The research objects are decision making support systems. subject research is a decision making process in management tasks using bio-inspired algorithms. A method of finding solutions using the population algorithm of global search optimization is proposed. Joint use of invasive weed algorithm is proposed, genetic algorithm and evolving artificial neural networks are improved. The method has the following sequence of actions:

– an input of initial data;

– processing of initial data taking into account the degree of uncertainty;

– formation of the optimization vector;

– creation of descendant vectors;

– ordering of vectors in descending order;

– reducing the dimensionality of the feature space;

– teaching knowledge bases.

The peculiarity of the proposed method lies in the placement of agents-weeds, taking into account the uncertainty of the initial data, improved procedures for reducing the space of signs about the analysis object state.

Training of synaptic weights of an artificial neural network, type and parameters of the membership function and the architecture of individual elements, and the architecture of an artificial neural network as a whole is carried out. The proposed method was simulated in the MathCad 14 software environment. The task to be solved during the simulation was to determine the route of the ships in the operational zones of the Black and Azov seas in the conditions of hybrid actions of the enemy. The use of the method makes it possible to increase the efficiency of data processing at the level of 21–27 % due to the use of additional improved procedures. The proposed method should be used to solve the problems of evaluating complex and dynamic processes in the interests of solving national security problems

Keywords: hybrid actions, artificial neural networks, bio-inspired algorithms, use of forces (troops) of the Naval Forces

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DEVELOPMENT OF THE SOLUTION SEARCH METHOD USING THE POPULATION ALGORITHM OF GLOBAL SEARCH OPTIMIZATION

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1. Introduction

Heuristic and metaheuristic optimization algorithms have gained active development – algorithms that include a practical method that is not guaranteed to be accurate or optimal, but is sufficient for solving the problem [1–5]. The correctness of these algorithms in all possible cases has not been proven, but it is known that such algorithms give a fairly good solution.

These algorithms make it possible to speed up the solution of the problem by 100–1000 times, which is especially important in problems with a large number of variables. In addition, heuristic algorithms allow to find a solution even in cases where the exact solution cannot be found or its search has a high computational complexity.

The works [1–5] present the practical areas of application of artificial intelligence algorithms and propose approaches that are based on the criterion of information processing efficiency, to increase their effectiveness.

One of the most famous representatives of heuristic methods is swarm intelligence, which describes the collective behavior of a decentralized, self-organizing system. There are a large number of representatives of this class of approaches, for example: particle swarm method, ant algorithm, cuckoo algorithm, weeds, etc. [6–8].

Usually, the evolutionary advantage of weeds is resistance to the external environment, fairly quick adaptation to changes in it and active (sometimes aggressive) occupation of the territory, suitable for their growth. Accordingly, the use of these invasive qualities results in a strong practical optimization algorithm [1]. At the same time, the value of the objective function determines the degree of adaptability of the population individual to the conditional «environment» in which the optimization takes place [4]. Such algorithms are able to find a close to optimal solution in an acceptable time. These algorithms are often used to solve problems belonging to the class of NP-complete, algorithms for exact solutions of which exist, but have time characteristics that are not used in practice [5, 6].

A joint use of an invasive weed algorithm, an advanced genetic algorithm and evolving artificial neural networks is proposed. The joint use of the proposed approaches is due to:

– reduce of the dimensionality of the space of features while assessing the objects state and making appropriate management decisions;

– increase of the accuracy of assessment and management decision making;

– the possibility of training individuals in the population in order to ensure the necessary accuracy of modeling and multidimensional forecasting of vector space parameters.

The problem that needs to be solved in the research is to increase the efficiency of solving tasks of analysis and forecasting the state of objects while ensuring the given reliability.

Taking into account the above, an urgent scientific task is the development of a method of finding solutions using the population algorithm of global search optimization, which would allow to increase the efficiency of the decisions made regarding the management of the parameters of the control object with a given reliability.

2. Literatue review and problem statement

The work [9] presents cognitive modeling algorithm. The main advantages of cognitive tools are defined. The lack of consideration of the type of uncertainty about the analysis object state should be attributed to the shortcomings of this approach.

