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Research paper

Development of Methodological Foundations of Logistical Intellectual Control of Complex Systems Based on Hybrid Heuristic Algorithms

Elena Skakalina[1]*

[1]Poltava National Technical University Yuri Kondratyuk University, Ukraine
Corresponding author E-mail:elenaskakalina2501@gmail.com

Abstract

Systematized and generalized existing models of managing the production class of complex distributed systems. A formalized logical-plural model of a complex system is constructed, a description of all its elements is given. A two-level control system for this class of complex systems has been developed. The advantage of the developed system is the possibility of eliminating the existing contradictions between the resource constraints that exist at different structural levels of complex production systems. Elements of a set of control actions based on the principle of hybridization of heuristic algorithms are described. A hybrid genetic algorithm using a fuzzy set machine for a selection operator was used, which was used to optimize the overall logistic transportation plan. Verification of this algorithm was performed both on test functions and on objects of subject domains. The use of the apparatus of fuzzy sets in regulating the dimension of current populations makes it possible, within one formal apparatus, to implement the existing algorithms for selecting suitable individuals for further crossing. A neural-network modification of the method of group accounting of arguments is described as a short-term forecasting model. This model is verified on objects of subject areas, its adequacy and advantages are shown with short-term forecasting of production, financial and statistical indicators.

Keywords: *management of complex systems , heuristic algorithms, hybrid genetic algorithm, neuro-network group method of data handling, theory of fuzzy sets, information technologies*

1. Introduction

One of the main trends in the development of information technology and information systems (IT and IS) in the 21st century will be the solution to the problem of the comprehensive integration of these technologies and systems with existing and future production and socio-economic structures and related control systems (CS). Therefore, one of the urgent scientific problems is the task of optimizing the management of complex geographically distributed systems, which include production and economic systems. The main type of production and economic system is a modern enterprise, that is, an economic entity. Such an entity can be agroholding, an oil and gas company, an energy complex, information systems, branch management systems, large banking structures, and similar complex geographically distributed systems.
As the main properties of complex systems, one can distinguish the following [1]:

1. a large number of interconnected and interacting elements
2. the complexity of the performed function to achieve the purpose of functioning
3. hierarchical structure, the ability to divide the system into a subsystem
4. Availability of management, intensive information flows and an extensive information network
5. interaction with the external environment and functioning under the influence of random factors.

2. Analysis of features, existing approaches and methods of managing complexly organized territorially - distributed systems

The analysis of existing models of management of complexly organized territorially - distributed systems (COTDS) as integrated structures and degree of compliance of COTDS implemented in COTDS ERP, BMP and other systems of corporate management for the modern needs of COTDS in optimizing all existing types of production and accompanying activity of economic entities allows us to reach a reasonable conclusion on the significant inconsistency of the methods used in these systems to optimize production and logistics processes. The objective challenges of modern activities in the conditions of COTDS require the use of intelligent information technology at all levels of management of complex objects in a minimization of such key parameters as the full cost of implementing ERP, BMP and other corporate governance systems, the timing of their implementation, the availability of staff with the appropriate level vocational training. The analysis of classical optimization techniques implemented in the well-known ERP systems shows that quite often they do not provide adequate managerial decisions due to significant time expenditures for finding the optimal solution. The use of innovative logistics as an independent competitive power will allow national COTDS to maintain leadership in the process of achieving the goal and implementing strategies in a rapidly changing world market.
At the current stage in Ukraine there is a considerable lag behind other EU countries and the USA on the quantity and quality of

