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MATHEMATICAL MODELING FOR UNIVERSITY RESOURCE OPTIMIZATION BASED ON QS WUR INDICATOR

The article presents a retrospective analysis of the key indicators of the QS World University Rankings for Ukrainian higher education institutions with the aim of establishing realistic development targets for NTU “KhPI.” The dynamics of ranking indicators are examined in comparison with leading Ukrainian universities, which made it possible to determine achievable growth limits for each indicator in the medium-term perspective. Based on the obtained results, a system of target values was formed, which can be used by the university to improve its position in the ranking. A mathematical model for optimizing resource allocation is proposed, aimed at minimizing the deviation between actual and target indicator values. The model is presented as a quadratic programming problem with Boolean variables and linear constraints that reflect the university’s limited resources and the set of possible measures for improving each indicator. Given the nonlinearity of interconnections and the incompleteness of initial data, the use of a genetic algorithm is justified, as it ensures an effective search for optimal resource allocation options under multicriteria conditions. It is additionally emphasized that the proposed approach enables the adaptation of the university’s development strategy to the dynamic conditions of the international educational environment and takes into account changes in the weights of individual indicators in the ranking methodology. The model can be used as a tool for scenario analysis and for generating various management decision options. The practical significance of the study lies in the possibility of integrating the obtained results into the university’s strategic planning system. The results form a foundation for creating an information system to support strategic management in higher education institutions. Further research includes experimental validation of the model using retrospective data from NTU “KhPI” and the development of a software tool aimed at enhancing the effectiveness of management decisions and improving the university’s position in international rankings.

Keywords: key performance indicators, resource allocation optimization model, decision-making, ranking, strategic management, information system

Introduction. In the modern competitive environment, improving the position of a higher education institution (HEI) in international rankings is a strategic task for university leadership. Among the most well-known rankings are ARWU (Academic Ranking of World Universities) [1], the Times Higher Education (THE) ranking [2], and the QS World University Rankings (QS WUR) [3]. The existence of these rankings intensifies competition among universities worldwide, as students, society, and governmental institutions consider ranking results to be significant. Therefore, these rankings shape perceptions and influence the decisions of the aforementioned stakeholders, creating a foundation for the development and application of requirements within the global knowledge system by which university performance is assessed. One of the most influential rankings is QS WUR, which is based on nine key indicators: academic reputation, employer reputation, faculty-to-student ratio, citations per faculty, international faculty ratio, international student ratio, international research network, employment outcomes, and sustainability [4]. To improve their ranking positions, university leadership must adapt strategic planning to the conditions of the global educational market. This requires effective allocation of available resources and identification of priority areas for development. Consequently, researchers and practitioners are paying increasing attention to studying university performance to improve ranking outcomes.

Analysis of research and publications. The authors of [5] examined the differences among major university rankings and the relationships among scientometric indicators, disciplines, and the positions of leading HEIs. The results of this study help administrators and education management specialists identify key parameters for university development and interact more effectively with stakeholders. In [6], the QS WUR ranking and its key indicators were analyzed, and their distribution and interrelationships were studied using statistical methods. The authors compared three forecasting models (linear regression, Random Forest, and XGBoost) and demonstrated that XGBoost provides the most accurate prediction of university positions, offering deeper insight into the QS ranking system.

In [7], an approach to building a ranking prediction system based on the analysis of global performance indicators was described. The researchers identified key factors influencing HEI positions and proposed a forecasting model that can help universities improve their results more effectively. In [8], a mixed-integer programming model was proposed, enabling universities to independently determine the weights of ranking criteria, thereby reducing the subjectivity of traditional methods and ensuring fairer and more flexible comparisons among institutions.

In [9], using the example of the THE ranking, the validity of performance indicators was assessed and their weights optimized using principal component analysis (PCA), while data from 200 leading universities were used to train a neural network that predicts future rankings. In [10], THE rankings were analyzed to evaluate model

performance and to identify relationships among individual indicators.

The study [11] conducted a scientometric analysis of global rankings using contrastive models. The use of 18 classifiers demonstrated that the top-100 universities in QS WUR are clearly distinguishable from others, with an average accuracy of 71 % . The proposed data visualization approach helps HEI administrators assess and form their own ranking strategies. In [12], a comprehensive analysis of the IRN indicator for 2023–2025 was conducted using big data, including statistics, scatterplots, and correlation and regression analysis. The authors highlight the need to improve this indicator to ensure transparency, consistency, and inclusiveness in assessing global research networks.

In [13], the influence of key indicators on QS WUR results and the position dynamics of the National University "Lviv Polytechnic" were studied, allowing identification of key trends and patterns for forming long-term development strategies for universities. In [14], the publication activity of Ukrainian researchers was analyzed using mathematical and statistical methods, and trend forecasting was performed using exponential smoothing (Holt's model), demonstrating high consistency with empirical data.

In [15], a comparative analysis of leading global, European, and Ukrainian rankings was conducted, identifying key differences in how HEIs' public images are formed. In [16], a system of indicators for assessing HEIs within a competency-based paradigm was justified, emphasizing the importance of international experience with modern evaluation methods. In [17–18], the strategic prospects for the development of higher education in Ukraine were examined, and key directions for reform were outlined to improve education quality, graduate competitiveness, and the sustainable development of the higher education system.

