

2. Генсерук Г. Р., Мартинюк С. В. Розвиток цифрової компетентності майбутніх учителів в умовах цифрового освітнього середовища закладу вищої освіти. *Інноваційна педагогіка*. 2019. № 19 (2). С. 158–161. URL: http://www.irbis-nbuv.gov.ua/cgi-bin/irbis_nbuv/cgiirbis_64.exe?image_file_download=1&image_file_name=pdf/innped_2019_19%282%29__36.pdf (дата звернення: 26.12.2025).

3. Рожкова А. Формування цифрової компетентності майбутніх учителів технологій: виклики та перспективи / за заг. ред. Д. Кільдерова, В. Харламенко. 2025. С. 253–256. URL: <https://enpuir.udu.edu.ua/bitstreams/95cf9ca9-baef-41cc-91b9-9a3e659c2e51/download> (дата звернення: 25.12.2025).

4. Gisbert Cervera M., Caena F. Teachers' digital competence for global teacher education. *European Journal of Teacher Education*. 2022. Vol. 45, No. 4. P. 451–455. URL: <https://www.tandfonline.com/doi/full/10.1080/02619768.2022.2135855> (date of access: 26.12.2025).

5. Skantz-Åberg E., Lantz-Andersson A., Lundin M., Williams P. Teachers' professional digital competence: An overview of conceptualisations in the literature. *Cogent Education*. 2022. Vol. 9, No. 1. Article 2063224. URL: <https://www.tandfonline.com/doi/abs/10.1080/2331186X.2022.2063224> (date of access: 26.12.2025).

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Mathematical Optimization in Educational Management under Uncertainty and Crisis: Current Developments and Future Directions

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Abstract. Educational systems operate under growing uncertainty and crisis conditions, where traditional deterministic management approaches lose effectiveness. This paper explores the shift toward resilience-oriented educational management based on mathematical optimization. It highlights the application of stochastic, robust, and fuzzy optimization methods to resource allocation, scheduling, and student retention. The study emphasizes the Smart Predict-then-Optimize paradigm, integrating machine learning and operations research through digital twins, data-driven and multi-criteria optimization. Key limitations related to data quality and ethical risks are also identified. Mathematical optimization is thus positioned as a strategic tool for sustaining educational systems in crisis environments.

Keywords: educational systems; educational management; mathematical optimization; crisis management; hybrid algorithms; digital transformation of education.

Introduction.

Modern educational ecosystems operate in conditions characterized by high turbulence and unpredictability, which in modern management theory is described by the concept of BANI (Brittle, Anxious, Non-linear, Incomprehensible). Exogenous shocks [1, 2], such as global pandemics, geopolitical conflicts economic crises and forced migration processes, lead to a significant increase in entropy in management processes [4, 5]. In such conditions classical deterministic approaches to planning, based on extrapolation of historical data, lose their effectiveness [6, 7]. The relevance of the application of mathematical optimization methods in this context is due to the need to transition from the efficiency paradigm (cost minimization at fixed parameters) to the resilience paradigm - the ability of the system to maintain functionality under the influence of destabilizing factors [8]. Mathematical modeling is transformed from an operational planning tool into a strategic framework for decision-making in conditions of incomplete information [9].

Results.

1. Transformation of mathematical management paradigms.

In conditions of stable functioning, educational management relied on deterministic linear programming models, where key parameters (student contingent, budget allocations, classroom fund) were considered as constants. Crisis phenomena translate these parameters into the category of stochastic variables or uncertain quantities, which requires the use of a more complex mathematical apparatus.

1.1. Stochastic Programming - this approach involves modeling system parameters as random variables with known probability distribution functions. In the educational context, this allows taking into account risks that have a probabilistic nature. For example, when planning the workload of a scientific and pedagogical employee, not fixed availability is taken into account, but the probability of his working capacity or the availability of technical access to the network. The objective function in such problems often consists of optimizing the mathematical expectation of the result.

1.2. Robust Optimization - unlike stochastic methods, robust optimization does not rely on exact probability distributions which are often impossible to establish in a crisis. Instead, it operates on sets of uncertainty, looking for a solution that remains admissible for any implementation of uncertain parameters within a given set. This is the so-called "worst-case scenario " approach, which allows guaranteeing the basic level of functioning of an educational institution even under extreme external influences, such as a complete lockdown or a sharp reduction in funding.

