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ANALYSIS OF SELECTED PROBLEMS OF THE OPERATION OF MEANS OF AIR TRANSPORT

ANALIZA WYBRANYCH PROBLEMÓW EKSPLOATACJI ŚRODKÓW TRANSPORTU

Abstract

The aim of this article is to analyze the operational periods of means of transport, present concepts of models of exploitation processes of technical objects, and processes occurring in these objects. A graphic illustration of the decision-making model of the exploitation system and the mass maintenance of the technical means of transportation was presented. Based on the analysis for development trends of maintenance systems, the main directions of improvement and enhancement of these systems were shown. Mathematical elaborations of the presented solutions were applied.

Keywords: aircraft, decision-making system model, maintenance of means of transport

Streszczenie

W artykule poddano analizie wybrane okresy eksploatacyjne środków transportu, zaprezentowano koncepcje modeli procesów eksploatacji obiektów technicznych oraz procesów zachodzących w tych obiektach. Przedstawiono ilustrację graficzną modelu decyzyjnego systemu eksploatacji oraz masowej obsługi środków technicznych. Dokonano opisu strategii eksploatacji, wskazano kryteria doboru oraz korzyści z ich stosowania. Na podstawie analizy tendencji rozwojowych systemów obsługowych wykazano główne kierunki usprawnienia i doskonalenia tych systemów. Zastosowano opracowania matematyczne prezentowanych rozwiązań.

Słowa kluczowe: statek powietrzny, model systemu decyzyjnego, eksploatacja środków transportu

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1. INTRODUCTION

Transport is an integral and essential element of modern society, enabling people and goods to move quickly and efficiently around the world. The transport industry enables the movement of goods and services, driving economic growth, and facilitating trade across borders. From the movement of raw materials to the delivery of final products, transport plays a critical function in the global economy.

However, the operation of modes of transport is not without challenges. Road, rail, sea and air transport have various issues of safety, maintenance, efficiency and sustainability. For example, accidents, human errors, or equipment failures can cause serious problems for passengers, drivers, and freight. Maintenance challenges are also a critical aspect of transport, as complex transport systems require regular maintenance to ensure they are safe and in good working order. In addition, operational efficiency is a constant concern for transport companies, which need to manage the costs associated with their operations while meeting customer demands. The environmental impact is also a significant challenge, as transport is a major contributor to air pollution and greenhouse gas emissions.

Despite these challenges, the transport industry continues to evolve, with new technologies offering new opportunities to improve the safety, efficiency, and sustainability of transport modes[1]. From electric vehicles and autonomous driving technologies to advanced logistics systems and intelligent transport infrastructure, there is significant potential for innovation in the transport industry.

The main novelty of this article is the examination of some of the key challenges facing the operation of transport modes, especially air transport, and explore potential solutions to address these challenges. Identifying and solving such problems will contribute to the development of safer, more efficient, and sustainable transport systems that can meet the needs of society today and in the future.

In this article, the authors attempt to address the specific problem of optimizing the operation of means of transport. In particular, the authors attempt to address the challenges faced by transport asset operators in achieving maximum productivity and efficiency in the operation of their fleet.

Understanding optimization problems allows transport asset operators to make the most efficient use of their resources, including vehicles, fuel, and personnel. This can help to reduce costs, improve safety, and increase customer satisfaction. However, achieving optimization can be difficult due to the complexity of the transport system, the large number of variables, and the unpredictability of factors such as traffic and weather.

By addressing the specific problem of transport optimization, the authors aim to provide practical solutions that can help transport operators achieve their goals more efficiently. These solutions may include the use of advanced modelling techniques,

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[1] Wang et al., ‘Fault Analysis and Reliability Evaluation for Motorized Spindle of Cycloidal Gear Grinding Machine Based on Multi-Source Bayes’.

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real-time data analysis, and new technologies such as artificial intelligence and machine learning. Ultimately, the objective is to improve the overall efficiency and effectiveness of the transport asset system, for the benefit of both operators and users.

2. PROCESS OF OPERATION OF AIRCRAFT

The life cycle of aircraft can be easily categorized into three phases, design and development, production, and operation. The design phase is generally a response to market demand. The result of the design process is technical documentation, which consists of many technical drawings, conceptual diagrams, and calculations. A high priority is attached to the design stage, all drawing work and calculations are done with due care to eliminate as much as possible the possibility of error during production and construction. This is due to the important fact that it is much more expensive to make changes to a manufactured component than to make corrections to the design. The aircraft design process can be considered very similar to other engineering products, but the complexity of the aircraft and the stringent safety regulations required increase the cost and length of the design phase.