The analysis of these works demonstrates that the issue of improving HEI ranking positions is multidimensional and highly relevant. Researchers use a systematic approach to analyzing rankings and key indicators, applying statistical methods, machine learning, and optimization models to forecast university positions. At the same time, insufficient attention is given to the optimal allocation of HEI resources and decision-support tools aimed specifically at improving indicator values. Rankings influence university reputation, the ability to attract talent, and access to funding.

Aim and tasks of the study. The aim of this work is to develop an approach to improving university ranking indicators using methods and techniques applicable under the conditions of limited resources in Ukrainian universities. To achieve this aim, a thorough data analysis must be conducted to determine the target indicators for selected Ukrainian universities, which will serve as the foundation for creating resource allocation scenarios designed to improve institutional effectiveness and enhance the university's international image in the educational landscape.

Materials and model. The object of this study is the National Technical University "Kharkiv Polytechnic Institute" (NTU "KhPI"). The university consists of structural units that ensure the implementation of the educational process, including educational and research institutes, departments, the postgraduate studies office, and others. Their functions and authority are defined by the University Statute [19] and relevant regulatory provisions. Strategic management of the university is carried out by the rector, who is responsible for educational, research, and financial-economic activities. Each year, the rector of NTU "KhPI" presents and publishes an open report on the achievement of key performance indicators, which enables an assessment of the university's effectiveness in accordance with modern educational trends and the requirements of international rankings [20–21]. To achieve these indicators, which are related to ranking metrics, optimal allocation of the university's available resources is required.

To this end, all QS WUR indicators and the methodology for their calculation were analyzed. The ranking includes the following indicators:

- K_1 – academic reputation (AR);
- K_2 – employer reputation (ER);
- K_3 – faculty-to-student ratio (FSR);
- K_4 – citations per faculty (CPF);
- K_5 – international faculty ratio (%), IFR;
- K_6 – international student ratio (%), ISR;
- K_7 – international research network (%), IRN;
- K_8 – employment outcomes (%), EO;
- K_9 – sustainability index (%), SUS.

According to the methodology [4], all indicators are normalized. Normalization is performed using methods such as min–max normalization with logarithmic smoothing and normalization based on relative indicators. This process involves transforming the indicators to a comparable scale from 0 to 100 to ensure that universities of different sizes are evaluated equally.

The overall QS WUR score is calculated based on nine key indicators:

$$S = \sum_{i=1}^{M} w_i \cdot K_i \,, \tag{1}$$

where

- S – overall current ranking score;
- w_i – weight coefficient of the i-th indicator, $i = \overline{1, M}$;

$$\sum_{i=1}^{M} w_i = 1,\ w_i \geq 0 \,, \tag{2}$$

- K_i – normalized value of the i-th indicator, $i = \overline{1, M}$.

To increase the current value K_i of a university to $\tilde{K}_i$ (the target value of the i-th ranking indicator), it is necessary to determine the qualitative impact of each indicator (1), which will allow the formation of optimal action scenarios. These actions require university

resources. The amount of expenditure that may be used to improve ranking performance is limited by available resources.

During the implementation of improvement actions, an HEI must achieve the target indicator values. In other words, this requirement can be formulated as follows: the squared deviation of the target value from the current value of the *i*-th indicator should be minimized:

$$\left(\tilde{K}_i - K_i\right)^2 \to \min,\ i = \overline{1, M}, \tag{3}$$

Thus, to achieve the target indicator value, it is necessary to determine actions that require resources. Since these resources are limited, it is proposed to consider alternative actions for improving each indicator. We introduce the following notation:

- ΔK_{id} – the *d*-th actions option for improving the *i*-th indicator, $d = \overline{1, D}$, where *D* is the number of actions, assumed identical for all indicators;
- h_{id} – the amount of resources required to implement the *d*-th action for improving the *i*-th indicator.

As a result, we obtain the following optimization model:

$$\sum_{i=1}^{M}\sum_{d=1}^{D} w_i \left(\tilde{K}_i - \left(K_i + \Delta K_{id} u_{id}\right)\right)^2 \xrightarrow[\{u_{id}\}]{} \min, \tag{4}$$

$$\sum_{i=1}^{M}\sum_{d=1}^{D} h_{id} u_{id} \le C, \tag{5}$$

$$\sum_{i=1}^{M}\sum_{d=1}^{D} u_{id} \ge 1,\ i = \overline{1, M}, \tag{6}$$

$$u_{id} = \{0, 1\},\ d = \overline{1, D},\ i = \overline{1, M},$$

where:

- u_{id} – a Boolean variable indicating whether the *d*-th action to improve the *i*-th ranking indicator will be implemented (u_{id} =1), or not implemented (u_{id} =0);
- $U = \{u_{i1}, ..., u_{id}\}$ – the set of actions for improving the *i*-th indicator;
- *C* – total resources planned to be allocated for indicator improvement in order to increase the HEI's ranking.

Model (4)–(6) is a quadratic programming model with Boolean variables.

The proposed model identifies which actions will allow the university to come closest to the desired target indicator values. As a result of applying this model, recommendations can be generated regarding optimal allocation of university resources to best support the achievement of strategic target indicators. To accomplish this, realistic target values must be defined for each indicator.