implemented ERP, BPM and other corporate governance systems. There is no modern automation of project management that is very common in other countries with the full use of resource management functionality. Optimization of business processes is realized mainly at the level of intuitive knowledge. That is, there is a contradiction between the requirements for the efficiency and timeliness of making managerial decisions and the limitations of existing scientific-methodological and applied components (methods, algorithms, software solutions). The most widespread in the world market of control system (SO) resources and logistics of enterprises of the class Enterprise Resource Planning (ERP), both overseas (SAP, Oracle, Microsoft, others), and domestic (1C, Alpha, others) make a significant amount. But it should be noted that basically these systems are accounting, and built as centralized, monolithic, hierarchical and sequential systems, which, in the conditions of constant growth of complexity and high dynamics of changes in any subject field, leads to various problems and often prevents the use of these systems in practice have a significant effect.
In addition, the main contour of allocation, planning, optimization, monitoring and control of resources remains without the automated support of decision-making processes, which deprives these systems of the necessary openness to change, flexibility and efficiency in resource management, in particular - if necessary, to operate in real time.
Taking into account all of the foregoing, one can state the existence of an important scientific and applied problem, the relevance of which is determined by the objective need to create new innovative information technologies for optimizing the management of production and logistics processes under the conditions of COTDS, in particular, algorithms, methods, etc. to increase the efficiency of their implementation through a combination of project management methods and evolutionary algorithms, which provides the opportunity to obtain a synergistic effect.
The STSs usually have a large geography, therefore, the system of rules, standards, plans and a substantiated system of reports on their implementation is of particular importance. The most important condition for stable operation and development of the COTDS is to improve the management system on a theoretical and practical basis. To date, such a perfect unified concept, which combines legislative, normative, advisory, and practical bases, does not exist. There is no concept of managerial accounting in the integrated structures of the COTDS, that is, including the theory, methodology, organization of managerial accounting with the use of modern innovative technologies, methods and models. There are also no priority theoretical and methodological concepts of the further development of control systems in conditions of increasing standardization, globalization. At present, there is not a single point of view on the composition, content of management accounting components, imperfect structure of the unified information management of the management of the COTDS in the conditions of the operation of intelligent information technology. For national COTDS , low degree and inadequate use of management accounting tools and tools in the direction of implementation of intelligent decision support systems. Not a well-defined, balanced system of performance indicators of the STS in terms of aspects of the analysis of production activities, forecasting indicators, resource planning, risk management, investment attraction. All existing at this stage, decisions on CS COTDS can be systematized into three clusters:
Cluster A - "1-C - Enterprise" Focused mainly on the task of accounting, not fully utilized the capabilities of modern IT.
Cluster B - performed on its own platform, the inherent defects of the specific own platform, not fully used the capabilities of modern IT.
Cluster C - with SAP, Oracle, IBM, Microsoft. Built on information ERP, ERP II, BMP - systems. Functions of optimization of business process management extremely expensive, require highly qualified personnel at all levels of implementation.

3. Set-theoretic representation of a complex system

In the set-theoretical form, the CAS model can be represented in the following form:

$$\sum == \{U,Y,X,A,S\}, \quad (1)$$

here $U=\{u_1,u_2,\ldots,u_n\}$ – is the set of control actions (control) by the system;
$Y=\{y_1,y_2,\ldots,y_m\}$ – set of output variables (output) of the system; $X=\{x_1,x_2,\ldots,x_k\}$ – is the set of input parameters of the system; $A=\{a_1,a_2,\ldots,a_j\}$ – is the set of intra-system parameters of the CTDS; $Y=S(U,X,A)$ – is a function that determines the dependence of output parameters on input parameters, control actions and intra-system parameters. Then, on the basis of this model, we get the set-theoretic model of a CTDS with control:

$$\sum ==\{U,Y,Y_G,X,A,F,S\}, \quad (2)$$

where F is the transition rule that forms the control action u to achieve the specified values of the intra-system parameters. But in the real conditions of the operation of the CTDS , uncontrollable disturbing influences are necessarily present, which introduce an uncertainty factor. To reduce this uncertainty factor, it is suggested to use the set of information technologies $\Omega = \{\Omega1, \Omega2, \Omega3, \Omega4\}$ as control actions U .

