UDC 519.854.2
Doi: 10.31772/2587-6066-2020-21-3-307-313

For citation: Lifar' A. S. Interpretation of ant algorithm for solving the problem of the technical impact program calendar planning. *Siberian Journal of Science and Technology.* 2020, Vol. 21, No. 3, P. 307–313. Doi: 10.31772/2587-6066-2020-21-3-307-313

Для цитирования: Лифарь А. С. Интерпретация муравьиного алгоритма для решения задачи календарного планирования программы технического воздействия // Сибирский журнал науки и технологий. 2020. Т. 21, № 3. С. 307–313. Doi: 10.31772/2587-6066-2020-21-3-307-313

INTERPRETATION OF ANT ALGORITHM FOR SOLVING THE PROBLEM OF THE TECHNICAL IMPACT PROGRAM CALENDAR PLANNING

A. S. Lifar'

Reshetnev Siberian State University of Science and Technology
31, Krasnoyarskii rabochii prospekt, Krasnoyarsk, 660037, Russian Federation
E-mail: Alifar15@mail.ru

Many strategically important sectors of the domestic industry are at the stage of transition to an investment approach to asset management. One of these industries is hydropower, where the current maintenance planning system needs new methods to deliver more efficient results. In general, the planning system for the main equipment (technical impact system) maintenance and repair can be formulated as a scheduling problem. The ant algorithm is of great interest from the point of view of solving the scheduling technical impact problem. Based on the specifics of planning, implementation and factors affecting the maintenance process, a modification of the ant algorithm is proposed. The mathematical description is a methodology for calculating parameters, basic elements of the graph, optimization criteria and constraints. A preparatory stage was also introduced into the solution algorithm, which determines the initial state of the equipment at the vertex K_0. The functional model of the technical impact planning process presented in the article can be used to develop a software package within the framework of an innovative approach to asset management for hydropower companies.

Keywords: technical impact system, ant algorithm, scheduling.

ИНТЕРПРЕТАЦИЯ МУРАВЬИНОГО АЛГОРИТМА ДЛЯ РЕШЕНИЯ ЗАДАЧИ КАЛЕНДАРНОГО ПЛАНИРОВАНИЯ ПРОГРАММЫ ТЕХНИЧЕСКОГО ВОЗДЕЙСТВИЯ

А. С. Лифарь

Сибирский государственный аэрокосмический университет имени академика М. Ф. Решетнева
Российская Федерация, 660037, г. Красноярск, просп. им. газ. «Красноярский рабочий», 31
E-mail: Alifar15@mail.ru

Многие стратегически значимые отрасли отечественной промышленности находятся на этапе перехода к инвестиционному подходу к управлению активами. Одной из таких отраслей является гидроэнергетика, где на текущий момент система планирования технического обслуживания и ремонта нуждаются в применении новых методов, дающих более эффективные результаты. В общем виде система планирования технического обслуживания и ремонта основного оборудования (система технического воздействия) может быть сформулирована в виде задачи календарного планирования. Большой интерес с точки зрения решения задачи календарного планирования технического воздействия представляет муравьиный алгоритм. На основе специфики планирования, реализации и факторов, влияющих на процесс технического обслуживания, предложена модификация муравьиного алгоритма. Математическое описание представляет собой методику расчета параметров, основных элементов графа, критериев оптимизации и ограничений. В алгоритм решения также был введен подготовительный этап, который определяет начальное состояние оборудование в вершине K_0. Функциональная модель процесса планирования технического воздействия, представленная в статье, может быть использована для разработки программного комплекса в рамках инновационного подхода управления активами гидроэнергетических компаний.

Ключевые слова: система технического воздействия, муравьиный алгоритм, календарное планирование.

Problem statement. General formulation of the problem. Many strategically important sectors of the domestic industry are at the stage of technical renewal of fixed assets, which entails a transition to an investment approach to asset management [1]. First of all, this approach is focused on improving the accuracy of assessing the technical condition of equipment, but it does not exclude the development of effective planning systems for technical impact – maintenance and repair of main equipment (hereinafter – MRO).

One of these industries is hydropower, where an index system for assessing the state of the main hydropower equipment has been developed and adopted at the moment [2–4]. At the same time, the MRO planning system remains at the level of regulatory management, that is, scheduled preventive maintenance with a fixed overhaul interval.

Thus, the existing principles of the formation of a MRO planning system based on data on the average operating time in hours for one calendar year, the standard turnaround time between overhauls and the calendar duration of the repair cycle [5; 6], are insufficient and require the use of new methods that provide more efficient results.