1.3. Fuzzy Logic. In conditions where quantitative measurements are complicated or delayed, the fuzzy logic apparatus is used. It allows you to formalize qualitative, linguistic variables (for example, "high level of student anxiety", "average quality of distance communication") and integrate them into mathematical decision-making models. This is especially relevant for assessing the psycho-emotional state of participants in the educational process and the quality of knowledge acquisition in non-standard conditions.

2. Applied aspects of optimization in crisis conditions.

2.1. Dynamic resource allocation. In conditions of resource shortage and growing needs, the budget allocation problem takes the form of a combinatorial optimization problem, in particular variations of the Knapsack Problem with fuzzy weight coefficients. Since the cost and value of resources can change dynamically, uncertainty coefficients are introduced into the model. This allows you to algorithmically determine the priority of expenses, balancing between capital investments (for example, equipment for energy independence) and operating expenses (cloud services), ensuring the maximization of the coverage of education seekers.

2.2. Adaptive Timetabling. The classical task of scheduling is NP-hard, and in crisis conditions it is complicated by the need for dynamic restructuring. Instead of static algorithms metaheuristic methods such as genetic algorithms or ant colony algorithms are used. These approaches allow real-time response to changes in the availability of teachers and classrooms, automatically generating new scheduling options. The objective function includes not only minimizing "windows" or conflicts, but also compliance with sanitary standards and optimizing the flow of people (network flow optimization) to ensure social distancing.

2.3. Contingent management and predictive analytics (Student Retention).

To minimize student dropout, predictive analytics methods are used in combination with Markov decision processes (MDP). The system analyzes the dynamics of success and behavioral patterns, calculating the probability of expulsion for each student. Based on this, the task of optimizing management influences is solved: the system recommends personalized interventions (financial support, academic leave, tutoring), which maximize the probability of retaining a student in the system with minimal resource costs.

3. Promising directions - Smart Predict-then-Optimize (SPO).

The most promising direction of development is hybridization [10], i.e. the integration of machine learning (ML) methods and operations research (Operations Research) within the Smart Predict-then-Optimize (SPO) paradigm. Firstly, this is the development of the technology of digital twins (Digital Twins) of educational institutions. Creating a full mathematical copy of the university allows for scenario modeling and stress testing of the system. This allows management to assess the resilience of the financial and academic model to hypothetical shocks (for example, a 40% reduction in enrollment) even before the crisis. Secondly, the transition to data-driven optimization (Data-Driven Optimization). Modern algorithms are able to independently detect hidden limitations and patterns in historical data, formulating the constraints of the optimization problem without direct human intervention. Thirdly, the widespread use of multi-criteria optimization (Multi-Criteria Decision Making – MCDM). In crisis situations management goals are often in conflict (for example, safety versus the quality of education). Methods for searching for a set of Pareto-optimal solutions allow finding balanced compromises where improving one indicator is impossible without critically worsening the other.

4. Limitations and implementaton risks.

It is worth noting the significant limitations of the application of mathematical methods in crisis conditions. The key problem is the quality of input data (GIGO principle – Garbage In, Garbage Out). In conditions of rapid change, the phenomenon of concept drift is observed, when models trained on historical data of stable periods give incorrect forecasts in new realities. A separate aspect is the ethical component of algorithmic management. Optimization solely by the criterion of "efficiency" can lead to discrimination against vulnerable groups of education seekers, which requires the introduction of additional "fairness constraints " into mathematical models.

Conclusions.

Summing up the above, it should be stated that in conditions of global uncertainty, the role of mathematical optimization in education management is undergoing fundamental changes. It is transformed from a tool for tactically improving indicators into a tool for strategically ensuring the viability of the system. The transition to robust and adaptive models allows educational institutions to form "immunity" to external shocks. At the same time, mathematical models act as a decision-making support system that enhances, but does not replace, managerial intuition and value orientatons of management.

