraft in the end of the 1980s – early 1990s. Successful works of Thomas C. Lawton, John Sheehan, Krajewski Lee, Weiss Howard J., Gdalevitch Manny, M.Andronov, E.Barzilovich, V.Vorobiev, M.Gromov, S.Daletskii, V.Dedkov, O.Derkach, A.Itskovich, V.Karasev, V.Kirin, I.Kirpichiov, A.Mayorov, A.Petrov, R.Sakach, V.Sennik, N.Smirnov, S.Stepanov, Yu.Chinyuchin, V.Frolov, V.Shapkin and others should be noted in these areas of aircraft technical operations process research. The particular note in this contribution to the development of this area was brought by Latvian scientists. By the 1970s a scientific school dedicated to the questions of organization, management and efficiency of the processes of aircraft maintenance was established at the RCAEI (РКИИГА) Chair of Aircraft and Engines Technical Maintenance led by A. Pugachev. This school has always occupied a leading position in the general system of the development of a scientific approach and the establishment of the technical operation of aircraft and aircraft engines as the scientific field. It has made a significant contribution to the development of scientific approaches to the system of aircraft maintenance and repair. Depending on the research tasks the process of aircraft technical operation can be represented as arbitrarily large number of its conditions and their sequential change in the time in accordance with the chosen strategy. This whole set of aircraft conditions on the ground can be divided into several groups: the condition of waiting for the maintenance, condition of undergoing maintenance and condition of waiting for the flight. Studies show that each aircraft state corresponds to a certain distribution of the random variable of its stay in the given condition. Knowledge of the laws of the time distribution for aircraft staying in various conditions makes it possible to assess the effectiveness of modes of technical operation and to develop measures for improving it. In the 1960-70s the possibility of net planning application in the aircraft maintenance was widely explored. Net charts of the maintenance process allow describing the logical sequence of separate tasks execution to assess the duration of the full range of maintenance tasks to define a set of tasks that do not allow earlier implementation of the entire package. Net management is a set of computational methods, organizational and monitoring activities for planning and managing of the work package using the net model. A fragment of a network graph is shown in Fig. 1.

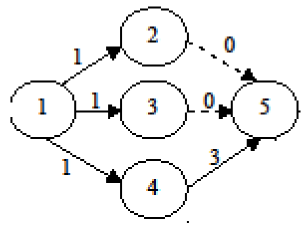


Figure 1. Fragments of the net model.

Net models of the work package execution process have a number of drawbacks which include the difficulties of describing different kinds of logical conditions for separate tasks execution possibilities which significantly limits their use.

By the mid-1980s development of a new direction started – application of Petri nets to the aircraft maintenance processes. Models are based on Petri nets unlike the other net models allow taking into account not only logical sequence of tasks execution but also resources involved by means of Petri net marking. It is possible to include in Petri net positions corresponding to the fact of “resource stand by”. The concept of Petri nets is a clear convenient and effective way to describe processes a fragment of a network graph in Fig. 2.

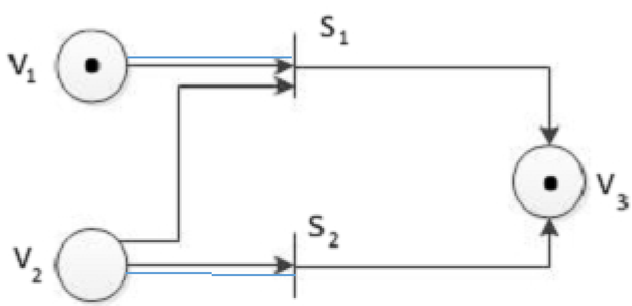


Figure 2. Fragments of Petri net model.

Such models provide wide opportunities for considering a variety of complex logical conditions that occur in the real situation and can be used in the aircraft maintenance management processes and also to carry out their analysis using modern computer technology. The analysis performed allows us to conclude that for the individual airline in today's conditions problems of efficiency model development of process control systems in the aircraft maintenance organizations remain insufficiently studied, in particular during preparing an aircraft for the flight and especially in failure situations. The lack of an integrated approach methodology to the lower level of aircraft maintenance production processes management hierarchy causes some organizational and technical difficulties and significant financial costs. By using modern information technologies the availability of the terminals for the workers by which they can pass information about separate maintenance tasks when completed promotes the given trend to the next level. Based on this we have developed two mathematical models. The first model is based on the laws of the distribution of the random variable of the aircraft being in various conditions on the ground during aircraft maintenance. The second is based on Petri nets for utilizing management of aircraft preparing for the flight.

Chapter 2. Development of the mathematical models of the processes of aircraft maintenance in airline

2.1. Model of technical operation

As mentioned above, the actual process of technical operation of the aircraft is formed by “stitching” of its individual conditions. Then denoting by t_1 the time point corresponding to the beginning of some state of a technical operation and denoting by t_2 its end it will be apparent that the interval $X = t_2 - t_1$ is a duration of the condition. The whole process of technical operation is characterized by a finite set of such conditions. Let us denote by δ_i the “state” of the process, where i - its serial number. We assume that:

a) the change of the technical operation conditions takes place consistently and continuously;

b) transitions from one condition to another are instant.

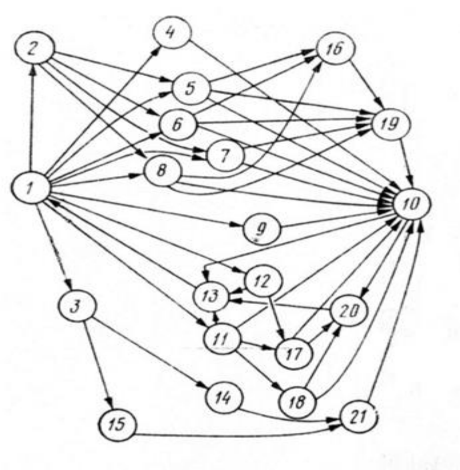
Many studies have shown that the process of technical operation possesses the properties of stationarity and ergodicity. Therefore as quantitative characteristic for transitions we will consider not the time of transition to a neighboring (adjacent) condition but the relative frequencies p_{1k} of aircraft transitions from the i-th condition into the k-th during time interval T_n (e.g. one year) and will obtain the transition matrix $P – || p_{ik} ||$. Transition probabilities p_{ik} to be determined in accordance with the aircraft transition matrix by directly counting the number of aircraft transitions from one state to another and valuating them to unit by the formula:

$$p_{ik} = n_{ik} / n_i \tag{1}$$

This allows determining the absolute frequencies π_i of aircraft getting into the *i*-th state during time interval T_n. Further, one-row frequency table to be calculated:

$$\pi = (\pi_1, \pi_2, ..., \pi_k, ..., \pi_N,) \tag{2}$$

Practically it is convenient to deal with conditions and transitions graph G (see Fig. 1) which is constructed for each type of aircraft based on a matrix of transition probabilities P – ‖ p_{ik} ‖. Let us mark on some plane all the elements of set V of graph G vertexes (Fig.1) and connect the i-th vertex of the V with the k-th vertex of the same set with edge E = (ik) if element (i, k) in P equals one. As a result of this construction we get an unmarked graph of aircraft technical operation. The marking of the edges and vertices of graph G is performed according to the data of transition probability matrix P – ‖ p_{ik} ‖ and a series vector of stationary probabilities π. The union of matrix P – ‖ p_{ik} ‖, vector π and graph G is to be a mathematical model of the aircraft technical operation (Fig.3).

