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SELECTED ASPECTS OF THE MAINTENANCE SYSTEM OPTIMISATION OF THE POLISH ARMED FORCES HELICOPTERS

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Abstract

The maintenance of helicopters at the airports of the Polish Armed Forces in the state of technical efficiency determines the possession – by the entity securing their maintenance, repair – of appropriate resources and the maintenance system. The article presents the current state of the operation processes of helicopters in the Polish Army. The characteristics of the helicopter maintenance system model and the basic assumptions were described, and the mathematical records of input data to the system were identified and presented. The selected elements of the optimisation task, its decision variables, and constraints were formulated. The initial assessment of the quality of the proposed solution of the helicopter maintenance system model. The essence of the system optimisation problem, which relates to minimising the cost function and maximising the system's readiness function, was emphasised. In addition, an example of appropriateness of applying such an approach is presented on the basis of the School Aviation Base. The article was concluded with a short summary, which stressed the importance of this type of the optimisation system.

Keywords: *helicopters, maintenance system, optimisation of systems*

1. Introduction

The proper implementation of tasks performed by the Polish Armed Forces depends, among others, on having certain resources, including the adequate number of aircraft. Among them, helicopters deserve special attention in terms of their unique flight parameters. The most important feature that proves uniqueness of this type of equipment is its ability to perform both take-offs and landings, as well as climbing and descending in the vertical direction with a zero flight speed.

Currently, in order to perform the tasks (training, transport, recognition, rescue, direct support of the activities of the Land Forces and the Polish Navy) assigned to the helicopters, the Polish Army uses their following types: SW-4 Puszczyk, W-3 Sokół, Kaman SH-2G Super Seasprite, Mi-24, Mi-17 Mi-14, Mi-8 and Mi-2, the total number of which is approx. 250 pieces.

The advantages of the helicopters associated with the specificity of their flight, including vertical take-off and landing, determine the costs of their operation higher than in case of aircraft. The reason for this state of affairs results from the fact that many elements of their construction are subjected of because variable of strength and direction. As a result, if negligence or errors in inspections, overhauls, or maintenance of helicopters are committed at the stage of the current operation, the effect may be damage to one of the essential elements (e.g. main rotor blade). Summing up, the system of performing the maintenance of helicopters is key for ensuring an adequate level of readiness of this type of aircraft.

Currently, the Polish Armed Forces, in its structures, do not have sufficient resources, including the properly trained engineering and aviation personnel, highly specialised equipment, spare parts, and materials necessary to perform all inspections and servicing of helicopters. As a result, a degree of readiness of the possessed helicopter fleet is not satisfactory. The helicopters waiting many days for repair lose their calendar resource. As a result of such behaviours, the helicopters, which instead of flying, most of the time spent uselessly in hangars or in the open air waiting for maintenance or repair, are withdrawn from use. In order to reduce this type of activities in the recent time, it is commissioned to external licensed companies to perform some inspections of the helicopters. These companies carry out periodic, hourly and calendar inspections.

A drawback of the maintenance provided by the external companies is their cost. In case of the maintenance carried out as part of the military resources, the person-hour costs are treated in a secondary way. In the era of the market economy, the Polish Armed Forces must take this factor into account more. Having regard to the above, the right decision on the implementation of the maintenance of helicopters requires, apart from many restrictions (resulting from the adopted operation strategy and maintenance capabilities of the maintenance system), taking into account the appropriate criterion for assessing the solution quality. According to the authors of the article, the optimal planning of the maintenance of helicopters should take into account, as a criterion of the assessment, both the level of readiness and the amount of incurred costs.

2. Maintenance of helicopters

The objectives and tasks of the maintenance directly result from the aircraft structure. The constructor has an impact on the simplicity of maintenance of a given aircraft type. The concept of maintenance is the performance of tasks and activities necessary to ensure the continuity of the aircraft airworthiness, including a single or a complex inspection, control, replacement, removal of the defect and the introduction of modifications or the repair performance. In the maintenance phase of the aircraft, the maintainability, also called maintenance producibility. It constitutes the adaptation of the structure to perform the necessary maintenance. Despite this fact, it is primarily in the area of interest mainly for maintenance bodies, it has to be taken into account by users, and it has a significant impact on both costs and real time of operation.

