

The method of controlling the efficiency of the airworthiness assurance subsystem in the system of means of transport operation

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Abstract. In order to ensure proper and effective performance of tasks in complex systems of means of transport operation, it is necessary to maintain an appropriate number of buses that are capable of carrying out transport. This is achieved as a result of the implementation of maintenance and repair processes at the stations of the workability assurance subsystem. The ability to perform maintenance and repair tasks assigned to airworthiness assurance subsystems depends on their readiness to drive. Ensuring the required readiness of the tested subsystems is possible by adjusting the number and structure of maintenance and repair stations, adjusting the equipment of these stations in such a way that, if necessary, it is possible to perform specific tasks at various types of stations and the use of devices and tools with high reliability, durability and efficiency. The article presents a description of the method of determining the optimal strategy for controlling the process of exploitation of means of transport with the use of decision-making semi- Markov processes. The selection of the optimal (suboptimal) solution is carried out using a genetic algorithm. As a result implementation numerical calculations , a set of solutions in the form of the so-called Pareto front is obtained for the applied criterion functions.

1 Introduction

In order to ensure proper and effective performance of tasks in complex systems of means of transport operation, it is necessary to maintain an appropriate number of buses that are capable of carrying out transport. During the implementation of the assigned tasks by the vehicles, as a result of the impact of forcing factors, such as a failure, the usable potential of technical facilities is exhausted. For this reason, most complex exploitation systems have their own technical facilities. The ability to perform maintenance and repair tasks assigned to airworthiness assurance subsystems depends on their readiness to drive. Ensuring the required readiness of the tested subsystems is possible by adjusting the number and structure of maintenance and repair stations, adjusting the equipment of these stations in such a way

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that, if necessary, it is possible to perform specific tasks at various types of stations and the use of devices and tools with high reliability, durability and efficiency.

The control of processes implemented in airworthiness assurance subsystems from the point of view of assessment criteria such as reliability and readiness is presented in many publications [1, 2, 3]. This applies to issues related to the selection of the optimal maintenance and repair strategy, as well as the assessment of the operation of subsystems for ensuring the suitability of service and repair stations. The papers [4, 5] propose methods of shaping the readiness of technical back-up stations, while the publications [6, 7] present methods for evaluating the effectiveness and efficiency of processes carried out at maintenance and repair stations. Paper [8] presents a method for determining the structure that can be coupled stations in vehicle service systems, while the method of determining the technically justified number of service and repair stations in transport systems is described in paper [9]. Among the many methods supporting the process of evaluation and control, semi - Markov decision processes [10, 11] and non-deterministic methods of determining optimal solutions were used.

The paper presents the results of research on a decision model, the application of which enables the determination of a rational strategy for controlling the operation process, taking into account selected criteria, while taking into account the requirements regarding the readiness of technical objects to perform the assigned transport tasks. considered when preparing them.

2 A decision-making model for determining the control strategy

Due to the random nature of factors influencing the operation process of technical objects (e.g. means of transport), stochastic processes are most often used for mathematical modeling of the operation process. Among the random processes, Markov and semi -Markov processes have been widely used in modeling the operation process of technical objects, while in the case of issues related to the control of complex operation processes - decision-making Markov and semi -Markov processes.

Assuming that the analyzed model of the exploitation process funds transportation is process stochastic $\{X(t): t \geq 0\}$ with finite number states process, then

$$D_i = \{d_i^{(1)}(t_n), d_i^{(2)}(t_n), \dots, d_i^{(k)}(t_n)\} \quad (1)$$

denotes the set of all possible decisions that can be applied in the i -th process state at time t_n , where $d_i^{(k)}$ denotes the k -th control decision made in the i -th process state at time t_n .

In the case when the optimization task consists in choosing the optimal strategy for controlling the operation process from among the admissible strategies, then the strategy δ is understood as a sequence whose expressions are vectors composed of decisions $d_i^{(k)}(t_n)$ made in successive moments t_n of changes in the states of the modeled operation process of technical objects

$$\delta = \left\{ \left[d_1^{(k)}(t_n), d_2^{(k)}(t_n), \dots, d_m^{(k)}(t_n) \right] : n = 0, 1, 2, \dots \right\} \quad (2)$$