Results and discussion. A comprehensive analysis of the dynamics of QS WUR ranking indicators was carried out for Ukrainian HEIs represented in this ranking. In the context of the Strategy for the Development of Higher Education in Ukraine for 2022–2032, a key challenge for HEIs is the implementation of key performance indicators that contribute to improving their positions in the rankings. In this work, the values of indicators for Ukrainian universities are compared in order to identify target indicators for NTU "KhPI" to improve the university's position in the ranking.

In Fig. 1, the dynamics of the academic reputation (AR) indicator for leading Ukrainian universities for 2022–2025 are presented [3].

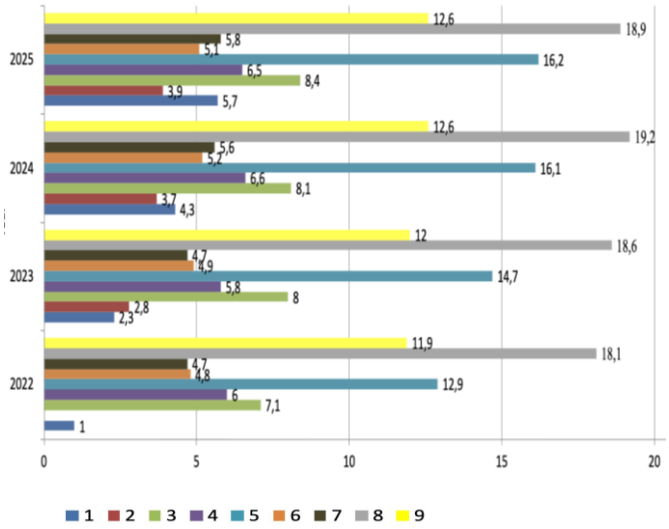

Fig. 1. Dynamics of the AR indicator

where:

- Ivan Franko National University of Lviv (1);
- Kharkiv National University of Radio Electronics (2);
- Lviv Polytechnic National University (3);
- National Technical University "Kharkiv Polytechnic Institute (4);
- National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" (5);
- National University of Kyiv-Mohyla Academy (6);
- Sumy State University (7);
- Taras Shevchenko National University of Kyiv (8);
- V. N. Karazin Kharkiv National University (9).

Academic reputation (AR), which accounts for 30 % in QS WUR in 2022–2025, shows a slight but stable increase among leading Ukrainian universities. The highest growth rates are observed at Taras Shevchenko National University of Kyiv (18,1 → 18,9) and Igor Sikorsky Kyiv Polytechnic Institute (12,9 → 16,2). Lviv Polytechnic, V. N. Karazin Kharkiv National University, and others also improve their indicators, but at a slower pace.

At NTU "KhPI," AR increased from 6,0 in 2022 to 6,5 in 2025. Despite this growth, among the considered Ukrainian universities, NTU "KhPI" has the lowest AR value. This confirms the presence of potential but indicates the need to strengthen the university's academic image.

Priority development areas include expanding international presence, participating in inter-university projects, increasing the visibility of KhPI publications, and developing partnerships with EU universities.

Next, the dynamics of the Employer Reputation (ER) indicator for Ukrainian universities for 2022–2025, presented in Fig. 2, are analysed.

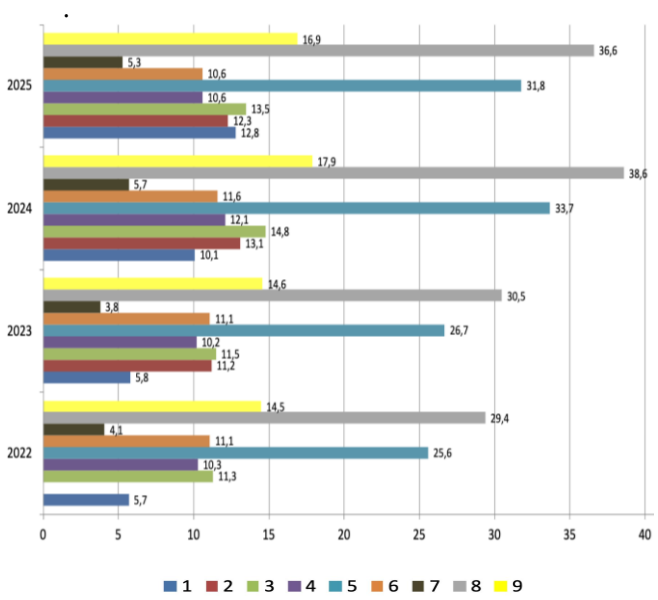

Fig. 2. Dynamics of the ER indicator

The ER indicator contributes 15 % to the QS WUR ranking and assesses the university's ability to produce competitive graduates. In 2022–2025, Ukrainian HEIs demonstrate different dynamics: Taras Shevchenko National University of Kyiv (29,4 → 36,6) and Igor Sikorsky Kyiv Polytechnic Institute (25,6 → 31,8) significantly improve their ER due to active cooperation with employers. Ivan Franko National University of Lviv also grows (5,7 → 12,8), while some universities, including Sumy State University, show lower results due to weaker ties with business and the impact of military actions.

For NTU "KhPI," ER is characterized by instability: the indicator changes from 10,3 (2022) to 10,6 (2025) after a short-term increase in 2024 (12,1). This signals weak interaction with employers and an insufficient practical orientation of educational programs. To improve ER, the university should strengthen partnerships with businesses, develop internships, dual degree programs, and career services, and involve companies in updating curricula. This will help reinforce the reputation of KhPI graduates in the labor market.