The most appropriate measure of maintainability is the frequency and scope of the maintenance performance. This factor completely affects both the costs and the real time of operation. Summing up, the lower the frequency, and scope of the performed maintenance, the longer the time of effective use of the helicopter for transport, combat, and flight training tasks.

In the maintenance of helicopters, there are many various types of maintenance and inspections. Their types are a contractual matter and those, which are required by the manufacturer of given aircraft, are used. Among the maintenance types, we distinguish current, periodic and special ones.

The current maintenance consists of: initial maintenance (A), pre-flight maintenance (B), start maintenance (C), after-flight maintenance (P) as well as periodic inspection (D) and special maintenance. The periodic inspection (D) and special maintenance are performed between the periodic maintenance in order to check the technical condition of the helicopter and to maintain it in the state of constant technical efficiency. The periodic inspection and special maintenance are performed within the initial maintenance, "days of technology" or other working days on the equipment dedicated for this purpose.

The periodic maintenance occurs in two types after a period (number of calendar days) or after working time (number of hours). The maintenance is performed when the earlier date comes.

The currently observed high technical level of helicopters, their saturation with electronic systems, including IT ones, affect the change of systems and the organisation of work of technical services. The systematic changes are observed both in the methods of maintenance, as well as in the methods of their implementation. The diagnostic devices, which provide a high level of the assessment of the technical condition of engines, or built-in devices, are more often used. Such a situation causes specific changes in the organisational forms and conduct of the operation service. It forces to extensively cooperate and exchange the information, methods of aircraft and technical supply, as well as to plan in details, and to forecast all possible adverse events that could result in the inability to use the aviation equipment or the occurrence of emergency states. However, there are some necessary distinguishable directions of the technical service operation, which are always the subject of organisational undertakings, regardless of the differences occurring in the helicopter operation systems.

For the purposes of further considerations regarding the maintenance system optimisation, it was assumed that we deal with the maintenance system performing the planned maintenance and that the maintenance performed by this system constitutes personal maintenance. The personal maintenance is maintenance in the process of implementation, the aircraft of which fully stays in the maintenance system. In such a case, the helicopters are transferred for the inspections to the companies dealing with maintenance. Some companies offer a service with access to the client, implemented with the appropriately equipped Mobile Operating Base (MOB) (Fig. 1). In this case, the client saves time and money associated with the helicopter delivery to the company. Such a mobile service, from the perspective of the Ministry of National Defence, is attractive in terms of both costs and maintenance time. Currently, all types of the helicopters that are at the disposal of the Polish Army can be maintained directly in units, based on the signed contracts. The whole service saves the helicopter's resources, reduces costs and lasts shorter – the helicopter returns to service faster.

Fig. 1. Navcomsystems Mobile Operation Base [1]

The standard course of such a service using the Mobile Operating Base consists of three stages:

1. A maintenance team comes to the helicopter in the Mobile Operating Base.
2. It disassembles the units in order to check them in the laboratory, and in the meantime, it performs the maintenance work on the airframe and engines.

3. After checking in the laboratory, the units are mounted on the helicopter and the final maintenance is carried out.

The duration of periodic activities is usually from 2 to 4 weeks. It is similar to the performance of higher-order maintenance activities (for example, engine maintenance), in such a case, after a maximum of 3-4 months, the machines can return to operation. In both cases, the time is shorter than in case, when the helicopters are repaired by the Polish Army employees or wait for the manufacturer's service. Of course, if some equipment elements require more extensive diagnostics than it can be provided by the Mobile Operating Base, such services are performed at the company's headquarters, which generates higher costs and maintenance time.

Taking into account the current state of the helicopter maintenance performance, it can be assumed that it is reasonable to develop the maintenance system, the purpose of which is to determine the optimal one in terms of costs and level. This system will be saved in the form of an optimisation task. In the further part of the article, the characteristics of the helicopter maintenance system model and the basic assumptions were described, and the mathematical records of input data to the system were identified and presented. The selected elements of the optimisation task, including its decision variables, constraints and the objective function were formulated.

3. Model of the helicopter maintenance system

The formal record proposed in the article for the optimisation task of the problem of operation of the helicopter maintenance system takes into account the actual system parameters. The application of the optimisation model allows making right decisions regarding the selection of parameters characterising the system, adopted by the company, which performs the maintenance. The values obtained as a result of solving the above task can be an element supporting the decision-making process in terms of development by particular units of the held resources with certain forecasts of the growth of the provided services.