The work [10] disclosed the essence of cognitive modeling and scenario planning. A system of complementary principles of building and implementing scenarios is proposed, different approaches to building scenarios are highlighted, the procedure for modeling scenarios based on fuzzy cognitive maps is described. The approach proposed by the authors does not allow taking into account the type of uncertainty about the analysis object state and does not take into account the noise of the initial data.

The work [11] carried out an analysis of the main approaches to cognitive modeling. Cognitive analysis allows: to investigate problems with unclear factors and relationships; to take into account changes in the external environment and to use objectively formed trends in the development of the situation in one's interests. At the same time, the issue of describing complex and dynamic processes remains unexplored in this work.

The work [12] presents a method of analyzing large data sets. The specified method is focused on finding hidden information in large data sets. The method includes the operations of generating analytical baselines, reducing variables, detecting sparse features and specifying rules. The disadvantages of this method include the impossibility of taking into account different decision evaluation strategies, the lack of taking into account the type of uncertainty of the input data.

The work [13] presents a mechanism of transformation of information models of construction objects to their equivalent structural models. This mechanism is intended to automate the necessary conversion, modification and addition operations during such information exchange. The shortcomings of the mentioned approach include the impossibility of assessing the adequacy and reliability of the information transformation process, and the appropriate correction of the obtained models.

The work [14] developed an analytical web-platform for the research of geographical and temporal distribution of incidents. Web-platform, contains several information panels with statistically significant results by territory. The disadvantages of the specified analytical platform include the impossibility of assessing the adequacy and reliability of the information transformation process and a high computational complexity. Also, one of the shortcomings of the mentioned research should be attributed to the fact that the search for solution is not unidirectional.

The work [15] developed a method of fuzzy hierarchical assessment of library service quality. The specified method allows to evaluate the quality of libraries based on a set of input parameters. The disadvantages of the specified method include the impossibility of assessing the adequacy and reliability of the assessment and, accordingly, determining the assessment error.

The work [16] presents an analysis of 30 algorithms for processing large data sets. Their advantages and disadvantages are shown. It was established that the analysis of large data sets should be carried out in layers, take place in real time and have the opportunity for self-learning. Among the disadvantages of these methods should be attributed their high computational complexity and the impossibility of checking the adequacy of the obtained estimates.

The work [17] presents an approach for evaluating input data for decision-making support systems. The essence of the proposed approach consists in the clustering of the basic set of input data, their analysis, after which the system is trained based on the analysis. The disadvantages of this approach are the gradual accumulation of assessment and training errors due to the lack of an opportunity to assess the adequacy of the decisions made.

The work [18] presents an approach to data processing from various sources of information. This approach allows to process data from various sources. The disadvantages of this approach include the low accuracy of the obtained estimate and the impossibility of verifying the reliability of the obtained estimate.

The work [19] presents a comparative analysis of existing decision-making support systems, namely: the method of analyzing hierarchies, neural networks, the theory of fuzzy sets, genetic algorithms and neuro-fuzzy modeling. The advantages and disadvantages of these approaches are indicated. The spheres of their application are defined. It is shown that the method of analyzing hierarchies works well under the condition of complete initial information, but due to the need for experts to compare alternatives and select evaluation criteria, it has a high share of subjectivity. For forecasting problems under conditions of risk and uncertainty, the use of the theory of fuzzy sets and neural networks is justified.

The work [20] developed a method of structural and objective analysis of the development of weakly structured systems. An approach to the research of conflict situations caused by contradictions in the interests of subjects that affect the development of the researched system and methods of solving poorly structured problems based on the formation of scenarios for the development of the situation. At the same time, the problem is defined as the non-compliance of the existing state of the system with the required one, which is set by the management entity. At the same time, the disadvantages of the proposed method include the problem of the local optimum and the inability to conduct a parallel search.

The work [21] presents a cognitive approach to simulation modeling of complex systems. The advantages of the specified approach, which allows to describe the hierarchical components of the system, are shown. The shortcomings of the proposed approach include the lack of consideration of the computing resources of the system.

The work [22] indicated that the most popular evolutionary bio-inspired algorithms are the so-called «swarm» procedures (Particle Swarm Optimization – PSO). Among them, there are optimization algorithms based on cat swarms (Cat Swarm Optimization – CSO), which are very promising both from the point of view of speed and ease of implementation. At the same time, these procedures are not without some shortcomings that worsen the properties of the global extremum search process.