In the case when decisions made in successive states of the process do not depend on the time t_n at which they are made, i.e. $d_i^{(k)}(t_n) = d_i^{(k)}$, then the strategy δ is called the stationary strategy. Then formula (2) takes the form

$$\delta = \left[d_1^{(k)}, d_2^{(k)}, \dots, d_m^{(k)} \right]. \quad (3)$$

In order to determine the optimal control strategy (decision sequence), it is possible to use semi- Markov decision processes. The decision semi- Markovian process is a stochastic process $X(t): t \geq 0$, the implementation of which depends on the decisions made at the initial

moment of the process t_0 and at the moments of process state changes $t_1, t_2, \dots, t_n, \dots$. In the case of using semi-Markov decision processes, taking a k -th control decision at the i -th state of the process at time t_n , means selecting the i -th row of the process kernel, from the set

$$\left\{ Q_{ij}^{(k)}(t) : t \geq 0, d_i^{(k)}(t_n) \in D_i, i, j \in S \right\}, \tag{4}$$

where:

$$Q_{ij}^{(k)}(t) = p_{ij}^{(k)} \cdot F_{ij}^{(k)}(t). \tag{5}$$

The choice of the i -th row of the process kernel determines the probabilistic mechanism of process evolution in the time interval $(t_n; t_{n+1})$. This means that for a semi-Markov process, in the case of a process state change from any to i -th (entering the i -th process state) at time t_n , a decision is made and the $d_i^{(k)}(t_n) \in D_{ij}$ -th state of the process is generated according to the distribution, $(p_{ij}^{(k)} : j \in S)$ to which the transition takes place at time t_{n+1} . At the same time, according to the distribution defined by the distribution function $F_{ij}^{(k)}(t)$, the length of the time interval $(t_n; t_{n+1})$ is generated to remain in the i -th state of the process when the next state is the j -th state.

In the work, in the developed decision model, criteria functions were used, such as: readiness, unit cost and load factor:

$$f_1(\delta) = G(\delta) = \sum_{i \in S_G} p_i^*(\delta) = \frac{\sum_{i \in S_G} \pi_i \cdot \bar{\theta}_i(\delta)}{\sum_{i \in S} \pi_i \cdot \bar{\theta}_i(\delta)} \tag{6}$$

$$f_2(\delta) = C(\delta) = \sum_{i \in S} c_i(\delta) \cdot p_i^*(\delta) = \frac{\sum_{i \in S} c_i(\delta) \cdot \pi_i \cdot \bar{\theta}_i(\delta)}{\sum_{i \in S} \pi_i \cdot \bar{\theta}_i(\delta)} \tag{7}$$

$$f_3(\delta) = W(\delta) = \frac{\sum_{i \in S_C} \pi_i \cdot \bar{\theta}_i(\delta)}{\sum_{i \in S_D} \pi_i \cdot \bar{\theta}_i(\delta)} \tag{8}$$

where:

$S_N \subset S$ – a set of undesirable states of the modeled exploitation process,

$S_G \subset S$ – a set of readiness states of the modeled exploitation process,

$c_i(\delta)$ – unit income generated in process states $X(t)$,

$p_i^*(\delta)$ – limit probabilities of being in the states of the considered process $X(t)$, determined on the basis of the limit theorem for semi-Markov processes [2]

$$p_i^*(\delta) = \frac{\pi_i \cdot \Theta_i(\delta)}{\sum_{i \in S} \pi_i \cdot \Theta_i(\delta)} \tag{9}$$

where:

$\Theta_i(\delta)$ – values medium unconditional times duration states process,

π_i – probabilities of the stationary distribution of the inserted Markov chain that satisfies the system of linear equations

$$\sum_{i \in S} \pi_i \cdot p_{ij} = \pi_j, \quad j \in S, \quad \sum_{i \in S} \pi_i = 1, \tag{10}$$

where

p_{ij} – conditional probabilities of transition from state i to state j , according to the dependence:

$$p_{ij} = \lim_{t \rightarrow \infty} p_{ij}(t), \quad (11)$$

$$p_{ij}(t) = P\{X(t) = j | X(0) = i\}. \quad (12)$$

In the semi- Markov decision model, the choice of a rational control strategy δ , called the optimal strategy δ^* , applies to a situation where the function (functions) constituting the criterion for choosing the optimal strategy takes an extreme value (minimum or maximum)

$$f_C(\delta^*) = \min_{\delta} [f_C(\delta)] \text{ lub } f_C(\delta^*) = \max_{\delta} [f_C(\delta)], \quad (13)$$

then, in the decision model presented in the paper, the choice of the rational (optimal) strategy δ^* is made on the basis of the following criteria:

$$r(\delta^*) = \min_{\delta} [r(\delta)], \quad (14)$$

$$G(\delta^*) = \max_{\delta} [G(\delta)]. \quad (15)$$

In developed model decision maker to choose from strategy δ^* control process exploitation funds transportation applied algorithm genetic . in case usage this type tools to determine _ strategy optimal δ^* control process operation, you must accept following assumptions:

- the modeled exploitation process has a finite number of states $i = 1, 2, \dots, 9$;
- the random process $X(t)$ being a mathematical model of the exploitation process is a homogeneous process;
- if the technical object (PZZ station) at time t is in state i , then $X(t) = i$, where $i = 1, 2, \dots, 9$;
- at the initial time $t = 0$ the process is in state 1, i.e. $P\{X(0) = 1\} = 1$.

Based on above assumptions, each possible strategy control you can introduce as m - position string composed of 0 and 1, then example strategy control for the 9-state model is specified as follows: $\delta = [0,1,0,0,0,1,0,1,1]$

3 Determination of a rational control strategy

The model of the operation process was built on the basis of the state space analysis and operational events related to city buses operated in the analyzed transport system. Due to the considered assessment criteria: the risk of adverse events and the readiness of technical objects, on the basis of the identification of the multi-stage operation process of technical objects, significant operational states of this process and possible transitions between the distinguished states were determined. The list of states of the modeled exploitation process and the matrix of transition probabilities between these states are presented below:

1 - stopover organizational positions, 2 - supply positions, 3 - waiting positions for implementation assigned tasks , 4 - implementation assigned tasks , 5 - handling positions after completion assigned quests , 6 - renewal planned positions (renewal preventive), 7 – service technical positions , 8 - waiting renewal positions _ unplanned (restoration after damage), 9 - unplanned restoration of the station (recovery after damage) .

Control process exploitation buses urban possible is as a result making appropriate decisions in the states decision making process. For considered model process exploitation buses urban based _ data consumables estimated values elements matrix probabilities pass P, determined possible decisions taken in decision-making states process (Table 1) and designated unconditional times and units income generated in the states analyzed process (Table 2).

Table 1. Decisions in decision states of the analyzed process

Process status	Decision "0"	Decision "1"
2	Procurement PZZ positions marked code "0" ("normal")	Procurement PZZ positions marked with the code "1" ("intensive")
4	Implementation tasks at the PZZ position marked code "0" ("normal")	Implementation tasks at the PZZ position marked code "1" ("intensive")
5	Handling PZZ positions after completion works Marked code "0" ("normal")	Handling PZZ positions after completion works Marked with the code "1" ("intensive")
6	From the begining planned PZZ positions (preventive) marked code "0" ("normal")	From the begining planned PZZ positions (preventive) marked code "1" ("intensive")
7	Service technical PZZ positions marked code "0" ("normal")	Service technical PZZ positions marked code "1" ("intensive")
9	From the begining unplanned PZZ position (after damage) marked code "0" ("normal")	From the begining unplanned PZZ position (after damage) marked code "1" ("intensive")

Table 2. Average times and unit income in the states of the analyzed process depending on the decision

State process	$\Theta_i^{(0)}$ [h]	$\Theta_i^{(1)}$ [h]	$c_i^{(0)}$ [PLN/h]	$c_i^{(1)}$ [PLN/h]
1	7.1	7.12	11	11
2	0.44	0.26	100	117
3	0.65	0.65	45	62
4	6.69	5.45	83	100
5	0.47	0.38	90	107
6	9.8	7.59	90	110
7	8.3	7.19	210	235
8	10.7	10.7	11	11
9	12.8	8.9	115	135

The second table shows the average times and unit costs that apply to individual states of the modeled process and refer to possible decisions made in the states. Columns 2 and 4 refer to the data for decisions marked with code 0, while columns 4 and 5 refer to decisions marked with code 1.

Among the states of the operation process can be distinguished. The following state groups:
- 1,2,3,4 - station readiness states,

- 2,4,5 - processes are carried out at the station,
- 2,3,4,5- states where employees are ready to perform tasks.

For operational data concerning the renewal stations (stationary stations of the Bus Depot) in the PZZ airworthiness assurance subsystem, calculations were made using a computer program using a genetic algorithm. On the basis of the performed calculations, suboptimal strategies for controlling the exploitation process implemented in the examined transport system were determined for the adopted criteria. The results of the calculations are presented in figures 1 - 6 and in tables 1 - 3.