Problem research statement. The features of MRO planning in hydropower include:

– equipment repair planning should include the development of long-term (from 5 years), annual and monthly plans for the main equipment repair;

– the system of maintenance and repair should provide for three stages of equipment functioning: the stage of maintaining the operable state (maintenance), the stage of scheduled maintenance and the stage of scheduled overhaul;

– high requirements for the regulation of repair work and terms, including due to the coordination of plans for repair work with SO UES JSC and its branches [7; 8];

– accounting of all operation resources, including material, labour and financial;

– ensuring effective planning of repair works, on the one hand, for obsolete hydropower equipment in operation, on the other hand, for newly commissioned hydraulic units.

In general, the system for planning maintenance and repair of the main equipment of hydroelectric power plants is reduced to solving the problem of scheduling repairs of technological equipment of an enterprise. At present, the problem is fairly well-known, and different methods are used to solve it: mathematical programming, combinatorial methods, statistical and heuristic methods [9].

In this work, it was necessary to investigate the possibility of adapting the ant algorithm method to automate MRO planning taking into account the specifics of the hydropower industry and to develop a functional model of the planning process, including the principles of an investment approach to asset management and automation of the MRO planning system.

Mathematical model. Mathematical model. Let us formulate the mathematical problem setting of scheduling maintenance and repairs for the main equipment of hydroelectric power plants (hereinafter referred to as HPPs).

In general, the ant colony optimization algorithm (ant colony optimization, ACO) is a heuristic that uses the idea of agents imitating the real behaviour of ants. Ants solve the problem of finding pathways to food with the help of chemical regulation – pheromones, which they leave in the path of movement. The more ants have passed along one path, the more pheromone, the sooner the ant will prefer this path to others.

An analysis of the literature [9–15] devoted to methods for solving the scheduling problem allowed us to conclude that the ant algorithm is the most optimal, since it:

– is quite effective with a small number of nodes;

– less susceptible to suboptimal initial decisions;

– allows you to analyze permutations of the same tasks within the same process.

In the context of the considered task of adapting the ant algorithm, the following parameters were determined, on which the quality of the solution depends:

1. The ρ coefficient affects the volatility of the pheromone. The coefficient takes values from 0 (no evaporation) to 1 (evaporates to the minimum level).

2. Coefficients α and β affect the operation of the algorithm, where α is the dependence on the level of pheramone, β is the dependence on the “quality” of the arc (weight of the arc), while: if $\alpha > \beta$, then the frequency of use has a greater influence on the ant's choice of path; if $\alpha < \beta$, then the quality of the next step (arc weight) has the greatest influence; if $\alpha = \beta$, there is a balanced relationship between the quality of the track and the degree of its operation; if $\alpha = 0$, then there is a heuristic based only on the quality of passage between successive points (ignorance of the pheromone level on the path); if $\beta = 0$, then there is a heuristic based only on the amount of pheromone (this is the path attendance factor); if $\alpha = \beta = 0$, then the decision is made uniformly and regardless of the amount of pheromone or the quality of the next step [10].

Thus, having specified the amount of pheromone (τ) and the weight of the arc (*V*) for the k-th arc, the probability of transition along the arc k takes the form:

$$P_k = \frac{\tau_k^{\alpha} \cdot V_k}{\sum\left(\tau_k^{\alpha} \cdot V_k\right)},$$

where *i*-th step, $i = 1,2,3,\ldots K$.

According to [5], the objects of repair at hydroelectric power plants can be: equipment (hydraulic turbine, hydrogenerator, transformer, pump, electric motor, diesel, valve, device, etc.); installations (hydro-turbine, hydrogenerator, transformer). However, the concept of investment asset management singles out a hydraulic unit as a piece of equipment as a key object of management. Let us introduce a description of the set of hydroelectric units at hydroelectric power plants:

$$G = \{G_c\}, c = \overline{1, c},$$

where is the G_c – th hydroelectric unit at the HPP, c is the number of hydroelectric units.

The planning period is on average 1, 5 or 10 years and will take the form:

$$t \in \{1, T\},$$

where *T* is the duration of the planning period. Let us assume that the minimum planning step is one year.

As noted earlier, the main equipment of a hydroelectric power station can be in three states: under maintenance (MOT), under current repair (CR) or under overhaul (TO); therefore, the vertex of the graph (K) will be characterized by one of three states (fig. 1).

The weight of the arc is determined by the aggregate indicator of the hydraulic unit, which characterizes the condition of the equipment when passing the peak К+1:

$$V_k = \left(AI_{K+1}\right)^{\beta},$$

where AI_K is the cumulative indicator of the c-th hydraulic unit at the current step.