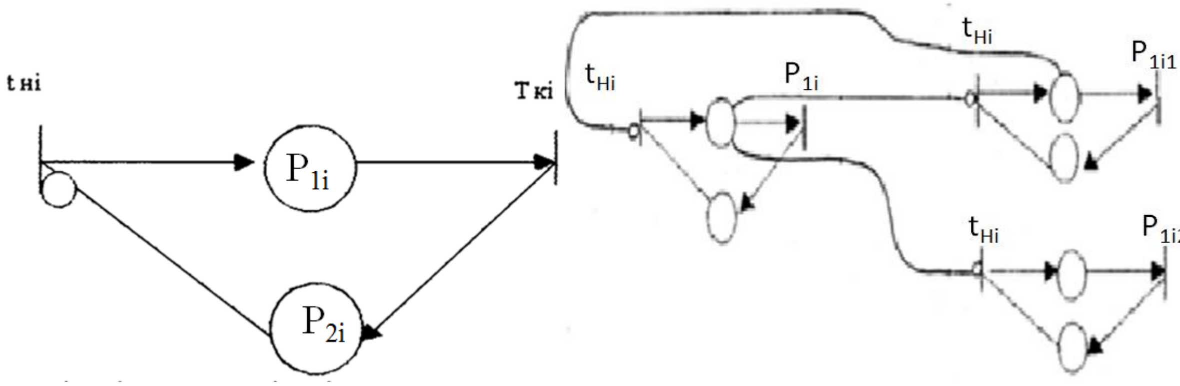


1 - Flight;
2 - Waiting for periodic maintenance;
3 - Waiting for the complex forms of service (repair);
4, 5, 6, 7, 8 - C-check: periodic maintenance in forms C1, C2, C4, C6, C8;
10, 11, 12 - A-check: prompt service in forms A1, A2, A4, A8;
13 - Transit check - provision of departure;
14, 15 - C-check, D-check;
16, 17 – Daily Check – Daily technical inspection (revised on bulletin, troubleshooting);
18 - Waiting for spare parts;
19;20; 21–Preparedness through periodic maintenance, operational, maintenance and repairs, respectively.

Figure 3. Graph of the aircraft condition and its transition process during its technical operation.

2.2. The model of the comprehensive preparation of the aircraft for the flight

Petri net modeling of the process of comprehensive preparation of the aircraft for the flight is reduced to managing transitions indicating the beginning of task execution t_{Hi}, see Fig. 4.



a b

Figure.4. Elements of the Petri net model.

Fig. 4a shows:

tнi – transition, indicating the beginning of the i-th operation;

Tki – transition, indicating the end of i-th operation;

P1i, P2i – events, modeling respectively conditions “i-th operation is carried out”, “i-th operation is done”. Formally, Petri net modeling of the i-th operation is presented as a set:

$$Gri = (Pri, Tri, Fri, \mu o) \tag{3}$$

where: *Pri* – set of the places (positions) of the graph,

$$Pri = \{p1i, p2i\} \tag{4}$$

Tri – set of transitions of the graph, Tri= {tнi, tкi}

Fri – function of incidence;

μo – initial net marking.

Function of incidence introduces inhibitory arcs for those pairs (*p*, *t*) for which its value is equal to 1. Inhibitory arcs connect only places with transitions. In the graph (Fig. 4b) they are depicted ending by circles, not arrows. The inhibitory network transition may fire if each input place associated therewith inhibitory arc (its multiplicity is always 1) has a zero marking. Inhibitory arc in the graph represent the ratio of tasks incompatibility.

Three kinds of works incompatibility *ri* can be used as represented in Figure 2:

a) by the scope of the tasks;
b) by functional (technological) incompatibility;
c) by the technical condition of aircraft systems.

Modelling is carried out by introducing the subset of control positions *Pyi* into the model:

$$\forall t\text{н}i \ \exists Pyi: F(Pyi, t\text{н}i) = 1 \qquad (5)$$

Expression (5) reads as follows: for each initial transition *tнi* there is control position *Pyi* with the function of incidence is equal to 1. A subset of control positions is marked. The marking is determined by expression:

$$\mu(Pyi) = 1 \ fy = fyz \qquad (6)$$

where *fyz* is a given control criterion after calculation of which the marker is placed into position *Pyi*. Expressions (5) and (6) make it possible to manage the process of comprehensive preparation of the aircraft for the flight in accordance with a predetermined criterion for optimal control. Models which are presented in this chapter provide better decisions on how to organize technical operation of the aircraft in an airline. The developed model can also simulate the process for the next calendar period, i.e. to forecast the efficiency of technical operation and to manage it.

2.3. Testing of mathematical models

Fragments of the original data characterizing types of maintenance for Boeing 737 aircraft and standard indicators of their execution under the current maintenance program for this type of aircraft performed during line and base maintenance are presented in Table 1.

