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## Metaheuristic Mathematical Optimization in Crisis Management of Educational Systems

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**Abstract.** *The article explores metaheuristic mathematical optimization as an effective tool for crisis management of educational systems under conditions of uncertainty and limited resources. It is argued that traditional linear management approaches are insufficient for addressing complex challenges caused by economic, demographic, and institutional instability. The study highlights the potential of metaheuristic algorithms, including evolutionary, collective intelligence, and stochastic methods, to solve multi-criteria and nonlinear management problems in education. The results demonstrate that metaheuristic optimization supports adaptive decision-making, efficient resource allocation, structural transformation, and risk assessment, enhancing the adaptability, resilience, and sustainability of educational systems in crisis conditions.*

**Keywords:** *educational systems, educational management, mathematical optimization, metaheuristic optimization, crisis management, digital transformation of education.*

**Introduction.** In the conditions of modern development of social systems, the social sphere (including the sphere of education) is faced with increasing pressure from instability factors associated with economic shocks, demographic changes, accelerated digitalization, institutional reforms, as well as exogenous crises of a global and local nature [1, 2]. Such a set of challenges significantly complicates the processes of managing social (including educational) systems and requires a revision of traditional (and currently outdated) management approaches focused on linear forecasting and environmental sustainability [3, 4].

Anti-crisis management in such conditions involves the use of flexible and adaptive tools that can take into account the multiplicity of goals, limited resources and a high level of uncertainty [5, 6]. Methods of mathematical modeling and optimization are of particular importance, which allow formalizing management tasks and justifying the choice of strategic decisions. Among them, a special place is occupied by metaheuristic mathematical optimization, focused on finding rational solutions in complex and poorly structured systems [7].

Metaheuristic algorithms, including evolutionary methods [8], collective behavior algorithms, stochastic search procedures and their combined forms, were initially used in technical and economic fields. However, their transfer to the field of educational management allows for a new approach to the analysis of resource allocation processes, human capital management, optimization of organizational and institutional structures, as well as increasing the resilience of educational organizations in crisis situations.

A distinctive feature of metaheuristics is their ability to function robustly and effectively in conditions of incomplete, noisy and dynamic data, as well as to take into account complex (including even continuous and non-convex) nonlinear dependencies between system elements [9]. This makes these methods particularly relevant for managing education, where management decisions affect not only economic but also social parameters, including the availability of educational services, the quality of training and the reproduction of human potential.

In this regard, the study of the possibilities of applying metaheuristic mathematical optimization in anti-crisis management of education is a relevant direction of scientific research, which corresponds to modern trends in the intellectualization of management and the introduction of digital tools in the public sector.

**Results.** The results of the conducted analysis allow us to assert that metaheuristic mathematical optimization has significant potential as a tool for anti-crisis management of educational systems. Its use contributes to the formation of more flexible and adaptive models of managerial decision-making, focused on the stability of the functioning of education in the conditions of an unstable external environment.

The use of metaheuristic methods provides an effective solution to multi-criteria problems typical for the field of education, including optimization of the distribution of financial, material and personnel resources, modeling of options for structural transformations, as well as assessment of risks associated with a decrease in the quality of educational services. The ability to take into account the dynamics of changes and the set of restrictions allows you to develop management strategies focused on long-term development and preservation of system integrity.

A significant advantage of metaheuristic optimization is its ability to integrate with digital management platforms, data analytics systems, and intelligent decision support tools. This creates prerequisites for the formation of hybrid management mechanisms that combine mathematical modeling, expert knowledge and elements of

artificial intelligence, which is especially important in the conditions of crisis transformations of the educational environment.

However, the introduction of metaheuristic approaches requires an increase in the level of analytical competence of management personnel and a careful attitude to the interpretation of the obtained results. The lack of a strict guarantee of finding a globally optimal solution is compensated by the possibility of obtaining practically-oriented, realizable and sustainable management alternatives, which corresponds to the logic of anti-crisis management.

In general, metaheuristic mathematical optimization can be considered as one of the key components of modern anti-crisis management of education, aimed at increasing the efficiency, adaptability and stability of educational systems. Prospects for further research are related to the development of applied models, empirical verification of the effectiveness of algorithms, and their introduction into institutional and national education management systems.

**Discussion.** The current stage of development of educational systems is characterized by the complication of management tasks, the increase in the level of uncertainty and the strengthening of the influence of crisis factors of various nature. In these conditions, the development of hybrid approaches focused on increasing the adaptability, stability and efficiency of crisis management [10] (in particular, educational activities and educational systems in general) is of particular relevance.

One of the key prospects is the integration of various metaheuristic algorithms within the framework of hybrid models that combine the advantages of evolutionary methods, collective intelligence algorithms and stochastic search procedures. Such combinations allow overcoming the limitations of individual algorithms, increasing the convergence speed and quality of obtained solutions when solving multi-criteria and high-dimensional problems [11] (in particular, educational management).

The significant potential of hybrid metaheuristic optimization is associated with its synthesis with artificial intelligence methods and big data analysis. The use of machine learning for adaptive tuning of algorithm parameters, forecasting crisis scenarios and identifying hidden patterns in educational data opens up the possibilities of forming intelligent decision support systems focused on real-time work.

Another promising direction is the integration of hybrid metaheuristics into digital education management platforms, including quality monitoring systems, resource management and strategic planning. This allows for dynamic optimization of management decisions taking into account changing external and internal conditions, as well as scenario modeling of the consequences of various anti-crisis strategies.

Special attention deserves the development of multi-criteria and robust optimization models that take into account social, economic and institutional constraints on educational activities. Hybrid metaheuristic approaches allow finding compromise

solutions between competing goals - accessibility, quality of education, financial sustainability and social justice, which is especially important in crisis conditions.

In general, hybrid metaheuristic mathematical optimization forms a methodological basis for the transition to intellectualized anti-crisis management of education, which ensures the sustainability of educational activities and the development of educational systems in conditions of systemic crises and uncertainty.

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