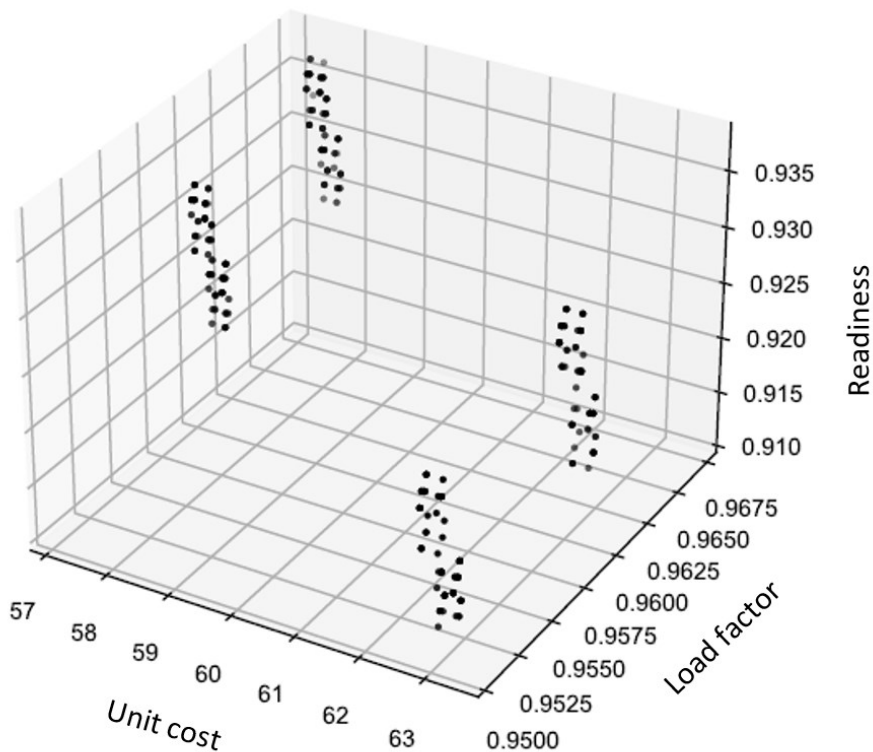


Fig. 1. Results obtained in subsequent iterations using a genetic algorithm (3-criteria)

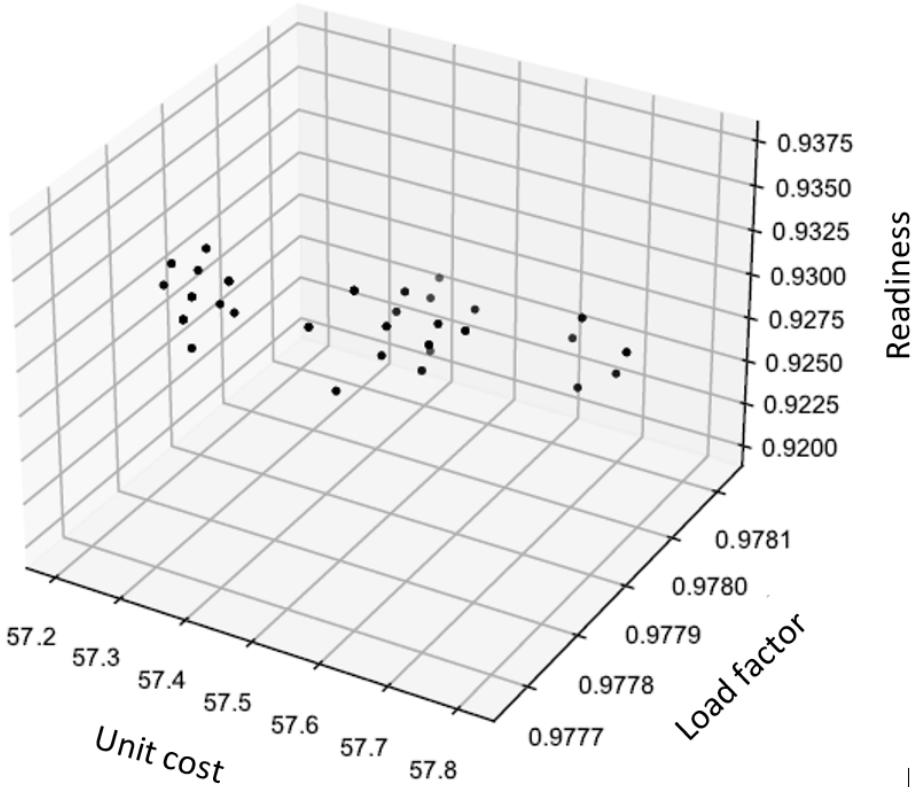


Fig. 2. Pareto front of optimal solutions determined using a genetic algorithm (3-criteria)