Table 1

The number of maintenance forms by type carried in one year time

	YL-B01	**YL-B02**	**YL-B03**	**YL-B04**	**YL-B05**	**YL-B06**	**YL-B07**	**YL-B08**	**YL-B09**	**YL-B10**	**YL-B11**	**YL-B12**	**YL-B13**
PRF FLT	1692	1692	1642	1491	1374	1645	1450	1493	1492	1352	1229	1549	1501
DLY	359	349	354	330	326	348	300	338	307	331	327	340	335
SVC	122	119	120	112	111	117	105	118	104	113	110	116	116
WLY	53	52	54	48	49	51	45	52	46	50	50	52	50
A1	13	12	12	11	10	13	10	11	11	11	11	12	12
A2	6	6	6	6	5	7	5	5	5	6	5	6	6

A4	3	3	3	3	2	3	2	3	2	2	3	3	3
A8	2	1	2	2	2	1	1	2	1	1	2	2	1
1C	-	1	-	1	1	1	1	1	1	1	1	1	1
6C	-	-	-	-	-	1	1	-	1	-	-	-	-

Table 2

The amount of time spent on maintenance by type during a year

	YL-B01	**YL-B02**	**YL-B03**	**YL-B04**	**YL-B05**	**YL-B06**	**YL-B07**	**YL-B08**	**YL-B09**	**YL-B10**	**YL-B11**	**YL-B12**	**YL-B13**
DLY	1077 44.875	1047 43.63	1062 44.250	990 41.250	978 40.750	1044 43.500	900 37.500	1014 42.250	921 38.375	993 41.375	981 40.875	1020 42.500	1005 41.875
SVC	366 15.250	357 14.875	360 15.000	336 14.000	333 13.875	351 14.625	315 13.125	354 14.750	312 13.000	339 14.125	330 13.750	348 14.500	348 14,.500
WLY	79.5 3.313	78 3.250	81 3.375	72 3.000	73.5 3.063	76.5 3.188	67.5 2.813	78 3.250	69 2.875	75 3.125	75 3.125	78 3.250	75 3.125
A1	65 2.708	60 2.500	60 2.500	55 2.292	50 2.083	65 2.708	50 2.083	55 2.292	55 2.292	55 2.292	55 2.292	60 2.500	60 2.500
A2	84 3.500	84 3.500	84 3.500	84 3.500	70 2.917	98 4.083	70 2.917	70 2.917	70 2.917	84 3.500	70 2.917	84 3.500	84 3.500
A4	69 2.875	69 2.875	69 2.875	69 2.875	46 1.917	69 2.875	46 1.917	69 2.875	46 1.917	46 1.917	69 2.875	69 2.875	69 2.875
A8	46 1.917	23 0.958	46 1.917	46 1.917	46 1.917	23 0.958	23 0.958	46 1.917	23 0.958	23 0.958	46 1.917	46 1.917	23 0.958

1C	-	652 27.167	-	843.5 35.146	842.5 35.104	Including 6C	Including 6C	361.5 15.063	Including 6C	868.5 36.188	750 31.250	438 18.250	363.5 15.146
6C	-	-	-	-	-	1189.5 49.563	1496 62.333	-	604.5 25.188	-	-	-	-
Total	1786.5 74.438	2370 98.750	1762 73.417	2495.5 103.979	2439 101.625	2916 121.500	2967.5 123.646	2047.5 85.313	2100.5 87.521	2483.5 103.479	2376 99.000	2143 89.292	2027.5 84.479

Note:

- PRE FLT (pre-flight inspection) in not considered a line or base maintenance task thus time spent on this task is not calculated. In Table 2 the amount of time spent on maintenance by type (conditions) during a year is shown. The first row shows downtime in hours and the second in days. The data of aircraft flight hours for one year is given in Table 3.

Table 3

Flight hours

	YL-B01	**YL-B02**	**YL-B03**	**YL-B04**	**YL-B05**	**YL-B06**	**YL-B07**	**YL-B08**	**YL-B09**	**YL-B10**	**YL-B11**	**YL-B12**	**YL-B13**
TFH	2818:05	2763:42	2932:52	2660:57	2601:01	2863:44	2435:30	2701:35	2538:37	2823:50	2435:03	2712:24	2730:22
TFC	1692	1692	1642	1491	1374	1645	1450	1493	1492	1352	1229	1549	1501

Note:

- TFH (Total Flight Hours) – for the period from 01/12/2012 to 30/11/2013;

- TFC (Total Flight Cycles) – for the period from 01/12/2012 to 30/11/2013.

One calendar year of operation was considered. Following parameters were determined:

a) t_i – - the total time spent in the given condition h;
b) n_i – the number of entering the condition;
c) $\mu_i = t_i / n_i$

The simulation results reflecting the frequency of entering into conditions are shown in Table 4.

As a result of analysis of the maintenance organization of the airline on Boeing 737 maintenance for one year distribution types of aircraft real condition as a random variable $x_r = \{x_r\}$ and their statistical characteristics were obtained. A fragment of the calculation is shown in Table 4.

Table 4

Simulation results

AC condition number	Condition	Statistical estimation of vector	Expected value of being in the condition in hrs.
1	Flight	0.3303	2.34
2	Waiting for periodic maintenance	0.00045	3.20
3	Line maintenance: A-check		
3.1	A1	0.005840	2.80
3.2	A2	0.3262	0.70
4	Transit check	0.0050	2.30
5	Base maintenance: C-check		
5.1	C1	0.06056	7.60

5.2	C2	0.00250	10.00
5.3	C4	0.0024	28.50
5.4	C6	0.00042	49.80
5.5	C8	0.00030	75.00

According to the results of statistical analysis the distribution of the time fund is determined by the condition of the aircraft maintenance for 1 year according to the formula:

$$Ki = \pi_1 \quad M[xi] / \sum_{k=1}^{N} \pi k M\,[xk] \qquad (7)$$

Where: *M [xi]* – expected value for the time of object staying in k-th condition.

To reduce the scope of work let us divide the whole set of conditions into subsets, describing the same type of aircraft condition, Table 5.

Table 5

AC conditions subsets

№	Type of operations/maintenance	Time, %
1	Flight (aircraft intended use)	0.3023 (30.23)
2	Aircraft waiting for maintenance	0.0044 (0.44)
3	Maintenance and repair conditions:	
3.1	Line maintenance	0.3912 (39.12)
3.2	Base maintenance	0.1013 (10.13)
4	Conditions of waiting for utilization	0.0237 (02.37)
5	Departure delays	0.0237 (02.37)

2.4. Testing of models comprehensive preparation of the aircraft for the flight

Simulation of maintenance process using Petri net for the developed model has been tested on the example of the aircraft maintenance during preparation for departure (B-737-300/500 fleet).

The duration of each of the maintenance tasks and the necessary amount of resources are taken from the technical documentation and gained experience. To carry out the intended scope of work three executors of different categories are required: v1, v2 and v3, and two more executors with the same category: v4 and v5. These executors in accordance with work package are required to perform three tasks: w1, w2, and w3. The full set of operations to be performed in this case includes 42 positions. Tasks w1 and w2 can be executed in parallel but task w3 can only be performed after completion of w1 and w2. To carry out task w1executors v1 and v2 are required and for task w2 executors v3 and v3 are both involved at the same time. To carry out task w3 executors v1, v3, v4 and v5 are required. The above conditions are reflected in the Petri net in (Fig.3): places v1, v2, v3, v1 ', v2', v3' and v4 represent executors waiting for the task to be started but positions w1, w2, and w3 represent tasks. A fragment of the model corresponding to the beginning of tasks execution is shown in (Fig. 5): here the fact of executors waiting for tasks to be started is marked by the tokens in places v1, v2 and v3, v4 which simulates the work process.