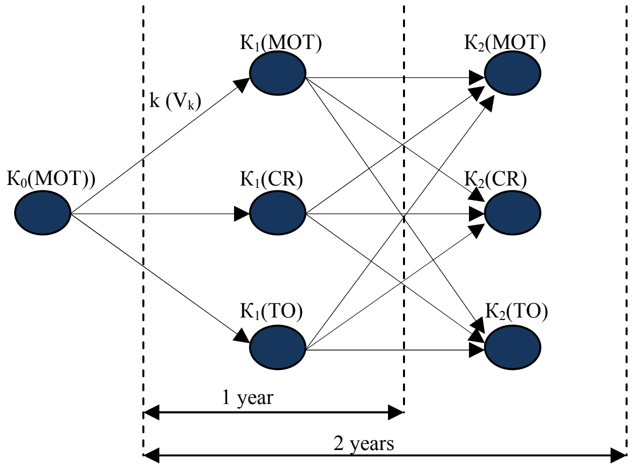

Fig. 1. Solution search graph example

Рис. 1. Пример графа поиска решения

The aggregate indicator of the hydraulic unit is determined by the product of functional indicators characterizing different aspects of the repair process (see table), taking into account the weight determined by the method of expert assessments.

$$AI = W_{\text{ТП}}\left(RR \cdot RPN\right) * W_{\text{ЭП}}\left(Z_r + Z_{lp}\right),$$

where W_i is the weight of the functional indicator.

Based on the possible directions of the company's technical policy, the following optimization criteria can be used to solve the scheduling problem. The first optimization criterion will be to minimize economic indicators along the way:

$$\text{ЭП} = \sum_{k=1}^{N} \text{ЭП}_k \to \min .$$

The second optimization criterion will be the achievement of the maximum technical indicators of the hydroelectric unit of the HPP:

$$\text{ТП} = \sum_{k=1}^{N} \text{ТП}_k \to \max .$$

In the classical model, after the ant successfully passes the route, it leaves a trace on all the traversed edges, which is inversely proportional to the length of the traversed path; in our implementation, the pheromone value will increase by the specified values in two cases – if the ant has chosen a composition that satisfies the constraints (for example, when optimizing in terms of economic indicators – restrictions on the minimum permissible residual resource) and in the case when the composition replaces the optimal solution. This change was made for reasons of the same number of edges passed by all ants (by the number of modules, each arc is a specific combination of versions in the module) and the absence of the length indicator, which was replaced by the weight indicator. Thus, the restrictions are:

– the minimum admissible residual resource at the final vertex of the graph ($K + n$)

$$RR_{K+n} \geq RR_{\min};$$

– the maximum allowable total cost of repair work

$$\sum_{k=1}^{N} \text{ЭП}_k \leq \text{ЭП}_{\max} .$$

A preparatory stage was also introduced into the solution algorithm, which determines the initial state of the equipment at the vertex K_0 and is calculated based on the technical state index [2]:

$$\text{ИТS}_G = \frac{\sum_i \left(P_i \cdot \text{ИТS}_i\right)}{\sum_i P_i},$$

where ITS_i is the index of the technical condition of the i-th functional unit included in the hydraulic unit; P_i is the reduction index (for hydro turbines / hydro generators – active electric power).

Functional model. To improve the efficiency of MRO planning processes, it is necessary to solve the problem of their automation and develop a program that takes into account the parameters, criteria and limitations. Its functionality should provide input of initial data (technical and financial indicators), modelling of the process of repair maintenance of both one unit and a group of units, the possibility of making changes to the original model for carrying out simulation experiments and the availability of tools for analysing and evaluating the obtained experimental results. The functional diagram of the system for planning maintenance and repairs is shown in fig. 2.

It is important to note that the first stage of optimization is implemented for each hydroelectric unit separately, with the determination of the sequence of performing types of repairs by year, along the entire planning corridor.

The second stage involves the construction of an aggregate MRO schedule for hydroelectric units (on average, about 12 hydroelectric units operate at HPPs), broken down by months and taking into account the flood and peak periods of operation of hydraulic units.

The parameters of the technical condition of the equipment, selected for the assessment of the technical condition, enter the unit for assessing the technical condition, where they are mathematically processed in accordance with [2–4]. The results obtained in the form of an index of technical condition make it possible to determine the starting points of the graph for each hydraulic unit.

The modelling block includes a method for calculating the weight of graph links and a system of constraints. The result of modelling is a graph, where the vertices are the state of the equipment (the type of technical impact on it), and the links are characterized by the aggregate indicator of the hydraulic unit.