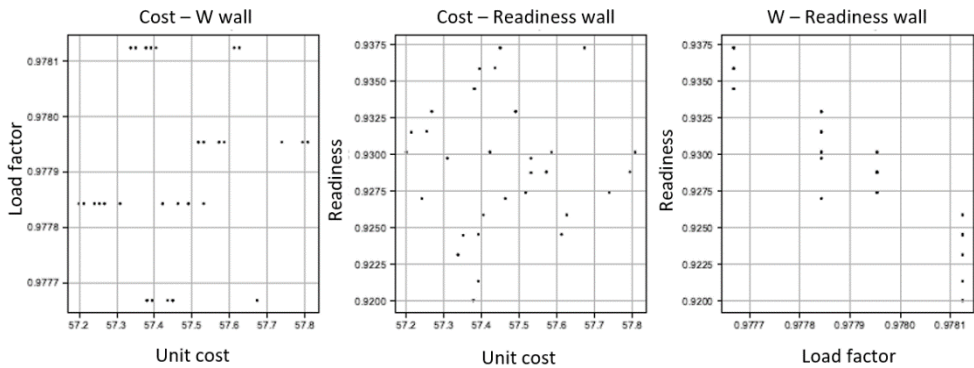


Fig. 3. Pareto front projections (3-criteria) of optimal solutions determined using a genetic algorithm

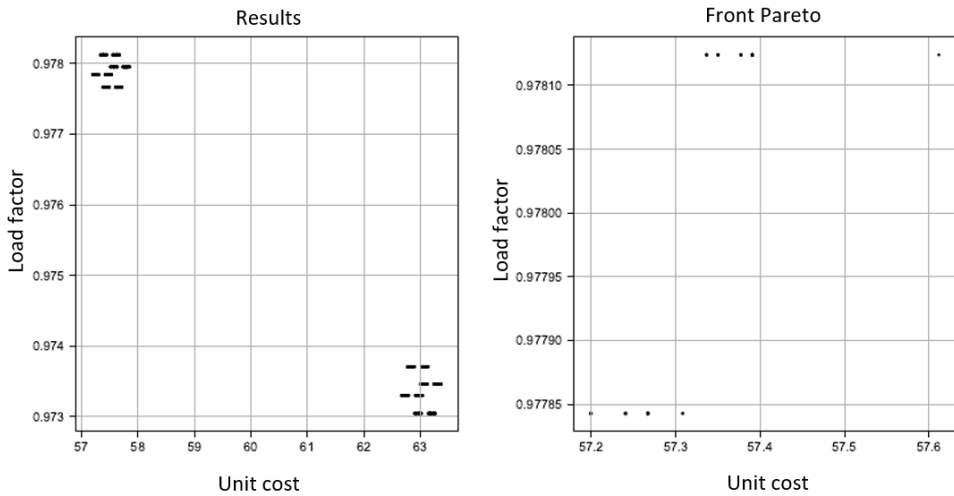


Fig. 4. The results obtained in subsequent iterations and the Pareto front (genetic algorithm)