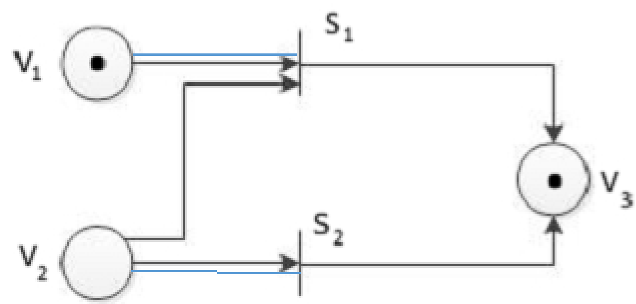


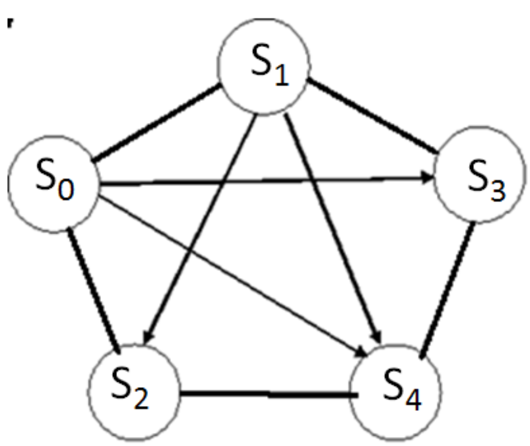
Figure 5. Fragments of Petri net model.

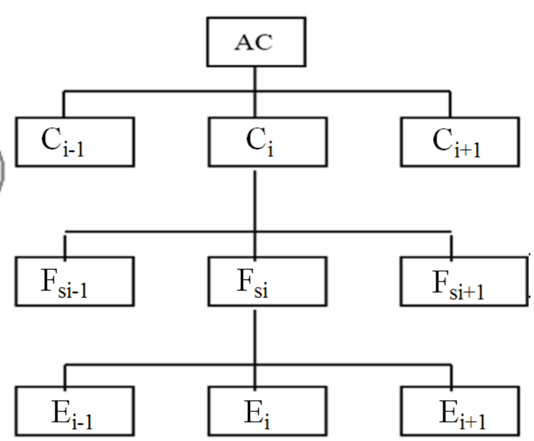
The full view of the processes of preparing the aircraft for the flight including the critical path for the cases of early and late planning is presented in the dissertation. Testing of this model showed its great potential to track a variety of complex logical conditions that occur in the real production especially in fault situations because the start-up sequence may be different, which corresponds to the fact of the possible differences of the workflow. The obtained indicators of the statistical analysis based on the considered models allow determining the expected relative reduction in the amount of time, labor and cost in the *i*-th condition of the aircraft maintenance (*i* = 1,2, ..., N) on the implementation of activities and eventually improving the performance the maintenance organization of the airline. The results of testing the models presented in this chapter are used in the fourth chapter of the paper for development of optimum management system of aircraft preparation for departure with delays due to technical reasons.

Chapter 3. Development of a mathematical model that characterizes the conditions of the aircraft in flight

To solve this problem we use an approach based on the theory of semiotic systems. It is known that in the recent years there has been rapid development of research in this area representing a mathematical basis for building intelligent systems of a qualitatively new level allowing describing adequately the modern problematic objects that are characterized by complex of organizational and constructive structure. As one of the approaches of knowledge representation in the semiotic system a model based on multi-level logic (Multi-layer logic or for short MLL) is used. MLL is an integration of the logical approach and the approach based on semantic theory and it is a convenient way for the formalization of the considered problem. The abstract hierarchical structure divided into blocks and levels makes it more compact and by applying the corresponding mathematical model we solve the problem.

Based on this approach we have developed a semiotic model of aircraft conditions in flight. Under aircraft conditions in flight in the dissertation we considered the situations arising in flight as a result of failures and malfunctions and leading to reduction in flight safety. On the basis of this concept five possible conditions of the aircraft during the flight can be identified. Let us denote them through S_i, where i = 0, 1, 2, 3, 4. Normal ("regular") flight in the absence of failures – S_0; complicated flight conditions – S_1; dangerous situation – S_2; emergency – S_3; the catastrophic situation – S_4, Fig.6.





a b

Figure 6. Semiotic models of the aircraft conditions in flight and the aircraft as a multi-level technical system.

We will also consider the aircraft as a complex multi-level technical system having a hierarchical structure. Subsystem of the lowest level consists of a set of technical elements. Exactly at this level in-flight failures and malfunctions take place causing the transition of aircraft from a normal (regular) condition into one of the abnormal conditions (Fig. 6a). We appoint the aircraft itself as the highest level of our structural diagram. The aircraft consists of a number of vitally important in terms of flight safety subsystems which we will call the *consumers*. *Consumers* – vital structural elements of the aircraft, whose characteristics directly determine different conditions of the aircraft in flight. Setting the list of the *consumers* on a particular aircraft type may be based on operating experience, accident investigation and other criteria. For greater reliability it can be done with the help of expert evaluations of aviation reliability specialists. Based on operating experience the list of consumers include: the aircraft control system, braking system, high-lift devices of the wing, life support system, cabin pressurization and others. Then *consumers* will form the second level in our block diagram of aircraft. The third level in the block diagram will consist of the functional aircraft systems which are serving the *consumers*. The fourth level in block diagram is to represent individual units and other elements of functional systems: components, pipes, relays, etc. Exactly at this level failures occur affecting the output parameters of functional systems and they subsequently affect the output parameters of *consumers* and so on down the chain. The semiotic model of the aircraft as a multilevel technical system is shown in (Fig. 6b)

a) 1st level – aircraft;
b) 2nd level – *consumers* – systems and components of the aircraft, whose characteristics directly determine its condition in the air (control system, braking system, lift devices, etc.);
c) 3rd level – functional systems of the aircraft, serving *consumers* (hydraulic, fuel, etc.);
d) 4th level – functional system elements.

To establish the conditions for the transition from one condition of the aircraft in flight to another statistics of technical failures in flight for Boeing aircraft and recommendations of technical standards for such cases were analyzed. Using a database of the Boeing aircraft incidents for 10 in-flight years, an analysis of the relationship between hydromechanical systems failure and conditions of aircraft in flight was carried out in accordance with the proposed model. Example of the analysis is as follows.