The work [23] investigates the effectiveness of one of the optimization algorithms for the global maximization of the IWO (Invasive Weed Optimization) algorithm of the fitness function. In the IWO algorithm, the model of weed behavior during colonization takes into account the following main properties of the process:

1. Distribution of the final number of seeds throughout the search area (population initialization).

2. Production of seeds grown by plants, depending on plant adaptability (reproduction).

3. Distribution of produced seeds in a random order in the search area (spatial distribution).

4. Repeat steps 2 and 3 until the set maximum number of plants is reached.

5. Selection of plants with higher adaptability, their reproduction and spatial distribution (competitive exception).

6. Repeating step 5 until the process termination condition is met.

Thus, plants and their offspring are evaluated together, and those with better fitness are allowed to reproduce. This mechanism allows less adapted plants to reproduce and if their offspring are well adapted, they can survive.

An analysis of works [9–23] showed that the common shortcomings of the above-mentioned researches are:

– the lack of possibility of forming a hierarchical system of indicators;

– the lack of mechanisms for adjusting the system of indicators during the assessment;

– a failure to take into account the type of uncertainty and noise of data on the analysis object state, which creates corresponding errors while assessing its real state;

– the lack of deep learning mechanisms of knowledge bases;

– a high computational complexity;

– the lack of consideration of computing (hardware) resources available in the system;

– the lack of search priority in a certain direction.

For this purpose, it is proposed to develop a method of finding solutions using the population algorithm of global search optimization.

3. The aim and objectives of the study

The aim of the study is the development of the method of finding solutions using the population algorithm of global search optimization. This will allow to increase the efficiency of assessment and multidimensional forecasting with a given reliability and the development of subsequent management decisions. This will make it possible to develop software for intelligent decision-making support systems in the interests of the combat management of the actions of troops (forces).

To achieve the aim, the following objectives were set:

– to determine the algorithm for the implementation of the method;

– to give an example of the application of the proposed method in determining the route of the movement of ships in the operational zones of the Black and Azov Seas.

4. Research materials and methods

Problem, which is solved in the research, is to increase the efficiency of decision making in management tasks while ensuring the given reliability, regardless of the hierarchy of the object. The objects of research are the decision-making support systems. The subject of the research is the decision making process in management tasks using artificial intelligence methods. The hypothesis of the research is to increase the efficiency of decision making with a given assessment reliability.

The research is based on the algorithm of invasive weeds, which is used to assess the condition of the object. The advantage of this approach is that this algorithm increases the efficiency of calculations in relation to the object state. An improved genetic algorithm is used to select the best individuals, thereby increasing the efficiency of the calculations, evolving artificial neural networks are used to train the weed agents, which allows to increase the accuracy of the calculations. Simulation of the work of the proposed method was in the MathCad 14 software environment (USA). The hardware of the research process is AMD Ryzen 5.

5. Development of the method of finding solutions using the population algorithm of global search optimization

5. 1. Algorithm for implementing the method of finding solutions using the population algorithm of global search optimization

The method of finding solutions using the population algorithm of global search optimization consists of the following sequence of actions.

Step 1. Input of output data. At this stage, the initial data available on the object to be analyzed are entered.

Step 2. Processing of raw data taking into account the degree of uncertainty.

Weed agents are placed taking into account the type of uncertainty about the analysis object state. At this stage, the type of uncertainty about the object to be analyzed is taken into account and the basic state model of the object to be analyzed is initialized [2, 19, 21–25]. At the same time, the degree of uncertainty can be: full awareness; partial uncertainty and total uncertainty. This is done with the help of appropriate correction coefficients.

The decisive criterion during classification is the percentage of incorrectly classified records. The smaller the share of incorrectly classified records, relative to the total mass, the better the classifier works on the given input parameters. In addition, the practical application of the classifier is strongly influenced by the time required for the training of the classifier and the classification itself. Due to the fact that the base of values may contain records about the object consisting of a set of parameters, which incurs a large expenditure of machine time, there is a need to reduce part of the informative features. The algorithm of invasive weeds is used as a classification algorithm. The dimensionality reduction of the space of informative features is carried out with the help of an improved genetic algorithm and the training of individuals is carried out using the method of training artificial neural networks [25–32].

Step 3. Formation of the optimization vector.