The production phase is the manufacture of a product that meets the requirements of the designers and developers. The positive fulfillment of the first two phases results in the transfer of the aircraft to aircraft companies and the operation phase begins.

The operation of aircraft in an aviation organization is one of the most important processes for ensuring the desired level of safety and the accomplishment of planned tasks[2]. Maintenance of aviation equipment by the operator in a state in which the aircraft can achieve high reliability and operational availability, will be in accordance with the prepared plan, must consider the deterioration of its condition with age as well as accidental failures, at the same time will be related to the organization of work, overhead costs, qualifications of technical personnel who must meet certification requirements. Operation can be divided into four phases: maintenance, management, use and operation.

It is common for the authors to refer to the technical object, which in aviation is the aircraft, but it should not be forgotten that an integral part of the operation are the people involved in the use of the aircraft - pilots and crew, maintenance of the aircraft - people involved in the operation, repair, maintenance and maintenance of the aircraft, as well as the environment, which includes airport infrastructure, weather conditions, location of the airport and the surrounding nature. The direct course of aircraft operation is also influenced by: the age, class, type and type of aircraft, the composition and level of training of people involved in maintenance, the conditions in which air tasks are performed.

In operation, the relationship between pilots, who are entrusted with the implementation of aircraft use, and aircraft maintenance personnel is extremely important because they depend on each other. Pilots provide information on how the aircraft

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[2] Żyluk et al., 'Analysis of Aircraft Operation System Regarding Readiness—Case Study'.

behaves in flight, report any kind of detected malfunctions or piloting difficulties that are impossible to detect during diagnostics or inspection. Safety in aviation is an overriding value therefore the planning of maintenance work is dependent on the environment in which the tasks are performed.

The aircraft is treated as a repairable, renewable, and susceptible to various types of upgrades device that is subjected to a process of operation. This process is, among other things, overcoming successive operating states and phases, among which three groups can be distinguished[3]:

- generating - states correlative with the introduction of aircraft into operation, e.g. modifying, receiving, masking;
- transit - states correlative to the basic work of aircraft use phases (1. Waiting for takeoff after engine startup 2. Flight, task execution 3. Waiting for landing 4. Landing) and maintenance of aircraft;
- absorption - withdrawal of aircraft from further operation e.g. decommissioning.

The operation process is also divided into types according to the sequence of events that occur:

- type one (PEI) - events between phases, includes exploitation cycles;
- type two (PEII) - events between states, includes changes in operational potential;
- type three (PEIII) - events inside any states in which the aircraft may find itself;
- type four (PEIV) - physical and chemical events directly within the aircraft independent of human actions.

The changes determining all these processes take place in the so-called operating time, that is, the basic parameter that characterizes the operation while the basic characteristics of all technical objects are technical condition and operating condition. Technical condition allows the qualification of an object into different operational states: serviceability, limited serviceability, unserviceability, and functional, task-related serviceability[4].

The maintenance process aircraft is a change of individual operational states aircraft enforced over time, where time is a conventional concept. The operating states can change slowly, over a cycle of a few hours and a few days resulting from the aircraft diagnostic process, or quickly, through flight.

Through the use aircraft subsystem by performing flight missions, the operational potential of the aircraft is used, which is reproduced in the maintenance subsystem by carrying out the technical operation and maintenance and overhaul program. These programs include work and overhaul plans, which are implemented through an operation strategy for a single aircraft, groups of aircraft and a fleet with identical characteristics, respectively. Through ICAO’s recommendations to standardize technical maintenance and renewal plans, aircraft have the ability to take off and land at airports of other countries or organizations. The implementation of maintaining

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[3] Żurek, ‘Review of the safety evaluation methods in aviation’.

[4] Dhillon, ‘Applied Reliability for Engineers’.

the airworthiness of a single facility is carried out using the strategies of operation by resurfacing and by condition. These strategies are related to the scope of maintenance and renewal performed by the engineering and aviation services and overhaul performed at prepared locations[5].