4. Formation of a set of control actions

The set Ω represents the integration of the corresponding IT and consists of the following elements:
Ω1 - information technology for optimizing the production activity of COTDS by means of project management (ITOPA);
Ω2 - information technology of optimization of logistic activity of COTDS on the basis of application of hybrid genetic algorithms and fuzzy sets (ITOLA);
Ω3 - Information technology for the optimization of financial risks of COTDS on the basis of fuzzy sets application (ITOFR);
Ω4 - information technology of short-term forecasting of any financial indicator of the COTDS on the basis of neuro-network modification of the method of group consideration of arguments (ITSTF).
As the criterion for the effectiveness of the management of the COTDS , the total cost of the expenditure part of the budget is applied when the selected process is optimized for the production cycle (PC): $Z = Re + He$, which is invariant to the type of the domain; where Z is the total cost of the expenditure part of the COTDS budget;
$Re \le \sum_{i=1}^{e} r\,i$ - the total sum of the value equivalent of all material resources for the realization of the production activity of the CTDS in the processing cycle;
r_i - value equivalent of the material resource for the i-th stage of the PC of the COTDS ;
$H_в \le \sum_{i=1}^{e} h_i$ - the total sum of the cost equivalent of all human resources for the realization of the production activity of the COTDS in the processing cycle;
h_i is the cost equivalent of the human resource for the i-th stage of the PC COTDS ;
$T_в \le \sum_{i=1}^{e} t_I$ - the total time of the cycle of the PC COTDS ;
t_i - the time of the i-th stage of the PC COTDS .

In the context of the systematic approach methodology, any COTDS is a resource converter. Dedicated as the main ones - at the strategic level of management - the tasks of optimizing the management of large pools of resources necessary for the implementation of the main activities of the COTDS , at the operational level - the tasks of optimizing logistics activities. These two tasks are the main objects for controlling influences on the COTDS in the form of IT.

5. Methodological and algorithmic basis of control actions

Element Ω1 (ITOPA) is based on the application of project management at all levels of the COTDS : institutional (strategic), managerial (operational), technical (lowest-operational execution). According to the International Project Management Association (IPMA), application of the project management methodology and tools allows saving 20-30% of the time and 15-20% of cash. Starting in 2011, the Office of the Prime Minister of the Great Britain established the Major Projects Authority. Its main functional responsibilities include support for management processes, the formation and development of competence in project and program management. Similar structures operate in Japan, the United States, and many other countries. There are national standards for project management in the public sector (PRINCE2, Projects In Controlled Environments in the UK, and PMI PMBOK Government Extension in the USA) [2]. In general, the demand for project management practices in world practice is growing very rapidly. There is a tendency to increase investment in megaprojects. One can give such a definition of project management - this is a special type of activity that can be applied to the management of any object, and not only that which has explicit features of the project.
The main features of the project include the following:

- having a specific goal that is aimed at solving a certain problem;
- clearly defined time frame realization;
- limited resources (financial, material, human) for its realization;
- presence of project team;
- certain uniqueness .

The implementation of projects requires the establishment of an appropriate management system and the following stages :
1. analysis of the situation taking into account features of the domain - analytical;
2. building a hierarchy of goals and objectives - conceptual;
3. selection of effective tools;
4. decomposition of the main goal to the level tasks and the order of their solution;
5. budgeting of the project;
6. determination of efficiency criteria project implementation, expected indicators and methods for their evaluation.

The Ω2 element (ITOLA) is based on the application of a hybrid genetic algorithm in which a fuzzy sets [3] is used to control the size of the incoming population of possible solutions to the task of optimizing the cost of the overall transport plan. The set of linguistic variables "Value of fitness function" is defined as "Very_Bad", "Bad", "Satisfactory", "Good", "Very_Good". Each cluster of this set corresponds to the values of the membership function.

The strategy of combining methods is applied in the work, since the application of one method is often insufficient to obtain a qualitative and adequate solution. Therefore, different methods combine, "launching" them either sequentially or in parallel. Generally, the following combining strategies are used: staged start, iterative launch, competition, division into data blocks (decomposition - divide the data into separate fragments, which are processed separately or by one method, or - different). In the investigated subject area of existence of the most important in the national production activity of COTDS - agro-sector and oil and gas-the applied methods of decomposition and phasing-in.

The trends in the development of modern economy testify to the growing role of logistics, which, in the face of growing competition, reducing information barriers and globalization, is becoming one of the most important components of the strategic development of enterprises. Leading world companies emphasize their activities on strategic logistics in order to be able to cover suppliers, logistics intermediaries and consumers.