Next, the dynamics of the faculty-to-student ratio (FSR) for Ukrainian universities for 2022–2025, presented in Fig. 3, are considered.

The FSR indicator has a weight of 10 % in QS WUR and reflects the quality of the educational process and the level of individual interaction. In most Ukrainian universities in 2022–2025, it decreases due to a reduction in the student body as a result of the war. For example, at Igor Sikorsky Kyiv Polytechnic Institute FSR decreased from 47,0 to 37,4, at Taras Shevchenko National University of Kyiv from 40,3 to 27,0, and at V. N. Karazin Kharkiv National University from 66,7 to 64,6.

At NTU "KhPI," FSR fell from 68,3 (2022) to 54,3 (2025), indicating an increased teaching load and a potential deterioration in the quality of education. To improve the situation, it is necessary to balance student enrollment, strengthen personnel policies, encourage young researchers to join the faculty, and increase the attractiveness of academic careers, in particular through better remuneration and workload optimization.

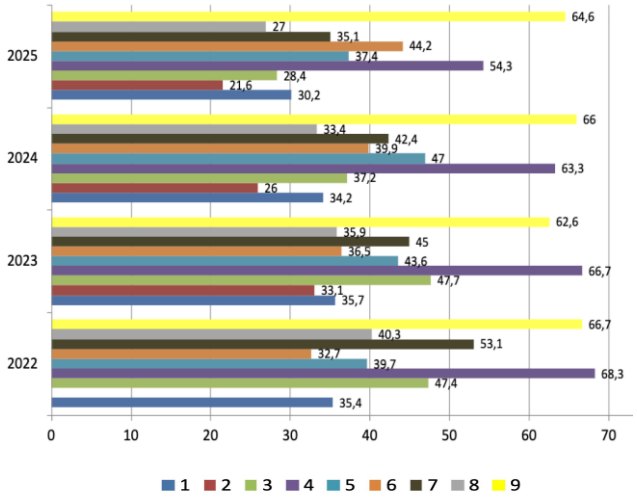

Fig. 3. Dynamics of the FSR indicator

Further, the dynamics of the QS WUR indicator related to citations per faculty (CPF) for 2022–2025, presented in Fig. 4, are examined.

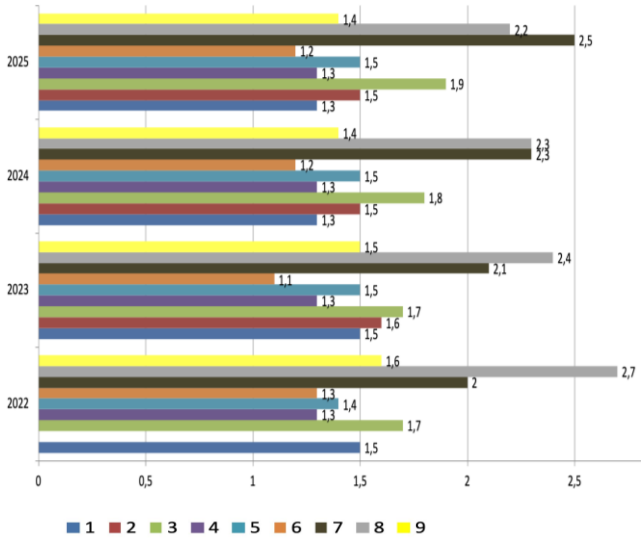

Fig. 4. Dynamics of the CPF indicator

The CPF indicator has a weight of 20 % in QS WUR and reflects the research productivity of the university. In Ukraine, it gradually increases; by 2025, Sumy State University has 2,5, Taras Shevchenko National University of Kyiv has 2,2, and Ivan Franko National University of Lviv reaches 1,3. Most HEIs have lower values due to low publication activity and limited international collaboration.

At NTU "KhPI," CPF remains stable (1,3) in 2022–2025, indicating low citation rates. To improve this, it is

necessary to encourage publications in Scopus/WoS, create expert groups for editing articles in English, expand participation in international projects, and involve young researchers.

The results on the dynamics of the international faculty ratio (IFR) for 2022–2025, presented in Fig. 5, are as follows.

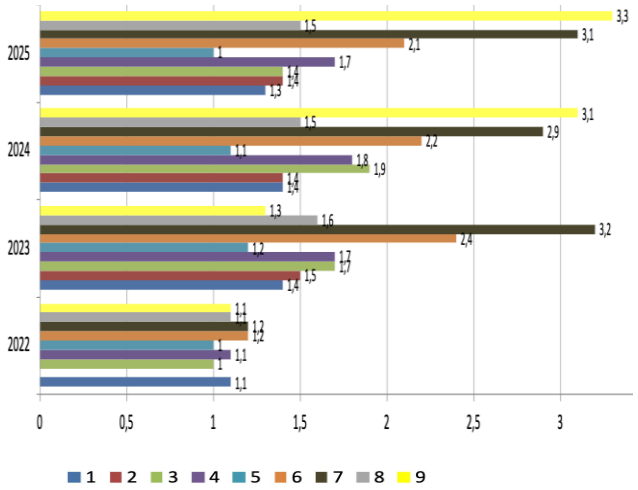

Fig. 5. Dynamics of the IFR indicator

The IFR indicator has a weight of 5 % in QS WUR and reflects the level of internationalization of the university. In Ukraine, the indicator is low; as of 2025, Igor Sikorsky Kyiv Polytechnic Institute has 1,0, Taras Shevchenko National University of Kyiv has 1,5, and V. N. Karazin Kharkiv National University has 3,3. The indicator is influenced by the war, limited mobility, and a lack of grants.