3. FUNDAMENTAL MODELS FOR OPTIMIZING THE OPERATION OF MEANS OF TRANSPORT

In contributions on the operation of technical objects[6] the authors distinguish two main types of models:

- object models - in which the object of modeling is an object (e.g., operating stations of a means of transport, means of transport);
- Process models in which the object of modeling is a sequence of consecutive phenomena (e.g., the process of operating an object).

Thus, it can be assumed that the object of modeling can be both objects and processes occurring in these objects. Studies[7] distinguish two concepts of decision-making models, viz:

- decision model described by an expression of the form:

$$MMD = \langle D,L,Z,F,P\rangle \tag{1}$$

Where the individual elements of the model take the interpretation:

- D – model domain (set of object elements);
- L – the set of relations that link the elements of the model domain;
- Z – model assumptions (set of constraints and simplifications);
- F – criterion function;
- P – the problem we are solving with the model.

The model distinguishes two of its components, namely:

- MM model of the operation system:

$$MM = \langle D,L\rangle \tag{2}$$

- MD decision-making model of the exploitation system:

$$MD = \langle Z,F,P\rangle \tag{3}$$

a) decision model (second concept) described by an expression of the form:

$$MMD = \langle X,Y,J,\alpha,\beta\rangle \tag{4}$$

where the individual elements of the model take the interpretation:

X – the set of parameters of the system;
Y – the set of characteristics of the system;
J – the set of system quality measures;

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[5] Lewitowicz, ‘Badania Eksploatacyjne Statku Powietrznego w Podsystemach Użytkowania i Utrzymywania Zdatności’.

[6] Goraj and Szender, ‘Badania Modelu Samolotu w Locie Na Dużych Kątach Natarcia’.

[7] Ambroziak et al., ‘O pewnym podejściu do modelowania systemu transportowego w aspekcie zrównoważonego rozwoju’.

$$\alpha: \boldsymbol{X} \longrightarrow \boldsymbol{Y}$$

$$\beta: \boldsymbol{Y} \longrightarrow \boldsymbol{J}$$

A graphic illustration of the decision model is shown in Figure 1.

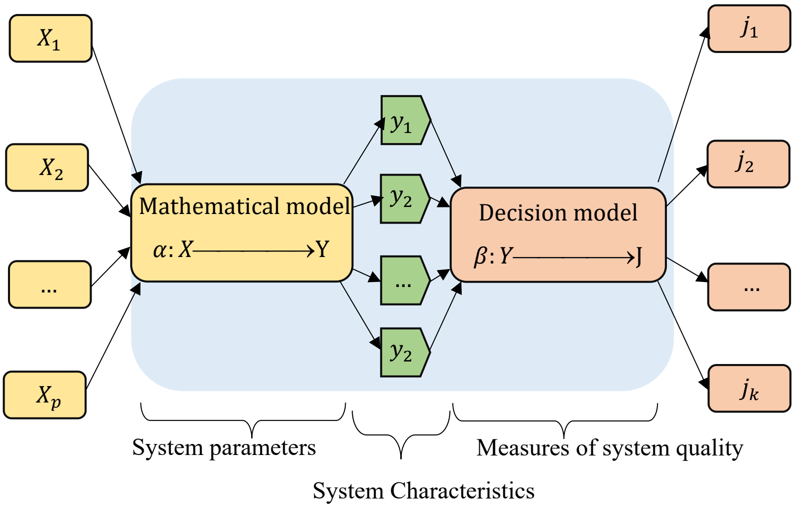

Figure 1. Graphic illustration of the decision-making model of the system of operation of technical means

Source: own elaboration based on: Kustroń, Lewitowicz, and Sasim, ‘Ergonomiczne Problemy Relacji Pilot – Kabina Samolotu w Badaniach Statku Powietrznego’.

In the work[8], the mathematical linear model describes the processes of operation of technical objects by means of linear equations. In practice, linear programming algorithms can be used to solve decision-making problems. A prerequisite for the applicability of linear programming is the linear nature of the objective function and all constraints. Typical practical problems formulated in terms of linear optimization are presented in works[9].

For example, the authors of the work[10] formulate a linear model of the decision problem as follows: Find such a vector x^0 of decision variables x:

$$x = \langle x_1, x_2, \ldots, x_n \rangle \tag{5}$$

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[8] Borgo, Malinowski, and Smoliński, ‘Rejestracja parametrów trwałościowych silnika’; Bubień, ‘Próby prototypu śmigłowca PZL-SW4 dla określenia maksymalnej prędkości lotu’.