The optimization vector is presented in the form of an array X_i and takes values from 1 to $\sum_{j=1}^{L} kO_j$, where L is the number of system input variables, k is the number of variables describing the state of the system, O is the number of states for the j-th variable. The number of iterations N and the maximum number of vectors that can be saved after each iteration S are specified. The parameters $n_{\min}$ and $n_{\max}$ are specified, which correspond to the minimum and maximum value of the descendant vectors that the parent vector can create at each iteration. The distribution parameter is specified. An initial vector X^0 is generated and the root mean square error and fitness function φ^0 based on the error are calculated for it.For each vector X^s (s takes values from 1 to the current number of vectors) is determined n^s that is the number of vectors that can generate this vector:

$$n^s = \frac{n_{\max} - n_{\min}}{\varphi^{best} - \varphi^{worst}} \varphi^s + \frac{\varphi^{best} n_{\min} - \varphi^{worst} n_{\max}}{\varphi^{best} - \varphi^{worst}}, \quad (1)$$

where φ^{best}, φ^{worst} are the best and worst values of the fitness function.

Step 4. Creation of descendant vectors. For each vector X, new vectors n^s are created according to the rules:

$$X_i^{s,j} = X_i^s + u, j = \left(\overline{1, n^s}\right),$$

$$u \sim N\left(0, \delta_N\right) = \delta_N \sqrt{-2\ln(a)}\cos(b), \delta_N = \delta\left(\frac{N - N'}{N}\right), \quad (2)$$

where N' is the number of the current iteration, a, b are random numbers [0, 1], X_i^s is the component of the vector X^s, u is the distribution function.

Step 5. The arrangement of vectors.

All vectors, including parent and offspring, are ordered by decreasing error. If the number of vectors exceeds S, the population is reduced to S. If the current iteration is less than N, then go to step 3.

Step 6. Reduction of the dimensionality of the feature space.

At this stage, an improved genetic algorithm is used to reduce the feature space, which was developed in the work [33–38].

For the genetic algorithm [4] of dimensionality reduction, the input data of the algorithm are the table of observations, the parameters of the algorithm and the array of chromosomes.

Step 7. Learning knowledge bases.

In this research, the learning method based on evolving artificial neural networks, developed in the research [2], is used for training knowledge bases.

The end of the algorithm.

5. 2. An example of the application of the proposed method while determining the route of the movement of ships in the operational zones of the Black and Azov Seas

The method of finding solutions using the population algorithm of global search optimization is proposed.

Simulation of the work of the proposed method was carried out in the MathCad 14 software environment (USA). The task to be solved during the simulation was to determine the route of the ships in the operational zones of the Black and Azov seas in the conditions of hybrid actions of the enemy.

The following is a list of hybrid actions that can be used against the forces (armies) of the Naval Forces in the course of their performance of the tasks of protecting the economic activity of the state at sea in the conditions of hybrid actions of the enemy [39–42]:

– closure of marine areas through which the recommended routes of movement of vessels pass;

– violation of norms of international maritime law;

– radio-electronic suppression of control and communication systems of forces (troops) of the Navy;

– cybernetic influence on the command and communication system of the forces (troops) of the Navy;

– sabotage actions against the forces (troops) of the Navy and objects of economic activity of the state;

– special actions against the forces (troops) of the Navy and objects of economic activity of the state;

– informational and psychological influence on the personnel of the forces (troops) of the Navy.

The movement of ships outside the limits of the recommended routes requires the implementation of measures for their protection by the forces (troops) of the Navy through:

– the probability of the presence of sea mines on such routes;

– the possibility of negative impact on commercial shipping, which is carried out on new routes. The negative impact is:

– the use of underwater diversionary forces and devices by the enemy against ships from the training areas that are close to the new shipping routes;

– the possibility of covert placement of sea mines by the enemy on new ship traffic routes, etc.).

The task of choosing the movement of ships should be carried out using the forces and devices of the Navy of the Armed Forces of Ukraine and is reduced to the typical task of a traveling salesman, which consists in finding the most profitable route.

An example of the temporary closure for navigation of maritime areas of the Black Sea under the pretext of naval exercises as of 09/21/2021, during which alternative routes for the movement of vessels were determined, is shown in Fig. 1.