The actual Helicopter Technical Maintenance System, in view of the large number of elements, is too complicated for a direct analysis; therefore, its model is constructed. The model's form depends on the research purpose, whereby the model should map the complexity and interdependence of phenomena occurring during the actual operation of the system.

For the purposes of constructing the model, it is necessary to map its basic properties, i.e.: the system elements and their characteristics. For the purposes of a formal description of the maintenance system modelling, the model's input data must be identified.

By taking into account the above, the helicopter maintenance system model was defined including the following elements:

– a collection of the system elements (helicopters, airports, maintenance companies) – *electromechanical security systems [ESO]*,
– characteristics of the system elements showing its actual properties (especially the characteristics of accessibility and restrictions) – F,
– the sizes of a stream of notifications identified at the entry to the system (volume of the demand for maintenance resulting from the operation system) – Z,
– organization of the helicopter maintenance performance – O.

By taking into account the above, the helicopter maintenance system model will be saved as ordered four, in the form of:

$$MSOTS = \langle ESO, F, Z, O \rangle . \tag{1}$$

The maintenance system of the organisation using the helicopters will be determined as a result of solving the optimisation task formulated adequately to the considered decision-making situation. It requires the definition of data and their characteristics of decision variables, constraints and the criterion function, which is a measure of the task solution quality.

The optimal organisation of the helicopter maintenance system enables the best – from the perspective of the adopted assessment criteria – maintenance implementation. The optimisation tasks of the considered decision situation require the definition of decision variables, constraints and the criterion function, which is a measure of the problem solution quality.

Some of the model's parameters, e.g. the current level of resources, were obtained from the SAN/SAMANTA BIS System. This system is designed to analyse and assess the operation processes of all types and versions of the aircraft operated in the Polish Armed Forces, both of individual units (their assemblies and elements) and any created collections. The software package supports the decision-maker in controlling the aviation technology operation, allowing for the recognition of symptoms of changes in the level of reliability, safety, and quality of the aircraft operation processes, as well as determination of the recommended directions of preventive activities.

By analysing the process of the maintenance of helicopters, the following sets and parameters were defined:

- S – a set of numbers of the helicopter types: $S = \{s : s = 1, ..., s', ..., S\}$,
- $L(s)$ – a set of numbers of s type helicopters: $L(s) = \{(s,k) : k = 1, 2, ..., L(s)\}$,
- P – a set of maintenance numbers: $P = \{p : p = 1, ..., p', ..., P\}$,
- I – a set of airport numbers: $I = \{i : i = 1, ..., i', ..., I\}$,
- A – a set of numbers of external companies and maintenance squadrons belonging to the Air Bases dealing with maintenance: $A = \{a : a = 1, ..., a', ..., A\}$,
- TE – a set of numbers of the applied technologies (related to the place and maintenance provider) $TE = \{t_e : t_e = 1, ..., t_e', ..., TE\}$,
- $\psi(s,p)$ – allocation of maintenance types to the helicopter types: $\psi(s,p) \in \{0,1\}$,
- $\lambda(s,t_u)$ – average intensity of the s type helicopter operation in the adopted time unit t_u, the parameter is determined on the basis of historical data, and if it is possible (e.g. in case of helicopters used for training), based on the anticipated demand for flights: $\lambda(s,t_u) \in \Re^+$,
- $ED_t((s,k),t)$ – the remaining value of technical resources at t moment (days), based on data obtained from SAMANTA,
- $EH_t((s,k),t)$ – the remaining value of technical resources at t moment (working hours), based on data obtained from SAMANTA,
- $ED_n((s,k),t)$ – the remaining value of technical resources at t moment, based on data obtained from SAMANTA,
- $EH_n((s,k),t)$ – the remaining value of technical resources at t moment, based on data obtained from SAMANTA,
- $O_h(p,(s,k),t)$ – time that passed since the last maintenance type (working hours) – intermaintenance resources,
- $O_h(p,(s,k),t)$ – time that passed since the last maintenance type (days) – intermaintenance resources.

The analysis of the availability of the maintenance system elements requires taking into account the passage of time in the system model. Therefore, the time was divided into sections of a constant length of time (day), the T set of which can be presented in the following form: $T = \{t : t = 1, ..., t', ..., T\}$ where: t – next period of time, T – number of all periods of a fixed length.