[9] Borgo, Malinowski, and Smoliński, ‘Rejestracja parametrów trwałościowych silnika’; Bubień, ‘Próby prototypu śmigłowca PZL-SW4 dla określenia maksymalnej prędkości lotu’; Konieczny, Inżynieria Systemów Działania; Kowaleczko et al., ‘Ocena Własności Lotnych Samolotu Na Podstawie Zarejestrowanych Parametrów Lotu’.

[10] Izdebski et al., ‘Decision Problems in Designing Database Architecture for the Assessment of Logistics Service’; Ziółkowski et al., ‘Method for Calculating the Required Number of Transport Vehicles Supplying Aviation Fuel to Aircraft during Combat Tasks’.

for the linear objective function **F** to reach an extreme value (max, min), i.e.,

$$F(x^0) = \mathrm{extr}\ \mathrm{F(x)} \tag{6}$$

with limitations:

$$Ax \leq b \tag{7}$$

where matrix A has the form:

$$\mathrm{A} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{ln} \\ \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \tag{8}$$

a vector of free terms b (constraints imposed on the selection of decision variables) is:

$$\mathrm{b} = \begin{bmatrix} b_1 \\ b_2 \\ \dots \\ b_m \end{bmatrix} \tag{9}$$

whereby:

$$x \geq 0$$

Notable is the approach presented in works[11], where operational issues solved by network methods are presented, such as:

- analysis of the organization of maintenance processes;
- construction of schedules for execution of maintenance processes;
- modelling of organizational structures of maintenance management systems.

On the other hand, papers[12] present the application of variational calculus in the analysis of multistage exploitation problems. The multistage decision-making process[13] can be represented in the form of a diagram illustrated in Fig. 2. where by S_{i-1} denotes the state of the system at the beginning of the i-th stage (i = 1, 2, ..., n) and x_i denotes the strategy of action taken at the i-th (i = 1, 2, ..., n) stage.

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[11] Klimaszewski, Kurdelski, and Leski, 'Pomiar Sił w Elementach Struktury Samolotu SU-22'; Kowaleczko et al., 'Ocena Własności Lotnych Samolotu Na Podstawie Zarejestrowanych Parametrów Lotu'; Lewitowicz, 'Badania Eksploatacyjne Statku Powietrznego w Podsystemach Użytkowania i Utrzymywania Zdatności'.

[12] Bubień, 'Próby prototypu śmigłowca PZL-SW4 dla określenia maksymalnej prędkości lotu'; Kowaleczko et al., 'Ocena Własności Lotnych Samolotu Na Podstawie Zarejestrowanych Parametrów Lotu'; Lewitowicz, 'Badania Eksploatacyjne Statku Powietrznego w Podsystemach Użytkowania i Utrzymywania Zdatności'.

[13] Gołda et al., 'Narzędzia informatyczne wspomagające podejmowanie decyzji podczas wykonywania operacji lotniskowych'; Nathanael, Tsagkas, and Marmaras, 'Trade-Offs among Factors Shaping Operators Decision-Making: The Case of Aircraft Maintenance Technicians'.

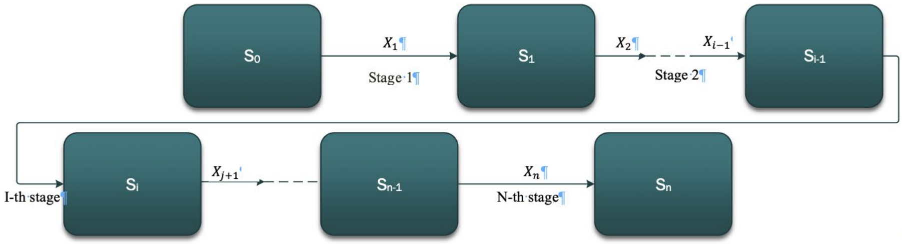

Figure 2. Multi-stage decision-making process

Source: own elaboration on the based on: Gołda et al., 'Narzędzia informatyczne wspomagające podejmowanie decyzji podczas wykonywania operacji lotniskowych.'