At NTU "KhPI," IFR increased from 1,1 (2022) to 1,7 (2025), but this is not sufficient for significant progress. It is recommended to develop English-taught programs, attract PhDs from the EU, conclude agreements with partner institutions, and create conditions for visiting professorships.

The dynamics of the QS WUR indicator related to the international student ratio (ISR) for 2022–2025, presented in Fig. 6, are considered next.

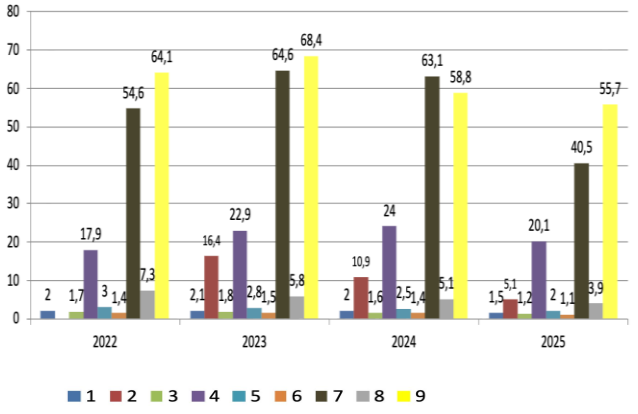

Fig. 6. Dynamics of the ISR indicator

The ISR indicator has a weight of 5 % in QS WUR and reflects the international attractiveness of the university. In Ukraine, V. N. Karazin Kharkiv National University leads with 55,7 % , Sumy State University has 40,5 % , Taras Shevchenko National University of Kyiv has 3,9 % , and other HEIs have up to 2 % .

NTU "KhPI" increased its ISR from 17,9 % (2022) to 20,1 % (2025), due to English-taught programs and international cooperation. To maintain this growth trend, it is necessary to expand English-taught programs, strengthen support services for international students, and develop the KhPI brand as a regional center of engineering education.

The next indicator is the international research network whose dynamics for 2022–2025 are presented in Fig. 7.

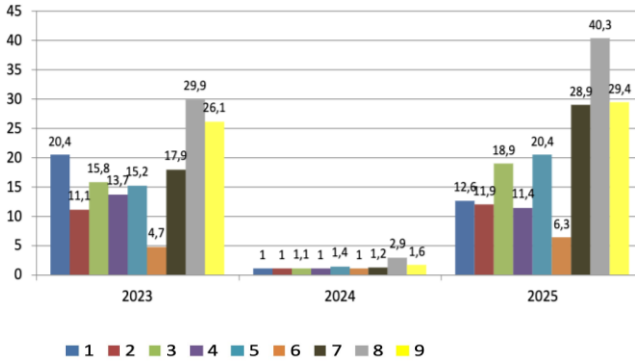

Fig. 7. Dynamics of the IRN indicator

The IRN indicator has a weight of 5 % in QS WUR and reflects the number of publications produced in collaboration with international partners. In 2025, leaders include Taras Shevchenko National University of Kyiv (40,3), V. N. Karazin Kharkiv National University (29,4), and Sumy State University (28,9); Igor Sikorsky Kyiv Polytechnic Institute has 20,4, Ivan Franko National University of Lviv reaches 18,9, and Kharkiv National University of Radio Electronics reaches 11,9.

At NTU "KhPI," IRN fluctuated: 13,7 (2023), 1,0 (2024), and 11,4 (2025) due to changes in QS methodology. In 2025, QS WUR updated the formula and normalization, eliminating some errors; as a result, the average value returned to the 2023 level, but this was accompanied by a "compression" of the scale and a loss of the indicator's discriminative power [12].

The dynamics of the QS WUR indicator related to employment outcomes (EO) for 2022–2025, presented in Fig. 8, are then considered.

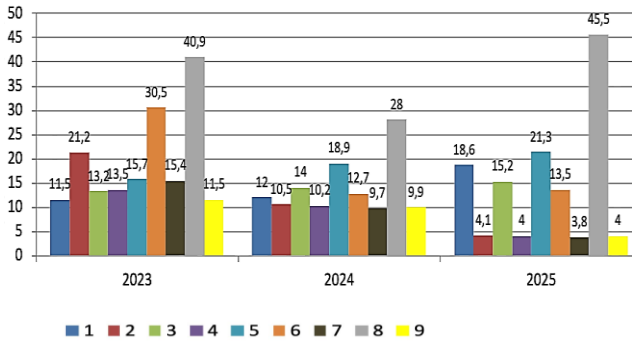

Fig. 8. Dynamics of the EO indicator

The EO indicator has a weight of 5 % in QS WUR and reflects the university's success in the labor market. In 2025, Taras Shevchenko National University of Kyiv reaches 45,5, Igor Sikorsky Kyiv Polytechnic Institute has 21,3, and Ivan Franko National University of Lviv has 15,2; low values are observed where practical training is insufficient.

At NTU "KhPI," EO remains low and equals 4 (2025), indicating the need to develop employment support, in particular career planning courses, a partner network, startup incubators, mentoring, and the involvement of alumni as ambassadors of the university brand.