1) The *consumer* – life support system. Functional system – cabin pressure control system of the pressurized cabin.

a) Pc> Pc (cabin overpressure). According to the flight manual such cases require a shutdown of the cabin pressurization, emergency descent and if the aircraft does not provide ram airflow cabin ventilation at low altitudes the landing at the nearest airport. In accordance with the critical attributes it is an emergency or a condition of -S_3 by the previously described rating.

b) Pc< Pc (Depressurization). This condition does not require pressurization system to be shut down so the crew has to take a safe flight level in terms of allowable altitude pressure and flight may be continued safely. Therefore, in accordance with critical attributes it will be a dangerous situation or a condition of -S_2 by the previously introduced rating.

c) dPc/dt> dPc/dt allow. This condition usually also leads to depressurization and it is the condition -S_2 by the previously introduced rating.

Statistics: According to the statistics, during the concerned period there were 10 accidents on Boeing aircraft caused by pressurization system fault and all of them were related to the depressurization. In 7 cases it was a failure of the exhaust valve (valve plate hang in an open position) and in all these cases unintended opening of one of the exhaust valves was the result of pressurization system element failures, which was sufficient for cabin pressure parameters to reach the level which corresponds to depressurization. That is the condition -S_2 of the aircraft by the previously introduced rating. Similar conditions in system of the pressure regulation arise in case of the failure of the command unit (2 cases) but in this case there is a possibility to move to the backup command unit with restoration of the operability of the system. But if the turning valve also has failed then the work of the system restore is also impossible. This will also match the aircraft condition – S_2.

In the dissertation, the failures in life support systems, hydraulic systems, control system and others have also been analyzed. Thus based on this analysis and based on practical experience we assume that the appearance of one adverse factor in a flight causes the condition of aircraft not higher than S_1 – complicated flight conditions. The appearance of a second adverse factor causes its transition to the next condition i.e. S_{i+1}. Then the aircraft immediately enters into a condition more dangerous, more complex flight conditions may occur when it is exposed at the same time to a combination of two or more unfavorable factors. The more factors act at the same time the more dangerous the condition of the aircraft is. This is evident from the analysis of normative and technical documentation. Based on the analysis data mathematical model of relationship between failures of aircraft components and aircraft conditions in flight was developed. It is based on the following assumptions: we assume S_i (i = 0 ...... 5) – aircraft conditions in flight; S_j – condition of the *consumers*; S_{ij} – condition of the *consumer* at the j-th value of the parameters specifying the i-th state of the aircraft; X_j – a set of parameter values at the output of the *consumer*; X0 – a set of parameter values at the output of the consumer standardized by technical documentation; X_j-X_0 – parameter values deviation from standardized values; C_j – the condition of the functional system (FS); C_{ji} – functional system condition at j-th condition of FS, leading to the S_{ij}-th condition of the *consumer* and S_i-th condition of the aircraft; Y_j – a set of parameter values at the output of the FS; Y_o –a set of parameter values at the output of the FS standardized by technical documentation; Y_j-Y_o – parameter values deviation from standardized values; C_k – the condition of k-th element of FS; C_{jk} – the condition of the k-th element of the FS at j-th values of parameter values leading to the i-th condition of the aircraft; Z_{jk} –set of parameter values of a separate element of FS; Z_{jo}- Z_{jk} –set of parameter values of a separate element of FS standardized by technical documentation; Z_j-Z_o – parameter values deviation from standardized values. Let us consider the interaction of some functional system and the *consumer* it serves so for any FS of the airframe the aircraft itself will appear as a *consumer*. Each *consumer* is characterized by a set of parameters $\{X_j\}$ that must be within the prescribed limits $\left\{\Delta X_j; \frac{dx_j}{dr}\right\}$ during the period of its functioning and ensuring of those conditions is the task of serving system consisting of a set of elements. The consumer in dependence on the values of the parameters $\{X_j\}$ can be in $\{S_j\}$ conditions. The values $\{X_j\}$ are dependent from multiple parameters $\{Y_j\}$ at the output of serving system. When the parameters $\{Y_j\}$ are within acceptable limits $\left\{X_j; \frac{dy_i}{dr}\right\}$ the parameters $\{X_j\}$ must not go beyond normal functioning limits. This condition can be assigned value S_{j_0} and values $\{Y_j\}$ are determined by the “output” parameters of each of the elements $\{Z_j\}$ included in the system. If the *consumer* condition in flight differs from S_{j_0} it will cause the appearance of some condition different from a normal (regular) S_i (i = 1…4). Therefore any state S_i which the aircraft in flight may enter corresponds to some conditions $\{S_{ji}\}$ of the consumer. Occurrence of the state $\{S_{ji}\}$ in flight depends on the values of the set of parameters $\{X_{ij}\}$ defined by subset of values $\{Y_{ij}\}$ of set $\{Y_j\}$. Obviously $\{Y_{ij}\}$ depends on some set of parameters $\{Z_j^{(i)}\} \le \{Z_j\}$ of system elements or the appropriate combination of values Z_{ji} of a group of elements. Therefore, the technical condition of the aircraft in case of failure can be described by the algorithm:

$$\{ Z jk \} \Rightarrow \{ Y ij \} \Rightarrow \{ Xij \} \Rightarrow Si \tag{8}$$

Where: N – the number of elements in the system;

k = 1, N – some element of the system;

Z_{jk} – some range of output parameters values of the k-th element defined by its possible conditions.

This model became the basis for aircraft maintenance management techniques during the aircraft maintenance and evaluation of the aircraft condition in case of equipment failures in flight. It is based on the statistics of failures of the individual units (4th level, Fig.4) and as a result of these failures a mismatch of output parameters (failures) of functional systems (3rd level Fig.4) of N planes of the same type for a certain period of time having a common flight time – T_Σ. The first step will be to identify the main *consumers* of the aircraft of this type. In the next step of the research the transition from the *consumer* conditions to the assessment of the operation of systems serving by the consumer is carried out. Further based on processing of the statistical probability of failure-free operation of certain elements of functional systems (4th level) and systems in general (3rd level) the probability of failure-free operation utilizing the relevant laws of the random variable is determined. Using the values of the probability of the system conditions leading to a special aircraft condition occurrence in flight we identify the most unreliable units in the functional system. We develop optimal technology for their maintenance including modification and action plan to improve maintenance processes.

3.1. Testing of these models

Testing of these models and techniques was carried out on the basis of the statistics on technical failures of AVRO-RJ70 aircraft for the period 1995-2005 operated by AirBaltic airline. Characteristics of failure-free operation of functional systems (level 3) and separate units (level 2) were obtained. Some fragments of the calculations results are shown in Fig. 7.