In the case under consideration, it is assumed that the state of the system at the end of this stage (S_i);i = 1, 2, …, n depends on the state of the system at the beginning of this stage (S_{i-1});i = 1, 2, …, n) and on the implementation of the action strategy undertaken at that stage (x_{i-1});i = 1, 2, …, n). However, it does not depend on how the system has reached a state of S_{i-1}(i = 1, 2, …, n). It can be written as the relationship:

$$S_i = \Im_i\left(S_{i-1,}x_i\right); \qquad i = 1,2,\dots,n \tag{10}$$

where: x_i is an element of the set X_i on the interpretation of acceptable action strategies at this stage.

Obviously, the elements of this set depend on the state of the system at the time of choosing the i-th action strategy, which can be written in the form of:

$$x_i \in X_i(S_{i-1}); \quad i = 1,2,\dots,n \tag{11}$$

Whereas the function of $\Im_i\left(S_{i-1,}x_i\right); \qquad i = 1,2,\dots,n$ is interpreted as the effect of the implementation of strategy with the state of the system S_{i-1}.

Therefore, the dynamic programming task[14] can be formulated as follows.

Determine the sequence of strategies x_1, x_2, …, x_n, for which the sum of the effects obtained at each stage is the maximum, i.e.

$$\sum_{i=1}^{n} \Im_i(S_{i-1}, x_i) \xrightarrow{\qquad} \max \tag{12}$$

when the conditions are fulfilled:

$$S_i = \Im_i(S_{i-1}, x_i); \quad \mathrm{i} = 1,2,\dots,\mathrm{n} \tag{13}$$

$$x_i \in X_i(S_{i-1}); \qquad i = 1,2,\dots,n.$$

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[14] Gołda et al., 'Narzędzia informatyczne wspomagające podejmowanie decyzji podczas wykonywania operacji lotniskowych'.

The sequence x_1, x_2, ..., x_n that satisfies the set of conditions (13) is called an acceptable control. On the other hand, any admissible control maximizing the sum of the effects obtained at the individual stages is called optimal control.

Different approach to the problem of optimising the operation of means of transport is presented by the authors of the paper[15]. They build renewal models, reliability models and mass service models for the purpose of optimization. The mass service model is schematically illustrated in Figure 3.

The division of mass service systems is most often made according to the classification introduced by Kendall[16]. It considers three basic characteristics of the system, namely:

- the characteristics of the call flow,
- characteristics of service times,
- number of handling positions.

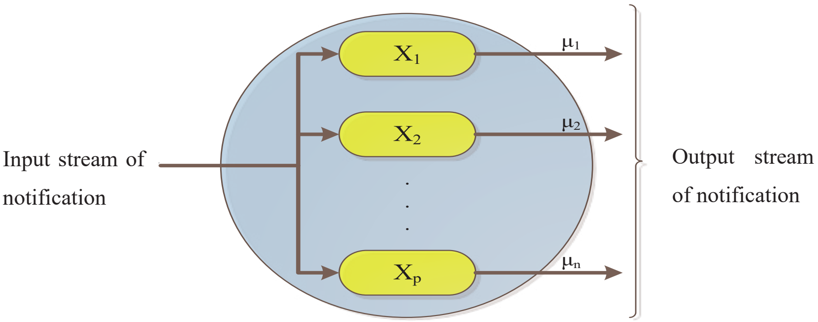

Figure 3. Mass service system model. ST_1, ST_2, ..., ST_n - service stations

Source: own elaboration based on: Gołda et al., 'Narzędzia informatyczne wspomagające podejmowanie decyzji podczas wykonywania operacji lotniskowych.'

The information concerning the characteristics of the mass handling system shall be recorded in the form $X/Y/n$, where:

X – represents the characteristics of the notification stream;
Y – represents the characteristics of the random variable of service times;
n – number of service stations.

4. OPERATING STRATEGIES OF TRANSPORT MEANS

The processes of use and maintenance of technical means of transport are carried out in enterprises based on the adopted exploitation strategies. The exploitation strategy[17]

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[15] Lewitowicz, 'Logistyka w eksploatacji statku powietrznego'.

[16] Gołda et al., 'Narzędzia informatyczne wspomagające podejmowanie decyzji podczas wykonywania operacji lotniskowych'; Lewitowicz, 'Podstawy eksploatacji statków powietrznych'.