The number of iterations, the minimum and maximum population size, the minimum and maximum number of scattered seeds, and the initial and final standard deviation are given in the Table 1. To simplify and speed up the numerical experiments, optimization was carried out for the two-dimensional functions of Himmelblau and Rosenbrock (Table 1).

Table 2 shows a comparison of the efficiency of swarm optimization algorithms for solving the task of laying out the route of the movement of ships according to the Rastrygin function.

Analysis of the results given in Table 2 allows to conclude that the improved algorithm of invasive weeds increases the efficiency of data processing at the level of 21–27 %.

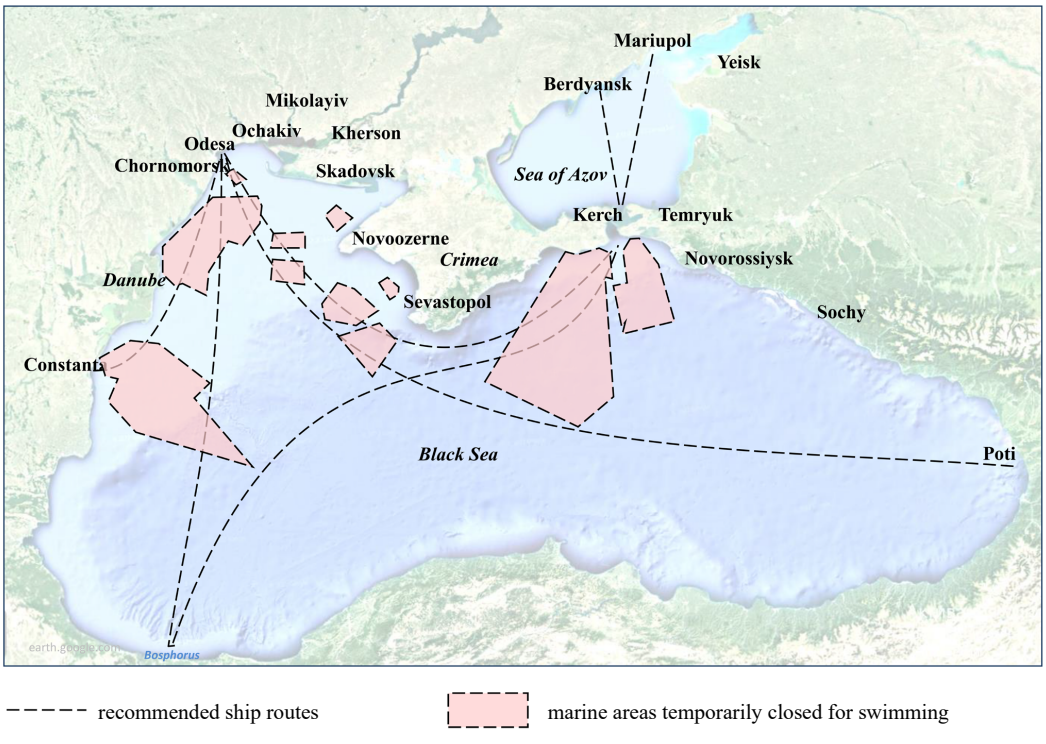

Fig. 1. An example of temporary closure for navigation of maritime areas of the Black Sea under the pretext of naval exercises as of 09/21/2021

Table 1

Computational efficiency results for route finding for Himmelblau and Rosenbrock functions

Function name	The number of iterations	Calculation error	
		Canonical IWO algorithm	Improved IWO algorithm
Himmelblau function $f(x,y)=\left(x^2+y-11\right)^2+\left(x+y^2-7\right)^2$	100	$20.9\cdot10^{-11}$	180.6
	500	$4.09\cdot10^{-11}$	180.6
	1000	$1.9\cdot10^{-11}$	180.6
Rosenbrock function $f(x,y)=-a\cdot\left(y-x^2\right)^2-\left(1-x^2\right)^2$	100	0.00746	–0.0019
	500	$12\cdot10^{-11}$	–0.000000001
	1000	$4.0\cdot45^{-11}$	–0.0000000006

Table 2

Comparison of the effectiveness of swarm optimization algorithms for solving the task of laying the route of the movement of ships according to the Rastrygin function