The dynamics of the sustainability index (SUS) for 2022–2025, presented in Fig. 9, are as follows.

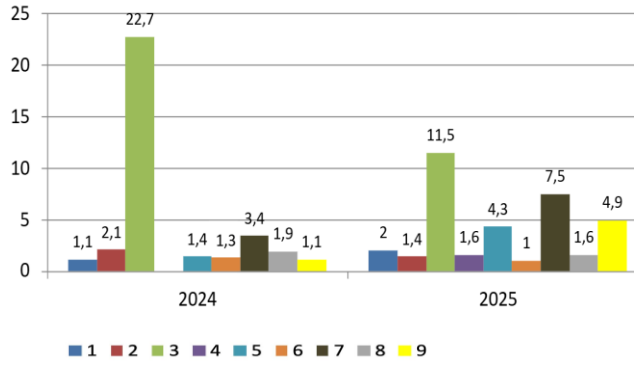

Fig. 9. Dynamics of the SUS indicator

The SUS indicator has a weight of 5 % in QS WUR and includes environmental and social impact as well as inclusion policies. In 2025, the leaders among Ukrainian HEIs are Sumy State University with 7,5, Ivan Franko National University of Lviv with 11,5, and KhPI and Taras Shevchenko National University of Kyiv with 1,6, which indicates the initial integration of sustainability principles.

At NTU "KhPI," SUS increased to 1,6 due to energy-efficient and innovative projects; however, there is no systemic ESG strategy, monitoring of social indicators, or public reporting. To improve this, it is advisable to implement inclusion policies, cooperate with local communities, and introduce sustainable infrastructure solutions.

For the analysis, Ukrainian universities officially represented in the QS World University Rankings in 2022–2025 were selected. Since NTU "KhPI" competes with these institutions within the national QS segment, their indicator values can serve as realistic benchmarks for determining its own target values. Indicators already achieved by other Ukrainian HEIs under similar economic, staffing, and organizational conditions indicate that such levels are achievable for KhPI as well. Table 1 presents characteristic values of key QS indicators for universities in different ranking clusters (1001–1200, 741–750, 701–710, etc.), which makes it possible to determine benchmarks necessary to improve KhPI's position.

Based on the comparison of the dynamics of key indicators for Ukrainian universities represented in QS WUR, realistic target benchmarks have been established for NTU "KhPI." Table 2 presents the current values of the university's indicators K_i, approximate upper limits, that reflect the maximum feasible level of indicator development in the medium term, as well as the maximum annual increment ΔK_i. The target values were determined taking into account the typical growth limits of specific indicators observed in Ukrainian HEIs under similar operating conditions, as well as the specifics of each metric–ranging from inertial reputation indicators to structural indicators of internationalization and research collaboration. The established system of constraints forms the basis for constructing an optimization model of university resource allocation.

Table 1. Ranking indicators of selected universities

Indicator value	Position of the HEI (4)	Position of the HEI (9)	Position of the HEI (8)	Position of the HEI (10)
AR	6.5	12.9	18.9	100.00
ER	10.6	16.9	36.6	100.00
FSR	54.3	64.6	27.0	100.00
CPF	1.3	1.4	2.2	100.00
IFR	1.7	3.3	1.5	99.30
ISR	20.1	55.7	3.9	86.80
IRN	11.4	29.4	40.3	96.00
EO	4.0	4.0	45.5	100.00
SUS	1.6	4.9	1.6	99.06

Table 2. Determination of target indicators

Indicator value	K_i	Max ΔK_i	ΔK_i
AR	6.5	15.0	1.0
ER	10.6	20.0	1.0
FSR	54.3	70.0	1.0
CPF	1.3	3.0	0.3
IFR	1.7	12.0	2.0
ISR	20.1	30.0	1.0
IRN	11.4	30.0	5.0
EO	4.0	15.0	2.0
SUS	1.6	10.0	1.0

A nonlinear programming problem with Boolean variables and linear constraints is solved. This type of problem can be addressed using implicit enumeration methods and nonlinear programming methods. Given the characteristics of the objective function and the defined constraints of the proposed optimization model, it is necessary to select an appropriate solution method. Due to the nonlinearity of dependencies and incomplete data, linear and nonlinear programming methods [22], deep learning, and agent-based modeling proved to be limited. The most effective approach selected is the genetic algorithm (GA), which is robust to nonlinearities and capable of integrating heterogeneous constraints [23].

To allocate resources among the activity areas of an HEI in order to improve ranking indicators, multicriteria optimization must be applied. To solve this problem, it is proposed to use a genetic algorithm and machine learning methods. This will make it possible to account for the resource constraints of the university and to propose effective options for resource allocation.

Conclusion and future work. The retrospective

analysis of indicators influencing university rankings made it possible to determine realistic target values whose achievement will contribute to improving the ranking position of NTU "KhPI." The proposed mathematical model for optimizing resource allocation is aimed at achieving these target indicators. The next step in solving this multicriteria problem is the application of a genetic algorithm, which will allow the university's resource constraints to be taken into account and will generate effective resource allocation options.

Future research will involve conducting experiments based on the university's retrospective data, which will serve as the foundation for developing an information system for allocating available resources. This will provide decision-support capabilities for strategic management of HEI development, oriented toward improving its position in international rankings.