[17] Siergiejczyk, Krzykowska, and Rosiński, 'Reliability-exploitation analysis of the alarm columns of highway emergency communication system'.

consists in determining how to manage the use and operation of means of transport and the relationship between them in the light of the adopted criteria.

In the literature on the exploitation of technical means of transport[18], there are considerations on exploitation strategies of means of transport, among which strategies are distinguished according to the following:

- technical condition;
- reliability of the means of transport;
- the amount of work done;
- economic efficiency.

In practice, there are usually mixed exploitation strategies adapted to the requirements and operating conditions of the means of transport. Based on the exploitation strategies of means of transport, maintenance systems for means of transport are built in enterprises.

According to the authors of the works[19], a transport means of the transport maintenance system is:

- a set of principles of technical servicing of means of transport;
- a set of objects carrying out servicing (service stations, workshops, plants);
- organizational and technological relations between these facilities.

Thus, it can be said that the operation of the means of transport maintenance system consists in the definition of control processes involving decision-making, which concern the answers to the questions: when, what, and how to operate.

The operating system of a means of transport is characterized by:

- the technology of maintenance work;
- the principles of the system; and
- the organization of the system.

It should be noted that the maintenance system is one of the basic elements (subsystems) of the transport means operation system. The selection of the type of maintenance system requires consideration of various criteria which include:

- acceptable values for the technical condition parameters of the means of transport;
- acceptable level of reliability;
- minimum unit maintenance costs.

As regards the organizational services program carried out in the system, the maintenance system is divided into open and closed systems. On the other hand, considering the principles of system operation, maintenance systems can be divided into the following:

- planned-preventive systems;

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[18] Świderski et al., ‘Wear of Brake System Components in Various Operating Conditions of Vehicle in the Transport Company’; Izdebski, Jacyna-Gołda, and Jakowlewa, ‘Planning International Transport Using the Heuristic Algorithm’; Jacyna-Gołda, Żak, and Gołębiowski, ‘Models of Traffic Flow Distribution for Various Scenarios of the Development of Proecological Transport System’.

[19] Galinski, ‘Gust Resistant Fixed Wing Micro Air Vehicle’; Gołda and Manerowski, ‘Model Systemu Operacji Kołowania Samolotów’.

- condition-based maintenance systems.

Analyzing the development trends of service systems[20], it is possible to identify the main directions for the improvement and enhancement of these systems, which include:

- extending the maintenance intervals of the means of transport;
- reducing the range of maintenance activities; and shifting these activities from lower to higher types of maintenance, which may be conducive to reducing the labor intensity of maintenance activities in lower types of maintenance:
  - an increase in the scope of diagnostics, concentration of servicing and the use of repairs by means of replacing assemblies in own maintenance facilities,
  - intensification of diagnostics development and the introduction of high-performance maintenance methods.

In the literature on the subject[21] the planned preventive system is understood as a set of undertakings and their mutual conditions consisting in the performance during the operation of means of transport of activities that prevent the occurrence of accelerated wear of its elements and assemblies.

A variant of the plan-and-prevent system is the plan-and-enforce system, which is because after a means of transport reaches the interservice mileage set by the norm, it is directed to service regardless of its actual technical condition.

The use of a scheduled-compulsory system[22] becomes expedient when:

- the service life of the individual assemblies of the means of transport is similar and the determination of the service life of the means of transport is easy with its small scatter;
- it is necessary to ensure a state of high efficiency of the means of transport;
- the overhaul costs are negligible compared to the losses that may result in losses that may arise from unforeseen failure of the means of transport.

The maintenance system according to technical condition[23] is characterized by the fact that maintenance is performed when the technical condition of the means of transport requires it, i.e. when further operation is economically unjustified or even impossible.

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[20] Galinski, 'Gust Resistant Fixed Wing Micro Air Vehicle'; Galinski et al., 'Results of the J-5 Marco Dynamic Similar Model Flight Tests Program'; Gołda and Manerowski, 'Model Systemu Operacji Kołowania Samolotów'; Goraj and Szender, 'Badania Modelu Samolotu w Locie Na Dużych Kątach Natarcia'; Konieczny, Podstawy eksploatacji urządzeń; Nowakowski et al., 'Study of Unmanned Aerial Vehicle Flight Capabilities in the Aspect of Civil and Military Aviation Safety'.