2-criteria chart: Unit cost - Load factor

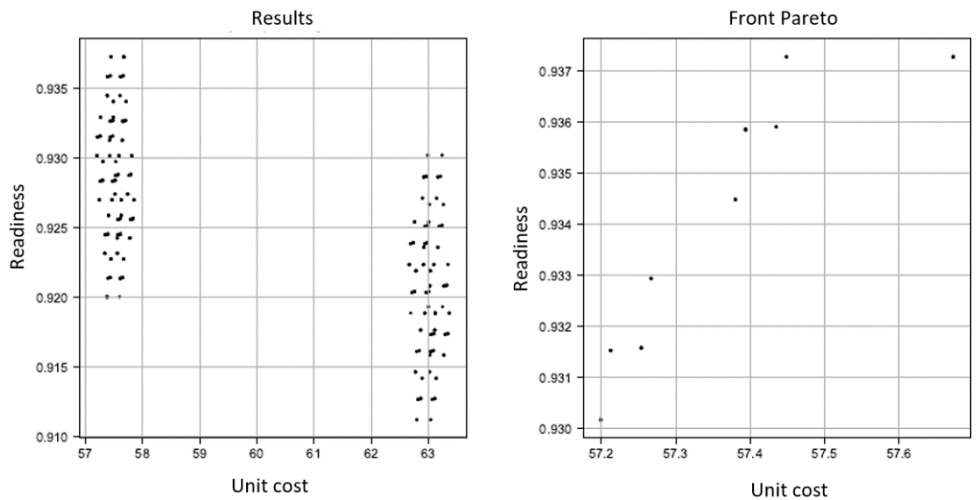


Fig. 5. The results obtained in subsequent iterations and the Pareto front (genetic algorithm) 2-criteria graph: Unit cost - Readiness

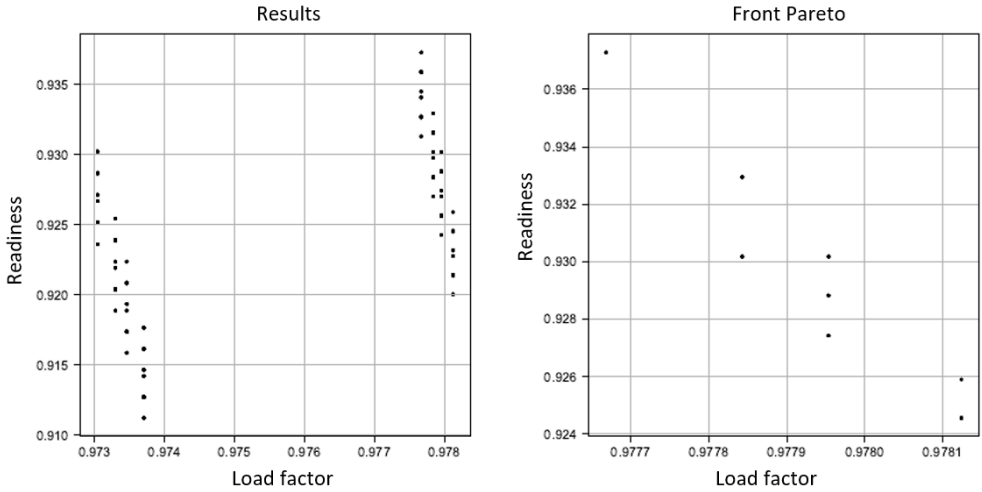


Fig. 6. The results obtained in subsequent iterations and the Pareto front (genetic algorithm) 2-criteria chart: Load Index – Readiness

In the developed model, not all states are decision-making states. The table shows the decisions that can be made in decision states. Decisions 0 concern normal conduct, when a given activity is performed longer, but the cost of the operation is reduced, while decisions 1 include intensive services.

Table 3. Examples of optimal δ^* strategies and criteria function values determined using a genetic algorithm (3-criteria)

δ^* strategy	$G(\delta^*)$	$C(\delta^*)$ [PLN /h]	$W(\delta^*)$
[1,1,0,0,1,1,1,1,1]	0.9373	57.45	0.9776
[1,1,0,0,1,0,0,1,1]	0.9345	57.38	0.9777
[1,0,0,0,0,0,0,0,1]	0.9232	57.34	0.9781
.	.	.	.
[0,0,1,0,1,0,0,0,1]	0.9274	57.73	0.9779

4 Summary

The work presents a model of the process of exploitation of means of transport, the application of which makes it possible to determine the control strategy in relation to three selected criteria (costs, load factor, readiness). For the determined values of the criterion functions, the corresponding rational control strategies were obtained, being sets of optimal solutions in the sense of Pareto . These solutions create the so-called Pareto front , on the basis of which the decision maker of the system can choose a solution from the set of optimal solutions on this front. The choice may be influenced by additional conditions beyond the knowledge of the decision-maker, such as the functioning of a given exploitation system or a specific decision-making situation.

The developed algorithm and decision model of the operation process can be used in solving problems related to the control of complex transport systems.

The model presented in the article is a partial result of the entire research carried out, the aim of which is to develop a comprehensive method of controlling the effectiveness of the airworthiness assurance subsystem in the system of operation of means of transport

In the tested subsystem, ensuring the required readiness of the airworthiness subsystem is possible by:

- adjusting the number and structure of maintenance and repair stations,
- adapting workstations and their equipment so that it is possible to perform specific tasks on different sets of workstations,
- the use of stations equipped with tools of higher durability and reliability.

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