At present, logistics is one of the fastest growing areas of productive activity. This process is connected not only with the growing demand for logistics services, but also with the strengthening of the mutual integration of the business opportunities of logistics and the simultaneous infrastructural development of the respective territories. The most significant development of methods and algorithms for interaction between the subjects of logistical processes is due to the rapid development of information technologies, which entailed a wide spread of network organizational forms of business, on-line document circulation, transition to electronic payment systems, virtualization of logistics processes, etc.

On the basis of innovative transformations of the information infrastructure of logistics, a transition to a new level of intellectual management of processes is carried out, new logistics concepts of "Party Logistics" are being formed. One of the main trends in the development of the world market is the increase in the concentration of capital for core business. Subsidiaries can be created to perform non-core functions. However, at the present stage, these functions are increasingly being outsourced. This tendency is also fully observed in the sphere of logistics services. As an example, we can cite the United States, where the turnover of logistics services is about 40 billion dollars.

Currently, logistics is one of the fastest growing areas of activity. This is due not only to the growing demand for logistics services, but also to the development of the infrastructure capabilities of this business. The most significant changes in the ways and forms of interaction between logistics entities are due to the development of information technologies, which entailed the spread of network organizational forms of business, the virtualization of logistics processes, the dissemination of electronic document management, the use of electronic payment systems.

On the basis of innovative transformations of the logistics information infrastructure, management tools are developing, new logistics concepts are being developed, such as "Party Logistics", which are based on determining the level of involvement of independent companies (logistics providers / operators) to solve business problems of the customer. Exact methods of solving logistical problems allow solving problems of only small dimension (for example, the number of destination points is not more than 50). To solve practical problems of large dimension, which reflect the existing economic realities, it is necessary to develop new approaches that are based on the use of innovative computer and information technologies. One of the most promising modern scientific trends is the use of integrated approaches that lie at the junction of various scientific directions. To solve complex multicriterial optimization problems, to a class of which logistical tasks belong, various methods are successfully used, including evolutionary algorithms, which include genetic algorithms.

The optimization tasks of transport logistics are not amenable to a quick and effective solution. Modern results of research on methods of solving the main problem of routing (VRP - Vehicle Routing problem) [4], include a variety of mechanisms for finding and improving an acceptable solution [5-8]. VRP belongs to the class NP - complex problems. For small dimensions, integer linear programming methods are used, for large dimensions - metaheuristics, which have become widely used in practice. Within the framework of the second direction, a hybrid genetic algorithm (GGA) is proposed, which differs from the classical genetic algorithm using the apparatus of the theory of fuzzy sets (FST) to regulate the size of the initial population.

The genetic algorithm is a heuristic search algorithm used to solve optimization problems using mechanisms that imitate biological evolution [9,10]. In this case, in the case of a genetic algorithm under evolution, we mean the evolution of a certain population of individuals (chromosomes) -solutions, the suitability of each of which is determined by the value of the target function that corresponds to this solution. In the simplest case of a canonical genetic algorithm, the simulation of such an evolution reduces to the simulation of the emergence of new individuals-descendants (new solutions) based on the intercourse of the parents-parents (old solutions), the simulation of the selection of the most adapted individuals (solutions with the best values of the target function) and the simulation of random mutations (rare random changes to solutions).

At the initial stage (n = 0) of the classical genetic algorithm, the initial population of the chromosomes is randomly generated, each of which represents a sequence of genes encoding an alternative solution (for example, a chromosome can encode a variant of the carriage of a particular VEHICLE (V) on a particular route). At the same time, each gene can carry the value of the corresponding type of V and the length of the route. Then the cycle begins, at each iteration of which the current population is applied sequentially: the reproduction operator randomly selects the chromosomes for crossing with the probability proportional to their fitness function (determined by the values of the target function of the corresponding pairs - V& route); a crossover operator simulating the creation of the descendants of chromosomes, borrowing separate parts of the genetic code from parents (the formation of new matching pairs of V& route that inherited different types of V and routes in different previously selected old pairs); the operator of a random mutation, with a given (small) probability, changes the chromosome in a random place randomly; and, finally, a recombination operator that determines the chromosomes that will be included in the next population (it selects the most suitable for further evolution of the pair of V&route in accordance with the value of their target function). As a target (fitness) function, the monetary value of the entire plan of transportation is applied. The cycle continues until the maximum number of iterations n is reached or a satisfactory solution is obtained. Scheme of traditional GA:

*BEGINNING / * genetic algorithm * /*
Create an initial population;
Evaluate the suitability of each individual;
stop: = FALSE
UNTIL DOES NOT STOP EXECUTE
*BEGINNING / * create a new generation population * /*
REPEAT (population size / 2) TIMES
*BEGINNING / * playback cycle * /*
Choose two individuals with high adaptability from previous generation to cross;
Broken selected specimens and get two descendants;
Assess the suitability of descendants;
Place in a new generation of descendants;
END
IF the population agrees TO stop: = TRUE
END

In the GGA after the creation of the initial population and the calculation of the fitness function for each pair of V&route, the operation of the FST is started. We define the set of linguistic variables "Value of fitness - functions" as "Very Bad", "Bad", "Satisfactory", "Good", "Very Good". Those pairs of V&route (chromosomes), values of fitness-functions of which arrive in the "VeryBad" FS, are excluded from further processing. Thus, the dimension of the current population decreases and the time of convergence of GGA decreases, which is relevant for problems of large dimension. Hybrid GA scheme:

*BEGINNING / * genetic algorithm * /*
Create an initial population;
Evaluate the suitability of each individual;
Formation of 5 fuzzy sets
*"VB-very bad", "B-bad", "S-satisfactory", "G-good", "VG-very good" individuals depending on the suitability value / * FST * /*
Reducing the dimension of the initial population by removing from it the fuzzy set "VB"
stop: = FALSE
UNTIL NOT STOP EXECUTE
*BEGINNING / * create a new generation population * /*
REPEAT (population size / 2) TIMES
*BEGINNING / * playback cycle * /*
Choose two individuals with high adaptability from previous generation to cross;
Broken selected specimens and get two descendants;
Assess the suitability of descendants;
Formation of 5 term sets "VD", "B", "S", "G", "VG" individuals depending on the value of the fitness function
*/ * FST * /*
Reducing the dimension of the initial population by removing from it the term set "VB"
END
IF the population agrees TO stop: = TRUE
END

The software implementation of the proposed GGA is performed on the .NET Framework platform and the MS Visual Studio development framework, the programming language C #. Experiments were carried out to evaluate the possibilities of the author's GGA. The first stage of the GGA testing was performed on the test functions of De Jong, Rosenbrock, Rastrigin [11-13]. The second stage of testing was carried out on real data obtained at the objects of the following subject areas: agrarian sector, oil and gas industry, distribution of gasoline in the network of gas stations.

The following characteristics of the GSA were used in the work: the type of crossover is one-point, parameter coding is real, which gives additional advantages over the speed of the GGA, as a new generation strategy, the Fuzzy Set apparatus is used. The results of the first stage of the experiments on the test functions showed that the GA showed the best results, both in terms of the rate of convergence, and in the probability of reaching the absolute optimum (Table 1), in comparison with the classical GA.

Table 1: Results of the first stage of testing

Type GA	Testing function		
	De Jong	Rosenbrock	Rastrigin
KGA	0.89	0.86	0.84
GGA	0.92	0.90	0.88

The results of the second experiments confirmed the results of the first one. The value of the total cost of the entire transport plan obtained with the use of GGA showed better results than KGA (Table 2).