[21] Galinski, 'Gust Resistant Fixed Wing Micro Air Vehicle'; Galinski et al., 'Results of the J-5 Marco Dynamic Similar Model Flight Tests Program'; Gołda et al., 'Narzędzia informatyczne wspomagające podejmowanie decyzji podczas wykonywania operacji lotniskowych'; Gołda and Manerowski, 'Model Systemu Operacji Kołowania Samolotów'.

[22] Jacyna, Modelowanie i Ocena Systemów Transportowych; Pyza, 'Modelowanie Systemów Przewozowych w Zastosowaniu Do Projektowania Obsługi Transportowej Podmiotów Gospodarczych'; Toruń et al., 'Challenges for Air Transport Providers in Czech Republic and Poland'; Zieja, Smoliński, and Gołda, 'Information Systems as a Tool for Supporting the Management of Aircraft Flight Safety'.

[23] Kowalski et al., 'Planning and Management of Aircraft Maintenance Using a Genetic Algorithm'; Żak et al., 'Assessment of Airside Aerodrome Infrastructure by Saw Method with Weights from Shannon's Interval Entropy'.

Therefore, such a system requires continuous monitoring of the technical condition of the means of transport. In this type of system, it is not possible to determine the extent of maintenance. It is therefore impossible to determine the periods between maintenance (these periods are random), the type and labor intensity of maintenance, which in turn makes it difficult to manage the maintenance system. In papers[24] we can find different definitions of the concept of exploitation. According to the PN-82/N-04001 standard, exploitation is defined as: ‘a set of intentional organizational, technical, and economic activities of people with a technical object and the mutual relations occurring between them from the moment the object is accepted for use according to its purpose until its decommissioning’.

In this approach, the definition of exploitation captures the meaning of the term in an organizational aspect. A different approach to the term exploitation is presented by the author of the paper[25], who defines this concept as the totality of all events, phenomena, and processes occurring in each means of transport from the moment of its completion until its decommissioning.

The technical state of any technical object, and therefore also of the means of transport, because of its exploitation, changes continuously, which means that, when passing from one state to another, the means of transport always passes through many intermediate states. In practice, it is sufficient to use a finite number of states in the operation of means of transport.

When examining the process of exploitation of any means of transport, it is easy to see that it is made up of individual types of time intervals repeating usually in a fixed and characteristic sequence for a given means of transport. Thus, it can be assumed that the exploitation of a single means of transport shown in Figure 4 is a representation of one of the possible realizations of its exploitation process.

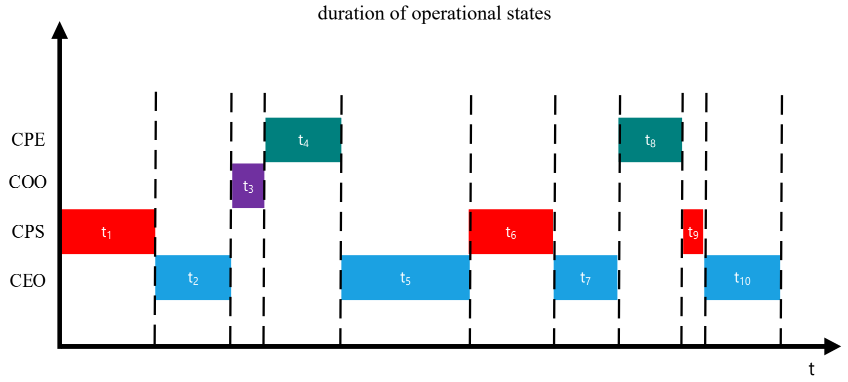

Figure 4. A segment of the operation of a statistical means of transport

Source: own elaboration based on: Prażewska, ‘Prognozowanie czasu wykonywania operacji naprawczej’.

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[24] Bowles, ‘The New SAE FMECA Standard’; Goraj and Szender, ‘Badania Modelu Samolotu w Locie Na Dużych Kątach Natarcia’; Konieczny, ‘Podstawy eksploatacji urządzeń’.

[25] Prażewska, ‘Prognozowanie czasu wykonywania operacji naprawczej’.

where:
CPE – effective working time of means of transport;
CPS – time of standstill of the means of transport;
COO – waiting time for service;
CEO – time of effective operation of the means of transport.