The name of the optimization algorithm	Rastrigin function		
	10 parameters	50 parameters	100 parameters
Canonical algorithm of invasive weeds [23]	1	1	0.33519
An improved invasive weed algorithm	1	1	0.5
Canonical algorithm of ant colonies [16]	0.37	0.27	0.18
The canonical cuckoo algorithm [16]	0.96	0.7	0.29
Canonical firefly algorithm [19]	0.62	0.5	0.19
Canonical algorithm of bats [16, 22]	0.43	0.96	1
Canonical algorithm of artificial bee colonies	0.81	0.49	0.23
Canonical algorithm for finding a school of fish [22]	0.48	0.38	0.11
Canonical particle swarm algorithm [16, 22]	0.21	0.12	0.06
Random search [20]	0.18	0.14	0.07
Canonical algorithm of a pack of gray wolves [16, 22]	0	0	0

6. Discussion of the results of the development of the method of finding solutions

The effectiveness of the proposed method, unlike the existing ones, is explained by the presence of additional procedures and the improvement of canonical ones.

The advantages of the proposed method are due to the following:

– while exhibiting weed agents, the type of uncertainty is taken into account (step 2);

– the universality of solving the task of analyzing the state of AC objects due to the hierarchical nature of their description (expressions (1)–(3));

– the possibility of quick search for solutions due to the simultaneous search for a solution by several individuals (steps 1–7);

– the adequacy of the obtained results (expressions (1)–(3));

– the ability to avoid the local extremum problem (steps 1–7);

– the possibility of in-depth learning of knowledge bases (step 7);

The main advantages of the proposed method are:

– it has a flexible hierarchical structure of indicators, which allows to reduce the task of multi-criteria evaluation of alternatives to one criterion or use a vector of indicators for selection;

– unambiguousness of the obtained assessment of the analysis object state;

– universality of application due to adaptation of the system of indicators during work;

– it does not accumulate learning error due to the use of the learning procedure;

– possibility of comprehensive learning of the architecture and parameters of artificial neural networks;

– taking into account the type of uncertainty of the initial data while building models of a heterogeneous analysis object;

– possibility of finding a solution in several directions;

– high reliability of the obtained solutions while searching for a solution in several directions;

– reduction of the space of features while assessing the analysis object state using an improved genetic algorithm;

– absence of falling into the local optimum trap.

The disadvantages of the proposed method include:

– loss of informativeness while assessing the analysis object state due to the construction of the membership function;

– lower accuracy of assessment on a single parameter of assessment of the analysis object state;

– loss of credibility of the obtained solutions while searching for a solution in several directions at the same time;

– lower assessment accuracy compared to other assessment methods.

This method will allow:

– to assess the state of the heterogeneous object of analysis;

– to determine effective measures to improve management efficiency;

– to increase the speed of assessment of the state of a heterogeneous object of analysis;

– to reduce the use of computing resources of decision making support systems.

The limitations of the research are the need to have an initial database on the analysis object state, the need to take into account the time delay for collection and proving information from intelligence sources.

The proposed approach should be used to solve problems of evaluating complex and dynamic processes characterized by a high degree of complexity.

The directions of further research should be aimed at reducing computing costs while processing various types of data in special purpose systems.

7. Conclusions

1. An algorithm for the implementation of the method is defined, which allows:

– to take into account the type of data uncertainty;

– to take into account the available computing resources of the state analysis system of the object of analysis;

– to take into account the priority of search by weed agents;

– to conduct an initial display of individuals of weed agents, taking into account the type of uncertainty;

– to carry out accurate training of individuals of weed agents;

– to reduce the space of features while assessing the analysis object state with the help of an improved genetic algorithm;

– to conduct a local and global search taking into account the degree of noise of the data on the analysis object state;

– to conduct training of knowledge bases, which is carried out by training the synaptic weights of the artificial neural network, the type and parameters of the membership function, and the architecture of individual elements and the architecture of the artificial neural network as a whole;

– to be used as a universal tool for solving the task of analyzing the state of analysis objects due to the hierarchical description of analysis objects;

– to check the adequacy of the obtained results;

– to avoid the problem of local extremum.

2. An example of the use of the proposed method was carried out on the example of choosing the route of the movement of ships in the operational zones of the Black and Azov Seas. The specified example showed an increase in the efficiency of data processing at the level of 21–27 % due to the use of additional improved procedures for the selection of individuals and deep learning.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

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Data availability

The manuscript has associated data in the data repository.

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