References

1. *Academic Ranking of World Universities (ARWU).* URL: https://www.shanghairanking.com/news/arwu (дата звернення: 20.09.2025).
2. *Times Higher Education World University Rankings.* URL: https://www.timeshighereducation.com/world-university-rankings (дата звернення: 20.09.2025).
3. *QS World University Rankings*. URL: https://www.topuniversities.com/qs-world-university-rankings (дата звернення: 20.09.2025).
4. *QS Quacquarelli Symonds.* URL: https://support.qs.com/hc/en-gb/articles/4405955370898-QS-World-University-Rankings (дата звернення: 20.09.2025).
5. Szluka, P., Csajbók, E., Győrffy, B. *Relationship between bibliometric indicators and university ranking positions*. URL: https://doi.org/10.1038/s41598-023-35306-1 (дата звернення: 24.09.2025).
6. Liu X. et al. *Analysis and Prediction of QS World University Rankings based on Data Mining Technology* https://doi.org/10.1145/3551708.3556207 (дата звернення: 29.09.2025).
7. Tabassum A. et al. *University ranking prediction system by analyzing influential global performance indicators*. URL: https://ieeexplore.ieee.org/abstract/document/7886119/figures#figures (дата звернення: 30.09.2025).
8. Kudela J. *Mixed-Integer Programming Model for Ranking Universities:Letting Universities Choose the Weights*. URL: https://doi.org/10.13164/mendel.2021.1.041 (дата звернення: 09.10.2025).
9. Yingao G. *The Rationality Analysis and Prediction of THE World University Rankings*. URL: https://www.researchgate.net/publication/367676722_The_Rationality_Analysis_and_Prediction_of_THE_World_University_Rankings (дата звернення: 12.10.2025).
10. De Luna Pámanes A. et al. *The World University Rankings Model Validation and a Top 50 Universities Predictive Mode.* URL: https://www.sciencegate.app/document/10.1109/iccais48893.2020.9096841 (дата звернення: 12.10.2025).
11. Loyola-González O. et al. *A Contrast Pattern-Based Scientometric Study of the QS World University Ranking*, URL: https://ieeexplore.ieee.org/document/9257464/citations?tabFilter=papers#citations (дата звернення: 16.10.2025).
12. Kim T., Kim K. Systemic Analysis of the QS International Research Network Indicator Using Big Data: Regional Inequalities and Recommendations for Improved University Rankings. URL: https://ieeexplore.ieee.org/document/11050413 (дата звернення: 16.10.2025).
13. Bublyk M. et al. *World Universities Strategic Analysis Based on Data from the QS World University Rankings*. URL: https://ceur-ws.org/Vol-3373/paper23.pdf (дата звернення: 16.10.2025).
14. Акбаш К., Пасичник Н., Ріжняк Р. Прогностичний аналіз публікаційної діяльності науковців українських університетів у контексті їхнього участі у рейтингу QS World University. URL: https://doi.org/10.31767/su.4(91)2020.04.07 (дата звернення: 16.10.2025).
15. Василенко В. *Система рейтингування як складова процесу формування іміджу закладу вищої освіти*. URL: https://doi.org/10.32461/2409-9805.2.2019.175882 (дата звернення: 20.10.2025).
16. Шаблиста Л. *Формування системи показників оцінки результативності діяльності закладів вищої освіти*. URL: https://doi.org/10.31767/su.4(83)2018 04.10 (дата звернення: 30.10.2025).
17. Райчева Л., Нестерова К. Стратегічні перспективи вищої освіти України. URL: https://doi.org/10.32782/2308-1988/2025-54-39 (дата звернення: 30.10.2025).
18. Hladchenko M. *Ukrainian universities in QS World University Rankings: when the means become ends*. URL:. https://doi.org/10.1007/s11192-024-05165-2 (дата звернення: 30.10.2025).
19. Статут НТУ "ХПІ" URL: https://public.kpi.kharkov.ua/administrativna-diyalnist/statut/ (дата звернення: 30.10.2025).
20. Grinchenko M., Shaposhnikov M. *Analysis of higher education institutions' performance indicators based on QS WORLD university rankings assessment* URL: https://doi.org/10.20998/2413-3000.2024.9.3 (дата звернення: 10.11.2025).
21. Zhang Q., Deb K. *Evolutionary Constrained Multi Objective* Optimization: A Review. Complex & Intelligent Systems. URL: https://link.springer.com/article/10.1007/s44336-024-00006-5 (дата звернення: 15.11.2025).
22. Neghină C. *A Competitive New Multi-Objective Optimization Genetic Algorithm. Engineering Applications of Artificial Intelligence.* URL: https://doi.org/10.1016/j.engappai.2024.107870 (дата звернення: 15.11.2025).
23. Li W., Zhang H., Chen F. *Evaluation of a Genetic Algorithm for Constrained Multi Objective Optimization. Computers & Structures*, URL: https://doi.org/10.1016/j.compstruct.2024.118773 (дата звернення: 15.11.2025).