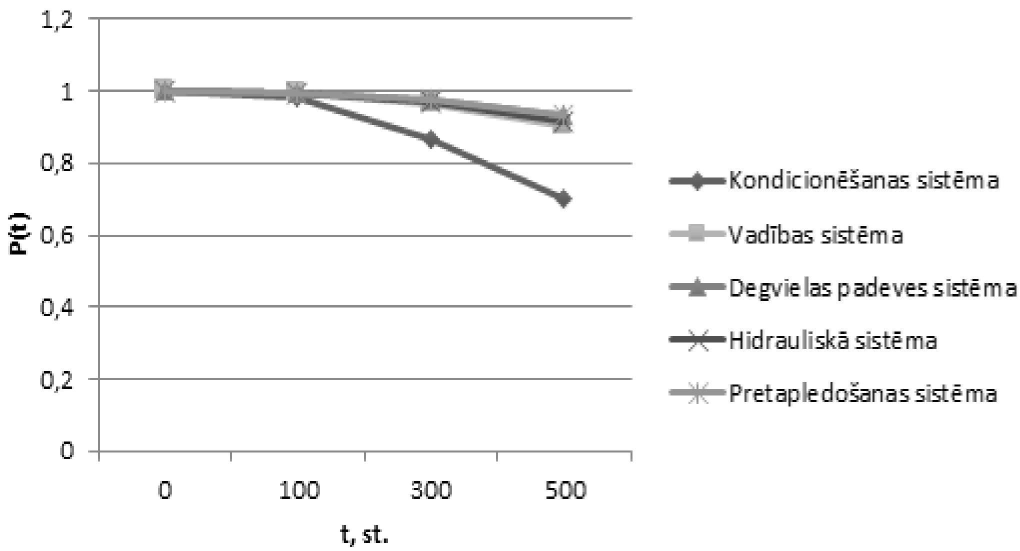


Figure 7. Failure-free operation characteristics of aircraft systems.

Failure-free operation probability of AC systems in this case was calculated by formula:

$$P(t) = \exp\left\{-\omega t + \frac{\omega}{\lambda[1 - \exp(-\lambda t)]}\right\} \tag{9}$$

Where the flow parameters are determined by formula:

$$\omega_c = \frac{n_{ic}}{T_\Sigma} \qquad \omega_a = \frac{n_{ia}}{kT_\Sigma}$$

Parameter λ denotes transition of the unit from the state of unstable functioning into the failure condition:

$$\lambda = [3\text{-}\ (9+24 * H/\tau_{in} * \ln (1\text{-}\ \tau_{ipus}/H)]: (2\ \tau) \tag{10}$$

Where: $H = T_\Sigma = 2684217$ h; $\tau = 500$ h (the periodicity of maintenance form A).

The results of air conditioning system components failure-free operation probability assessment calculation are shown in Fig. 8.

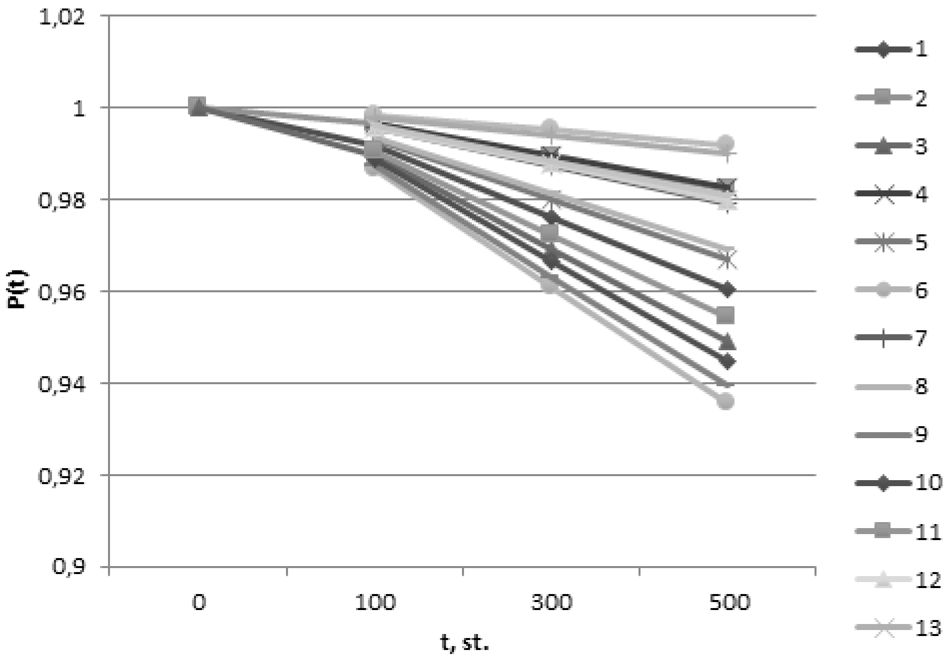


Figure 8. Air conditioning system componets failure-free operation probability.

The calculations performed allowed us to identify three most unreliable functional systems which are fuel, anti-icing, air conditioning and also 10 most unreliable functional components in the examined systems of this type of aircraft. In accordance with the above multi-layered structure of the aircraft (Fig.8) the first two systems can be considered as *consumers*. Failure of these systems in flight can cause the catastrophic situation. A more detailed analysis of the identified components allowed us to improve reliability.

Chapter 4. Development of the mathematical model of the optimum system for control of the preparation of aircraft for the flight

In the fourth chapter of the dissertation based on the analysis of the existing management system of the aircraft preparation for the flight a mathematical model of optimal management of the process was developed and its testing for the cases of delays due to technical reasons was carried out. In general, the model of the aircraft maintenance in preparation for departure includes technological circuit and organizational management circuit and appears as shown in Fig. 9.