When analyzing a sufficiently large set of separate realizations of the process of operation of means of transport, it is possible to see many statistical regularities, based on which it is possible to establish a typical picture of the operation of a statistical means of transport (Figure 5). The operating time of a means of transport should be understood as the sum of the time segments during which the means of transport is in operation or in service.

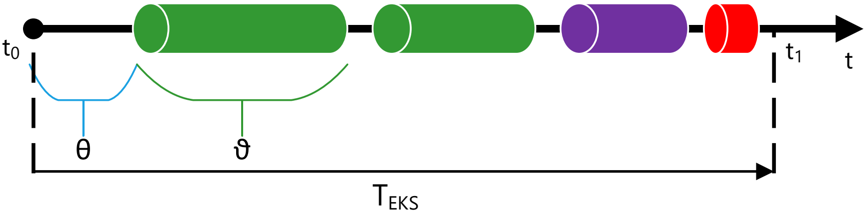

Figure 5. A representative image of the life of a «statistical» aircraft
Source: own elaboration.

In Figure 5, the image of the 'average' aircraft life is presented, where t_0 and t_1 represent the moments of aircraft operation start and end respectively. T_{eks} represents the duration of its operation, ϑ indicating the duration of a single service, and a θ represents the effective aircraft operation time between consecutive services.

In the transportation asset utilization model, two states are distinguished[26]:

- The utilization state of the transportation asset;
- The servicing state of the transportation asset.

Every aircraft undergoes physical ageing as a result of utilization, leading to partial or complete loss of utility properties.

On the aircraft, certain types of maintenance are performed, which form a collection $O = \{1,2,\ldots, o, \ldots, O\}$, with O being the number of types of service.

The need for maintenance of the o-th type, where $o = 1,2, \ldots, O$ is caused by irregular wear of individual aircraft components (subassemblies). The degradation rate of the aircraft or its parts depends on the intensity of the operation and increases with the time of operation. It can be assumed that for each aircraft in service, there is a measure of the amount of work done. This measure for aircraft is measured by the number of hours in the air.

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[26] Prażewska, 'Prognozowanie czasu wykonywania operacji naprawczej'.

Wear and tear on a means of transport increases over time, i.e. $\gamma = \gamma(t)$, which means that at a certain time , after a certain amount of work has been done, it should be sent for service.

In general, the manufacturer of the means of transport sets certain values for the gauge ,which have an interpretation of the mileage of the means of transport. Directly related to mileage, the types of maintenance are defined. The mileages followed by the o-th type of maintenance, $o = 1, 2, \ldots, O$, will be referred to as the inter-maintenance mileage Ω_O, $o = 1,2, \ldots, O-1$, and the largest of them the total run $\Omega_O \equiv \Omega_0$.

The specified runs Ω_O determine the moments t^0, at which the means of transport should be directed to the next service. Moments t^0 are defined by the equation:

$$\gamma\ (t^o) = \Omega_0 \tag{14}$$

The magnitudes Ω_O, are ordered in a sequence of increasing waveform values, i.e:

$$\Omega_1 < \Omega_2 < \ldots < \Omega_{P-1} < \Omega_P \tag{15}$$

The mileage value Ω_O may change in the event of:

- a change in the production technology of the means of transport;
- a change in design (assembly, parts).

Changing the mileage toward higher values, entails an increase in the price of the value of the whole means of transport. In such a situation, the designers of a means of transport are always faced with a dilemma: whether to design a means of transport with better technical parameters, thus increasing its value, or to reduce these parameters with a corresponding decrease in the value of the means of transport. When constructing a means of transport, the principle applies that the value of the inter-service mileage for a higher level of service is a multiple of the value of the inter-service mileage of the lower level, i.e. there is a relation:

$$\frac{\Omega_{p+1}}{\Omega_p} = \tau \qquad\qquad \tau = 1,2, \ldots \tag{16}$$

5. SUMMARY

The implementation of a suitable maintenance system in an aviation organization operating an aircraft allows the efficient use of its equipment. Knowledge of maintenance methods can help in the effective selection of a proper maintenance strategy. Conducting analyses of malfunctions, damage, and proper prevention will ensure a high level of safety. The results of a well-functioning maintenance system will be a high technical and operational readiness of the equipment. A well-functioning system will also be essential in the continuous monitoring of equipment aging processes and, consequently, the planning of equipment changes in the aviation organization. All these elements contribute to optimum financial management, making the company competitive in the aviation market.

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