Among the characteristics on the entities performing the maintenance, we can distinguish:

- $\tau(s,t_e,p,a)$ – execution time of the p maintenance on the s type of the helicopter with the use of the t_e technology by the a entity: $\tau(s,t_e,p,a) \in \Re^+$,
- $\chi(s,t_e,p,a)$ – the cost of maintaining the maintenance system performing the maintenance with the number p on the s-type of the helicopter with the use of the t_e technology: $\chi(s,t_e,p,a) \in \Re^+$,

and other.

The optimisation task defines two types of binary decision variables, i.e.:

- $x((s,k),p,t_e,t,i)$, equal to 1, when the helicopter with the number (s,k) from the i airport, is operated within the t period in the scope of the p type maintenance with the use of the t_e technology by the service group from the parent unit, otherwise $x((s,k),p,t_e,t,i) = 0$,
- $y((s,k),p,t_e,t,a,i)$, equal to 1, when the maintenance of the p type with the use of the t_e technology of the helicopter with the number (s,k) being the i, airport equipment, is performed within the t period by the a external company, otherwise $y((s,k),p,t_e,t,a,i) = 0$.

The optimisation task of the maintenance system operation is characterised by many restrictions, among which it is possible to distinguish:

- restrictions on the nature of decision variables,
- restrictions on the duration of individual maintenance,
- restrictions on the number of maintenance of resources held by the provider (service groups, process lines),
- restrictions on the number of employees,
- restrictions on the cost of performing the maintenance,
- restrictions on repairing resources,
- restrictions on technological resources,
- restrictions on maintenance resources,
- restrictions on the allocation of helicopters to technologies,
- restrictions regarding the achievement of a minimum level of readiness in individual units,
- and other.

The criterion for assessing the operation of the system for periodic maintenance of the helicopters placed at military airports should reconcile different objectives. The proposed model includes two criteria, i.e. minimising the maintenance costs – *F1* and maximising the level of readiness – *F2*.

The *F1* function constituting the system assessment criterion is the sum of the cost of maintenance of repairs performed in the area of the parent unit and performed in the external company's plants:

$$\forall i \in I \;\; F1(X,Y) =$$
$$= \sum_{t\in T}\sum_{s\in S}\sum_{(s,k)\in L(s)}\sum_{p\in P}\sum_{t_e\in TE} \chi(s,t_e,p,a)\left(\sum_{a\in A} x\big((s,k),p,t_e,t,a,i\big) + y\big((s,k),p,t_e,t,a\big)\right) \rightarrow \min, \quad (2)$$

where the second measure of the assessment of the maintenance system is a general coefficient of technical readiness in the t moment:

$$\forall t \in T \;\; F2(X,Y) = \frac{V_{GT}(t)}{V_{EX}} =$$
$$= \frac{\sum_{s\in S} L(s) - \sum_{s\in S}\sum_{(s,k)\in L(s)}\sum_{p\in P}\sum_{t_e\in TE}\left(\sum_{a\in A} x\big((s,k),p,t_e,t,a,i\big) + y\big((s,k),p,t_e,t,a\big)\right)}{\sum_{s\in S} L(s)} \rightarrow \max. \quad (3)$$

4. Example of the legitimacy of the presented methodology development

The legitimacy of dealing with the optimisation issue of the helicopter maintenance system on the example of SW-4 Puszczyk helicopters belonging to the Air Base.

During the "Puszczyk" operation, the current maintenance is performed, i.e.:

– *Emergency* – performed immediately at the time of the announcement of higher states of combat readiness, the receipt of the order to immediate perform a combat task and a rescue flight,
– *Initial (A)* – performed during the transfer of the helicopter between the maintenance systems on the days of performing the technical maintenance, e.g. the so-called "days of technology" and it is valid for next 15 days or 25 hours of flight,
– *Pre-flight (B)* – performed on the day of flights before the first flight of the helicopter,
– *Start (C)* – performed before each flight of the helicopter,
– *After-flight (P)* – performed immediately after the end of flights, after the completion of periodic or special maintenance, if the helicopter does not take part in flights and after each day of work on the helicopter,
– *Periodic inspection (D)* – performed after every 50 hours of the helicopter flight,
– *Periodic inspection (D2)* – performed after every 100 hours of the helicopter flight.