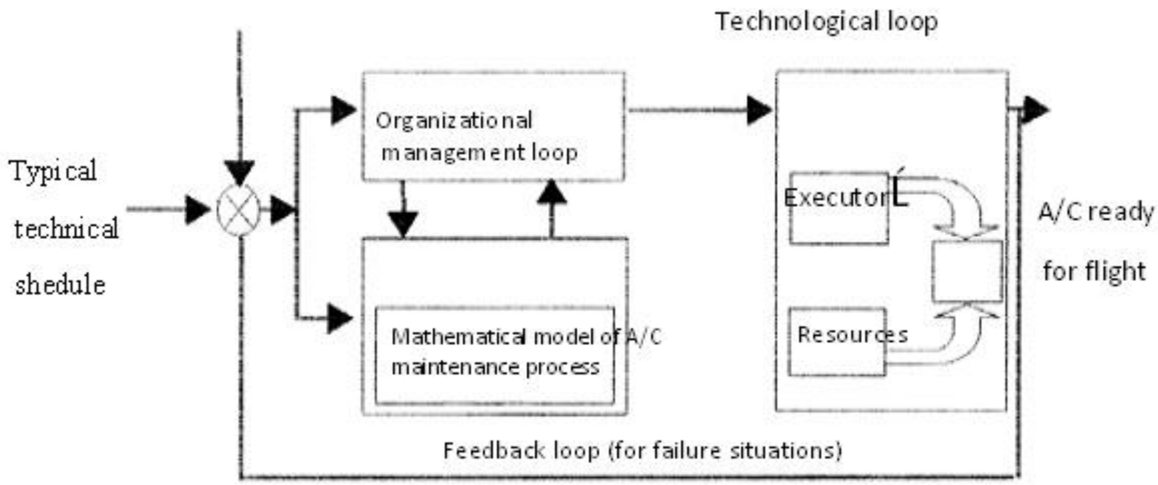


Figure 9. Aircraft maintenance model.

As a general rule, the maintenance service of airline usually uses 3-level management structure with a definite number of professionals involved in the aircraft preparation for the flight, which are production planning, shifts supervisors and technicians. In the process of preparing the aircraft for the flight each level of management solves a certain number of tasks. Let us denote the number of professionals involved in AC preparation for the flight by k_0 and the number of them on each level – by K_1, K_2, $K_{3,}$ then the total number of professionals involved in the preparation of aircraft for the flight will be equal to:

$$k_0 = k_1 + k_2 + k_3 \tag{11}$$

Where: 1..3 are the levels of management. Let us also denote the totality of problems solved in aircraft maintenance service through Mo. This coefficient includes all kinds of problems at all three levels during AC maintenance. Then:

$$M_0 = \sum_{i=}^{1} M_i = \sum_{i=1}^{1} \sum_{j=1}^{J_i} M_{ij} \tag{12}$$

Where:

M_i – the number of problems arising in the i-th shift;

M_{ij} – the number of problems arising at the j-th area of the i-th shift;

I – the number of shifts;

J_i – the number of areas in the i-th shift.

To solve these problems resources are required that are at the disposal of the 1st, 2nd and 3rd levels of maintenance control center. Then:

$$M_j = M_{1j} + M_{2j} + M_{3j} \tag{13}$$

Here M_{1j} – the number of problems arising in the j-th section of the aircraft preparation system and requiring their solution resources of the 1st level. Accordingly, M_{2j} and M_{3j} are the number of problems arising in the j-th section and eliminated by resources of 2nd and 3rd levels. Let us denote ς_1, ς_2, ς_3 the shares of amount of problems solved at 1st, 2nd, 3rd levels from the total number of problems arising in the maintenance center for a certain calendar period of time, which can be expressed analytically in the form of:

$$\varsigma_1 = \frac{M_1}{M_0}, \ \varsigma_2 = \frac{M_2}{M_0}, \ \varsigma_3 = \frac{M_3}{M_0} \tag{14}$$

Obviously,

$$\zeta_1 + \zeta_2 + \zeta_3 = 1 \tag{15}$$

The amount of all problems that are fixed respectively by resources of 1st, 2nd and 3rd layer can also be written as:

$$M_1 = \sum_{j=1}^{J} M_{1j}, \ M_2 = \sum_{j=1}^{J} M_{2j}, \ M_3 = \sum_{j=1}^{J} M_{3j} \tag{16}$$

The mathematical model of optimal management of aircraft preparation for flight was developed and tested for the cases of departure delays due to technical reasons. As shown in the second chapter, the percentage of departure delays due to technical problems during the analyzed period is 2.37% of the annual limit of time for the aircraft being in different conditions. Let us introduce a measure for optimal management of the aircraft preparation for flight. As a measure (indicator) of optimal management of the aircraft preparation for flight in the presence of flight delays due to technical reasons we will consider the probability of the case when the delay time will not exceed some permissible value τ.

The indicator of optimal management $P_j\ (\tau_j \le \tau_d)$(j=1..3) can be expressed through the distribution density $f_j\ (\tau)$ of the random variable τ:

$$P_j(\tau_j \le \tau_d) = \int_0^{\tau_d} f_j(\tau)d\tau \tag{17}$$

In order to identify the distribution law of the random variable τ a database of delays was analyzed. As the analysis showed, up to 80% of departure delays do not exceed one hour. Therefore, the entire range has been divided into two parts: the duration of delays up to one hour and all other delays. Pearson - χ^2 and Romanowski (*r*) were used as goodness of fit criteria . As the analysis showed, the density of distribution of all delay times obeys the exponential law and for the duration of up to one hour – Weibull law (see Fig. 10).

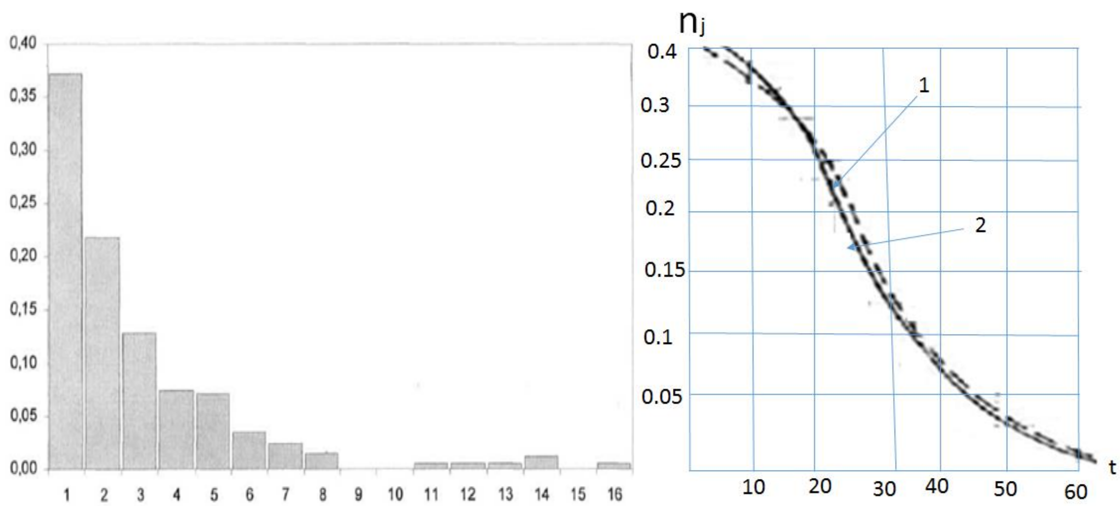


Figure 10. Density of the total distribution of time of flight delays due to technical problems in the airline.