References

1. Ostapenko T., Onopriienko D., Hrashchenko I., Palyvoda O., Krasniuk S., Danilova E. (2022) Research of impact of nanoeconomics on the national economic system development. *Innovative development of national economies: collective monograph*. – Kharkiv: PC TECHNOLOGY CENTER, 2022. – pp. 46-70.
2. Tsalko T. R., Nevmerzhytska S.M. (2023) Risk assessment in innovative activity. *Actual problems in economics, finance and management: materials of the International Scientific and Practical Conference*. East European Center for Scientific Research (Odesa, 25 october 2023). Research Europe, 2023. pp. 92-94 <https://researcheurope.org/product/book-31/> [in Ukrainian].
3. Nevmerzhytska S. M. (2018). Formation of a strategy for the innovative development of enterprises in conditions of uncertainty. *Scientific Bulletin of the Kherson State University. Series: Economic Sciences*. 2018. Vol. 32. pp. 99-103. URL: <https://ej.journal.kspu.edu/index.php/ej/article/view/422/418>.
4. Nevmerzhytska, N. Buhas (2022). Opportunities, threats and risks of implementation the innovative business management technologies in the post-pandemic period COVID-19. *WSEAS Transactions on Business and Economics*. Volume 19. Pp. 1215–1229.
5. Hrashchenko I.S., Khmurova V. V. (2016). Innovative policy as a tool for organizational change. Economic development: theory, methodology, management. *Materials of the 4th International Scientific and Practical Conference*]. Budapest-Prague-Kyiv, 28-30 November 2016. 386, p. 361-369. [In Ukrainian].
6. Mykytenko V.V., Hryshchenko I.S. (2008). Adaptive management system of innovative processes at enterprises. *Problems of science*, (4), pp. 32-37.

7. Naumenko, M. (2024). Methodology of determining factors of activity efficiency and competitive position of the enterprise on the market in crisis conditions. *Scientific innovations and advanced technologies*, № 7(35) (2024). DOI: [https://doi.org/10.52058/2786-5274-2024-7\(35\)-648-665](https://doi.org/10.52058/2786-5274-2024-7(35)-648-665) [in Ukrainian].

8. Krasnyuk M.T., Naumenko M.A. (2024). Efektyvne zastosuvannia henetychnykh alhorytmiv u vyrishenni bahatoekstremumnykh optymizatsiinykh zadach v menedzhmenti konkurentnoho pidpriemstva [Effective application of genetic algorithms in solving multi-extremum optimization problems in the management of a competitive enterprise]. *Grail of Science*, №41, June 2024, 65-73. URL: <https://archive.journal-grail.science/index.php/2710-3056/issue/view/05.07.2024/29> [in Ukrainian].

9. Kulynych Y., Krasnyuk M., Krasniuk S. (2022). Efficiency of evolutionary algorithms in solving optimization problems on the example of the fintech industry. *Grail of Science*, №14-15, May 2022, (pp. 63-70) DOI: <https://doi.org/10.36074/grail-of-science.27.05.2022>

10. Krasnyuk, M. (2014). Hibrydyzatsiia intelektualnykh metodiv analizu biznesovykh danykh (rezhym vyiavlennia anomalii) yak skkladovyi instrument korporatyvnoho audytu [Hybridization of intelligent methods of business data analysis (anomaly detection mode) as a standard tool of corporate audit]. Stan i perspektyvy rozvytku oblikovo-informatsiinoi systemy v Ukraini - The state and prospects of the development of the accounting and information system in Ukraine: materials of the III International science and practice conf. [m. Ternopil, October 10-11. 2014]. TNEU, 2014. pp. 211-212 [in Ukrainian].

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Challenges of Distance Learning in the Methodology of Studying Literature in Institutions of General Secondary Education

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Abstract. The article analyzes the main challenges faced by the methodology of teaching literature in institutions of general secondary education in the conditions of distance learning. The specifics of literature as an educational subject, which involves emotional and aesthetic perception, dialogicity and interpretation of artistic works, are considered. The key problems were identified: a decrease in the motivation of students, the difficulty of organizing interactive interaction, limited opportunities for the development of oral speech and critical thinking. Ways to overcome these challenges through the integration of digital tools, the adaptation of methodological techniques and the creation of an interactive educational environment are proposed.

Keywords: distance learning, literature teaching methods, digital technologies, interactive methods, institutions of general secondary education.