However, among the periodic maintenance of SW-4 helicopters, it is possible to distinguish:
– *p = 1-300-hour/year* – performed after every 300 hours of flight or every 12 months,
– *p = 2-600-hour/2-year* – performed after every 600 hours of flight or every 2 years.

The periodic maintenance is performed at the same time in all specialities (airframe and engine, equipment, radio). It is on dates determined by the number of hours of the helicopter flight or the passage of calendar time, whichever comes first.

All the current and special maintenance on the helicopters operated in the Air Base in the City A are performed mostly by technicians from the maintenance squadron. However, the periodic maintenance is performed by the technical squadron and the Polish Air Force (PWL) City B.

The analysis of the legitimacy of development of the system optimising the helicopter maintenance carried out for data of 2015-2018.

Figures 2-5 show the maintenance performance diagrams for a given period. The diagram clearly shows that in extreme cases – the turn of 2015/2016, 7 (6 in the City A) helicopters were operated at the same time per 20 possessed ones. Thus, the level of readiness was significantly reduced. The average maintenance time $p = 1$ in the City A is 203.87 days, however, in the City B, it is 157.17. The average maintenance time $p = 2$ in the City A is 167.2 days, however, in the City B, it is 139.36.

Such long maintenance time, especially in case of maintenance $p = 1$ taking place in the City A (often over 300 days), results in combining the maintenance $p = 1$ with maintenance $p = 2$.

Summing up, according to the analysis of the obtained results it appears that the introduction of the system supporting the organisation of the maintenance of helicopters is justified and it should protect individuals from the situation, in which too many helicopters are maintained at the same time.

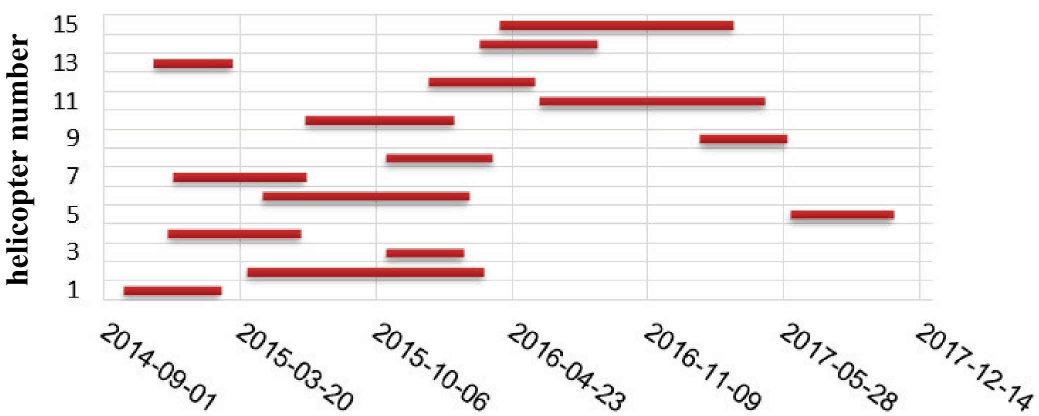

Fig. 2. Diagram of the performance of p = 1 300 h type maintenance carried out in the Air Base in the City A

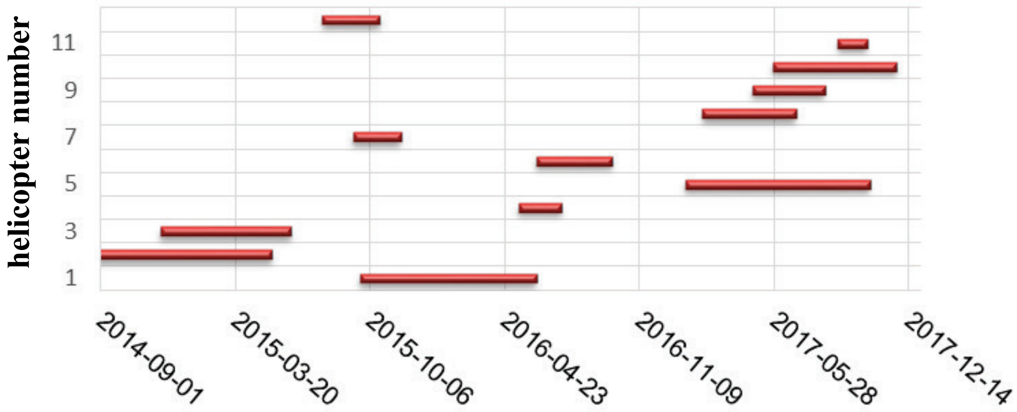

Fig. 3. Diagram of the performance of p = 1 300 h type maintenance carried out in the City B