Bearing in mind that the aircraft maintenance management system should be designed for a long period of operation it was decided to use the time in this development an exponential law for distribution of flight delay due to technical reasons, as a simpler indicator. However, in this regard it is advisable to evaluate analytically the difference between Weibull law for the time interval under consideration and the exponential law. To solve this problem Weibull distribution has been presented in the form of a series of system functions taking as reference exponential law f(t). Then the probability density f_0 (t) can be written as:

$$f(t) = f_0(t)\,[S_0\Psi(t) + S_1\Psi 1(t) + ... + Sn\Psi n(t)] \tag{18}$$

where: Ψ_1, ... Ψn (t) – the system of polynomials normalized with respect to the distribution of f(t) and the coefficients Ci are the Fourier coefficients of the function f(t). By expansion (4.18) distribution laws of any random variables can be represented as continuous, discontinuous and mixed. In order to obtain a good approximation it is necessary to take the appropriate “reference” distribution of f(t). In this case, as has already been noted, an exponential distribution was taken as a reference. The calculations have shown that in this case the deviation of Weibull distribution from the exponential distribution does not exceed 15%. Consequently, the distribution density of delays time by Weibull law in this interval is different from the exponential and this should be borne in mind when organizing the best management system of aircraft preparation for the flight due to failures caused by technical reasons.

4.1. Testing of these models

Thus random duration of flight delay elimination can be described by an exponential function:

$$f_1(\tau) = \frac{1}{\tau_j} \cdot e^{-\frac{\tau}{\tau_j}} \tag{19}$$

here τj – the average duration of the fault elimination on the j-th level of management system. Depending on the number of professionals in the technical center, the average duration τj of failure elimination for the j-th level of the system can be represented as:

$$\tau_j = \frac{\tau_{0j}}{k_j} \tag{20}$$

Where: Kj - the number of professionals of j-th level; τ_{0j}– the average duration of fault conditions elimination if handled by one specialist. Mathematical model of aircraft preparation for the flight with delays due to technical reasons will appear as:

$$P_0(\tau \le \tau d) = \left(1 - e^{-\frac{\tau d}{\tau_{01}} \cdot k_1}\right) \cdot \left(1 - e^{-\frac{\tau d}{\tau_{02}} \cdot k_2}\right) \cdot \left(1 - e^{-\frac{\tau d}{\tau_{03}} \cdot k_3}\right) \tag{21}$$

On the basis of this model the Manual for optimization of management system for the flight preparation due to technical problems was developed and tested. Testing was done to address the issue of optimal distribution of the total number of specialists between the production levels of the flight preparation in the management system. The optimality criterion is the least probability of delays. In other words, the distribution is considered to be optimal if the maximum of the probability that the delay in all three levels will not exceed the permissible value is reached:

$$P_1(\tau_1 \leq \tau_d) = P_2(\tau_2 \leq \tau_d) = P_3(\tau_3 \leq \tau_d) \quad (22)$$

The task of determining the number of professionals kj on each j-th production level by optimal management criterion can be set this way: find such K_1, K_2 and K_3 so that the probability that a flight delay will not exceed a certain limit value τ_d is the maximum, and the total number of professionals involved in the elimination of delays at the three levels of aircraft preparation for the flight will remain unchanged. The developed method of analysis of the system for aircraft preparation for the flight has been tested on the example of the aircraft maintenance in the airline. Permissible flight delay time was set at 0.25 h ($\tau_d = 0.25$). The resulting distribution of the number of professionals of different categories turned out to be different from the actual and required to reallocate both professionals and a list of their tasks. The logical continuation of the development of optimal maintenance management of aircraft was further development. Implementation and evaluation of the effectiveness of measures of the maintenance quality showed improvement The indicator which characterizes the probability of avoiding nonconformance's during activities of the technical staff was taken as the main criterion of importance and significance of the measures. Therefore, variations in the activities of the technical staff of the airline for the past five years were analyzed. Nonconformances committed during maintenance and aircraft preparation for flight led to delays, forced landings, aircraft damage on the ground and incidents. However, it was difficult to clearly identify all the causes of nonconformances in the work of experts due to the ambiguity of their records in the appropriate documentation, lack of statistics, imperfections of the production documentation and difficulties of its filling. During analysis of the deviations and nonconformances that happened during maintenance revealed the main reasons and direction of preventive measures for the improvement of the aircraft management system.

CONCLUSIONS

1. Mathematical models which were developed in Chapter 2 to minimize the time of the aircraft being on the ground in various conditions allow us to simulate the processes of the aircraft maintenance for the assigned aircraft park of an airline in different combinations. Models have been tested in relation to the maintenance processes of 13 B-737 aircraft fleet in the real airline. As a result, the types of distributions of actual aircraft conditions as a random variable xr = {xr} were obtained and their statistical characteristics which makes it possible to perform aircraft maintenance maintaining the required level of flight safety and regularity, increase the utilization of assigned aircraft fleet and its serviceability and efficiency of operation.

2. On the basis of semiotic models of aircraft condition in flight and multi-layered structure composed in the third chapter the mathematical model of relationship between failures of aircraft components and aircraft condition in flight has been developed. Based on this the methodology of the aircraft maintenance management during the aircraft maintenance and evaluation of the conditions of the aircraft components failures in flight has been developed. The approbation of the developed method has been carried out based on the database of technical failures of AVRO-RJ70 aircraft for the period 1995-2005 operated in AirBaltic airline.

3. Mathematical model of optimal organizational structure of maintenance management system of the aircraft preparation for the flight on the basis of the index of optimal distribution of the professionals on each production level in one of the airlines has been developed. The method was tested in the maintenance organization of the airline in terms of the distribution of technical staff and their tasks between different levels of management in failure situations which allowed the company to reduce economic losses due to flight delays by reducing the total duration of delays due to technical reasons.

4. The approbation of the developed measures on the basis of the obtained results with an aim to improve aircraft maintenance quality in the airline has been carried out and has confirmed their high efficiency.

Thus, the introduction of the developed models into practice in the airline maintenance organization of the airline showed their effectiveness:

a) The number of discrepancies related to the maintenance staff during aircraft maintenance has significantly decreased;

b) The effectiveness of different levels of the system of control of aircraft maintenance processes became more clear and transparent;

c) Due to improvement of the technological process of the aircraft maintenance and increase in the qualification of the maintenance personal the labor requirement has decreased;

d) The reliability of the functional systems and their components have increased;

e) Possibility to perform additional flights if needed has been obtained.