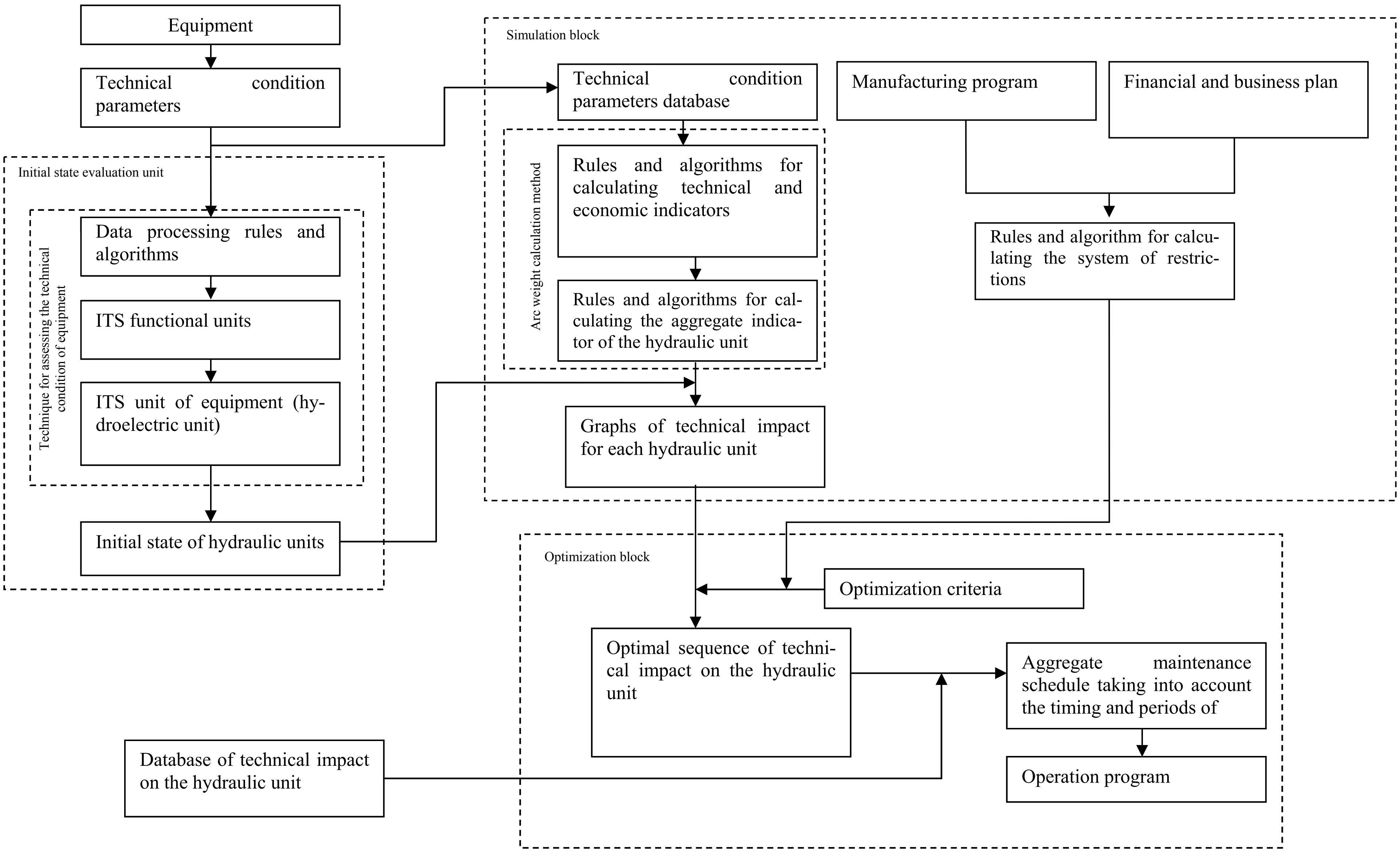

Fig. 2. Functional diagram of the system for maintenance and repairs planning

Рис. 2. Функциональная схема системы планирования технического обслуживания и ремонтов

Repair process indicators

Functional indicators	Private functional indicators	Unit of measurement	Symbol	Calculation formula
Technical indicators (TI)	Residual resource		RR	The sum of the residual life of the main units of the hydroelectric unit after repair (maintenance) at the top К+1
	Criticality index		RPN	RPN = SOD, where S is the severity of the consequences of failure of a piece of equipment, O is the probability of equipment failure within a certain period of time, D is the probability that the failure will not be detected before the manifestation of its consequences [16].
Economic indicators (EI)	Regulatory repair (maintenance) costs	Thousand rub.	Z_r	The amount of expenses for the implementation of repair work
	Lost profit	Thousand rub.	Z_{lp}	Number of days of equipment downtime due to repair *Amount of funds not received due to insufficient supply of electricity per day