Table 2: The value of the total shipping plan

Domain Object	KGA ($)	GGA ($)
DO#1	21598.70	16124.61
DO#2	83305.60	65984.84
DO#3	58179.20	47630.10
DO#4	112384.67	94781.93
DO#5	25384.98	12021.75
DO#6	97359.50	82840.36
DO#7	25292.50	16977.14
DO#8	11091.83	7308.28
DO#9	273595.78	223387.96
DO#10	308625.32	317943.95
DO#11	233056.21	215091.83

The main advantage of using evolutionary algorithms in general and genetic algorithms in particular in solving optimization problems is their ability to operate with a variety of solutions - a population that allows one to reach the global extremum without getting stuck in the local. At the same time, the information about each person in the population is coded in the chromosome (genotype), obtaining the optimal solution (phenotype) is obtained after the implementation of the evolution (selection, crossing, mutation) after decoding. The proposed GGA allows the process of controlling the size of the source and current populations using the FST apparatus and has the advantage of using real coding. The obtained results testify to the expediency of applying this modification to solve logistic problems in various subject areas.

Evolutionary algorithms provide enormous materials for further research due to the availability of a large number of modifications and the parameters of their work. It should be noted that the effectiveness of the operation of the SA greatly depends on the setting of the parameters. But this does not diminish the value of GA as one of the most explored and developing algorithms of global direct search optimization.

Element Ω3 (ITOFR) implements the methodology of using fuzzy sets of devices for risk minimization under the conditions of COTDS and the optimization algorithm for the business portfolio of the COTDS . On the basis of this IT the automated information system "Optima-Risk-Agro" was created.

Element Ω4 - (ITSTF) informational technology of short-term forecasting is based on the neuro-network modification of the group method of data handling (GMDH) [14]. Most GMDH algorithms use a polynomial basis function. The general connection between the input and output variables can be expressed in the form of a Volterra functional series, the discrete analog of which is a Kolmogorov-Gabor polynomial:

$$y = a_0 + \sum_{i=1}^{M} a_i x_i + \sum_{i=1}^{M}\sum_{j=1}^{M} a_{ij} x_i x_j + \sum_{i=1}^{M}\sum_{j=1}^{M}\sum_{k=1}^{M} a_{ijk} x_i x_j x_k ,$$

where $= (x_1, x_2, \dots, x_M)$ input vector variables; $A(a_1, a_2, \dots, a_M)$ vector of coefficients or weights.

The components of the input vector X can be independent variables, functional forms or final difference members. Other nonlinear basis functions, such as differential, logistics, probabilistic or harmonic can also be used to build the model. The method can simultaneously receive optimal structure of model and dependence on the selected output parameters most important input parameters of the system [15-17].

6. Conclusions

The rapid development of the digital economy requires the appropriate development of information systems (IS) and information technologies (IT), changes the direction of the state strategy to overcome the current challenges of the need to build relationships with the global giants of the IT industry (Google, Apple, Facebook and Amazon), total capitalization which exceeded the GDP of many developed countries of the European Union. For Ukraine, the question arises about the choice of priorities, which requires an extremely rapid transformation of the traditional economy into its traditional paradigm to the modern information intellectual digital economy, which involves a synergistic effect from building the foundation on the concepts of "digital economy", "knowledge economy", "information society". In this context, the process of "consumption" of IT products becomes more significant. That is - not only to produce powerful IT solutions for other countries, but also to implement modern IS and IT in the national manufacturing sectors. In addition, the analysis of deep trends in energy and raw material geopolitics shows a sharp increase in energy, natural resources and food needs, which will exacerbate tensions due to access to these resources. Producers and at the same time consumers of these resources are complex territorially-distributed systems (COTDS) or - economic entities for which the tasks of management of large pools of resources (labor, financial, material, etc.) are the most relevant and significant.

The results of the studies presented in this paper are the basis for the formation of models and algorithms for optimizing the management of complex geographically distributed systems. The developed information technologies allow to solve a very complicated task of coordination of the three-level system of organizational management of the COTDS, as this problem is substantially complicated by the necessity of harmonizing the criterion of operation of the COTDS in general with the criteria for its separate components, which in turn are also complex systems. In addition, these IITs can be applied autonomously in the structural subdivisions of vertically integrated business entities as basic to the federal DSS and integrated into existing ERP and BPM systems on the strategic management horizon. As a promising direction for using these IITs, the possibility of their implementation within the framework of the Blockchain concept, which is the basis of the concept of distributed data management systems, can be considered.

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