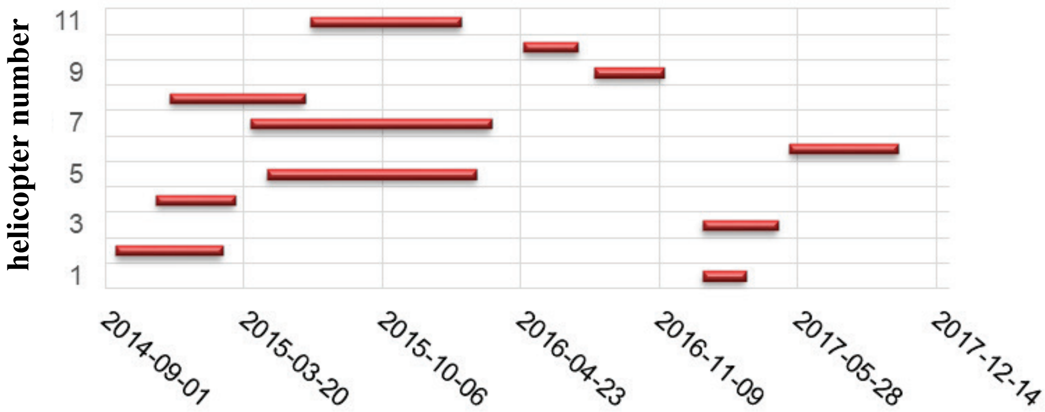

Fig. 4. Diagram of the performance of p = 1 600 h type maintenance carried out in the Air Base in the City A

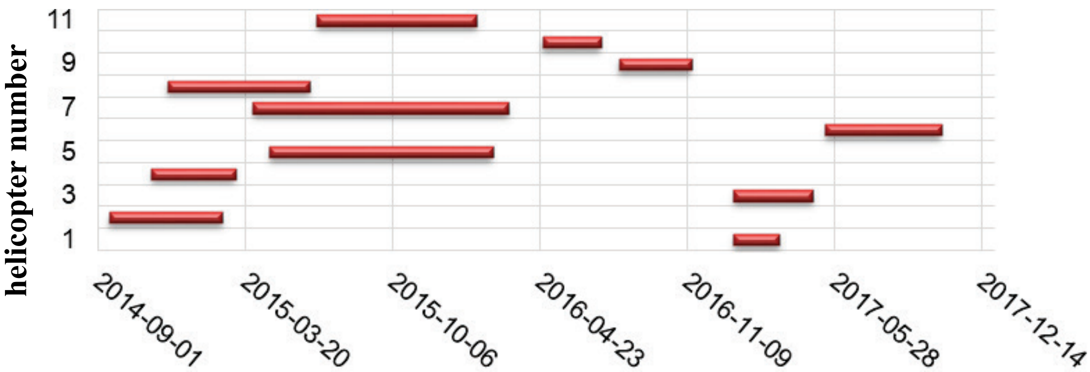

Fig. 5. Diagram of the performance of p = 2 600 h type maintenance carried out in the City B

5. Conclusions

The dynamic development of air transport, also in the military area, is associated with increased demand for the performance of the technical maintenance of helicopters. The maintenance should be organised in such a way as, on the one hand to reduce its cost, and to prevent the unexpected failure of one of the helicopters, resulting from its negligence, on the other hand. The maintenance of the helicopter maintenance system at the airports of the Polish Armed Forces in the state of technical efficiency determines the fact that the units have the system optimising the process of the technical maintenance performance.

The currently used helicopters will be operated in the Polish Army for many years. Their effective operation requires providing the appropriate service, both professional and fast one, as well as possibly inexpensive.

The quantities obtained as a result of the optimisation task solution being a model of the system optimising the maintenance performance can be an element supporting the decision-making process in the scope of transferring the helicopters to the companies dealing with maintenance.

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