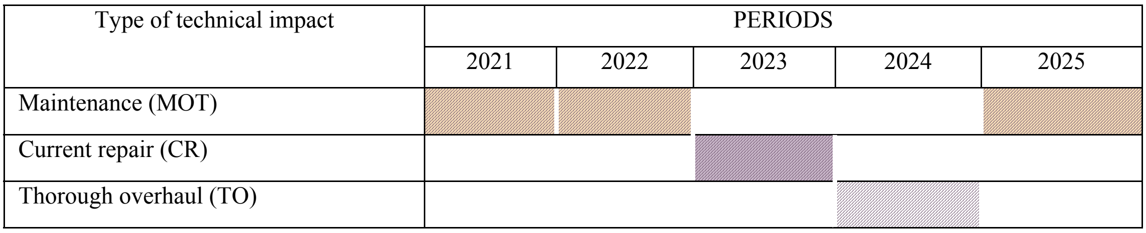

Fig. 3. Gantt chart by type of technical impact

Рис. 3. График Ганта по видам технического воздействия

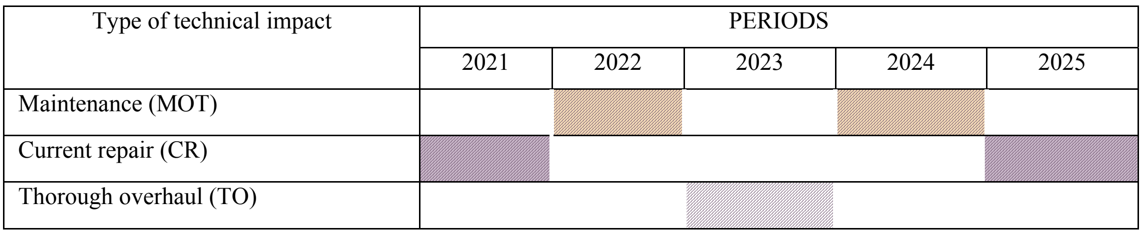

Fig. 4. Planned schedule by type of technical impact

Рис. 4. Плановый график по видам технического воздействия

In accordance with the technical policy adopted in the company (ensuring maximum technical performance of equipment or minimizing the cost of the equipment life cycle), the necessary option is selected, which is the most optimal, taking into account all the conditions and criteria. Based on the results of optimization calculations, which are based on the ant algorithm, an aggregate maintenance schedule is formed, containing the terms and types of technical impacts for all hydraulic units for any planning period.

Experimental research. The software implementation of the method was used when planning the repair cycle for the period from 2021 to 2025 for the hydroelectric unit of the station, which is part of the largest Russian private energy company, JSC EuroSibEnergo.

The following indicators were used as input parameters: a list of possible links in the graph (possible transitions from one state of an object to another); link weight, which is calculated from such equipment parameters as the cost of repairs, lost profit due to equipment downtime, equipment criticality index and residual resource.

It is important to note that the criterion was the minimization of economic indicators, while the limitation is the minimum allowable residual resource at the final vertex of the graph.

The output data is a five-year technical impact program, presented in the form of a Gantt chart (by type of technical impact) (fig. 3).

In comparison with the planned repair work schedule adopted at the hydroelectric power station (fig. 4), the technical impact program, obtained on the basis of the ant algorithm, provided a reduction in the total economic indicators (the cost of repair work and lost profits due to equipment downtime) by 5 %. Saving for the group of costs for repair work amounted to 1,175.8 thousand rubles subject to condition RR2025 > 0.9.

Conclusion. The ant algorithm makes it possible to successfully solve scheduling problems, including planning a maintenance and repair program for the main hydropower equipment. The article formulates a mathematical statement of the problem of scheduling repairs and a functional model of the process of planning maintenance and repair. The results presented in the article can be used to develop a software package as part of an innovative approach to asset management for hydropower companies.

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Lifar' Aleksandra Stanislavovna – applicant, Reshetnev Siberian State University of Science and Technology. E-mail: alifar15@mail.ru.

Лифарь Александра Станиславовна – соискатель, Сибирский государственный университет науки и технологии имени академика М. Ф. Решетнева. E-mail: alifar15@mail.ru.