References (transliterated)

1. *Academic Ranking of World Universities (ARWU)*. Available at: https://www.shanghairanking.com/news/arwu (accessed: 20.09.2025).
2. *Times Higher Education World University Rankings*. Available at: https://www.timeshighereducation.com/world-university-rankings (accessed: 20.09.2025).
3. *QS World University Rankings.* Available at: https://www.topuniversities.com/qs-world-university-rankings (accessed: 20.09.2025).
4. *QS Quacquarelli Symonds.* Available at: https://support.qs.com/hc/en-gb/articles/4405955370898-QS-World-University-Rankings (accessed: 20.09.2025).
5. Szluka P., Csajbók E., Győrffy B. *Relationship between bibliometric indicators and university ranking positions*. Available at: https://doi.org/10.1038/s41598-023-35306-1 (accessed: 24.09.2025).
6. Liu X. et al. *Analysis and Prediction of QS World University Rankings based on Data Mining Technology*. Available at: https://doi.org/10.1145/3551708.3556207 (accessed: 29.09.2025).
7. Tabassum A. et al. *Abdullah and T. Musharrat. University ranking prediction system by analyzing influential global performance indicators.* Available at: https://ieeexplore.ieee.org/abstract/document/7886119/figures#figures (accessed: 30.09.2025).
8. Kudela J. *Mixed-Integer Programming Model for Ranking Universities:Letting Universities Choose the Weights*. Available at: https://doi.org/10.13164/mendel.2021.1.041 (accessed: 09.10.2025).
9. Yingao G. *The Rationality Analysis and Prediction of THE World University Rankings.* Available at: https://www.researchgate.net/publication/367676722_The_Rationality_Analysis_and_Prediction_of_THE_World_University_Rankings (accessed: 12.10.2025).
10. De Luna Pámanes A. et al. *The World University Rankings Model Validation and a Top 50 Universities Predictive Mode.* Available at: https://www.sciencegate.app/document/10.1109/iccais48893.2020.9096841 (accessed: 12.10.2025).
11. Loyola-González O. et al. *A Contrast Pattern-Based Scientometric Study of the QS World University Ranking*. Available at:

https://ieeexplore.ieee.org/document/9257464/citations?tabFilter=papers#citations (accessed: 16.10.2025).
12. Kim T., Kim K. *Systemic Analysis of the QS International Research Network Indicator Using Big Data: Regional Inequalities and Recommendations for Improved University Rankings*. Available at: https://ieeexplore.ieee.org/document/11050413 (accessed: 16.10.2025).
13. Bublyk M. et al. *World Universities Strategic Analysis Based on Data from the QS World University Rankings*. Available at: https://ceur-ws.org/Vol-3373/paper23.pdf (accessed: 16.10.2025).
14. Akbash K., Pasychnyk N., Rizhniak R. *Prohnostychnyi analiz publikatsiinoi diialnosti naukovtsiv ukrainskykh universytetiv u konteksti yikhnoho uchasti u reitynhu QS World University* [Predictive analysis of the publication activity of scientists from Ukrainian universities in the context of their participation in the QS World University ranking]. Available at: https://doi.org/10.31767/su.4(91)2020.04.07 (accessed: 16.10.2025).
15. Vasylenko V. *Systema reitynhuvannia yak skladova protsesu formuvannia imidzhu zakladu vyshchoi osvity* [The rating system as a component of the process of forming the image of a higher education institution]. Available at: https://doi.org/10.32461/2409-9805.2.2019.175882 (accessed: 20.10.2025).
16. Shablysta L. *Formuvannia systemy pokaznykiv otsinky rezultatyvnosti diialnosti zakladiv vyshchoi osvity* [Formation of a system of indicators for assessing the effectiveness of higher education institutions]. Available at: https://doi.org/10.31767/su.4(83)2018 04.10 (accessed: 30.10.2025).
17. Raicheva L., Nesterova K. *Stratehichni perspektyvy vyshchoi osvity Ukrainy* [Strategic prospects of higher education in Ukraine]. Available at: https://doi.org/10.32782/2308-1988/2025-54-39 (accessed: 30.10.2025).
18. Hladchenko M. *Ukrainian universities in QS World University Rankings: when the means become ends*. Available at: https://doi.org/10.1007/s11192-024-05165-2 (accessed: 30.10.2025).
19. *Statut NTU "KhPI"* [Charter of NTU "KhPI"]. Available at: https://public.kpi.kharkov.ua/administrativna-diyalnist/statut/ accessed: 30.10.2025).
20. Grinchenko M., Shaposhnikov M. *Analysis of higher education institutions' performance indicators based on QS WORLD university rankings assessment.* Available at: https://doi.org/10.20998/2413-3000.2024.9.3 (accessed: 10.11.2025).
21. Zhang Q., Deb K. *Evolutionary Constrained Multi Objective Optimization: A Review*. *Complex & Intelligent Systems*. Available at: https://link.springer.com/article/10.1007/s44336-024-00006-5 (accessed: 15.11.2025).
22. Neghină, C. *A Competitive New Multi-Objective Optimization Genetic Algorithm. Engineering Applications of Artificial Intelligence.* Available at: https://doi.org/10.1016/j.engappai.2024.107870 (accessed: 15.11.2025).
23 Li W., Zhang H., Chen F. *Evaluation of a Genetic Algorithm for Constrained Multi Objective Optimization. Computers & Structures.* Available at: https://doi.org/10.1016/j.compstruct.2024.118773 (accessed: 15.11.2025).

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МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ ДЛЯ ОПТИМІЗАЦІЇ РЕСУРСІВ УНІВЕРСИТЕТУ НА ОСНОВІ ПОКАЗНИКА QS WUR

У статті проведено ретроспективний аналіз ключових показників рейтингу QS World University Rankings для українських закладів вищої освіти з метою формування реалістичних цільових орієнтирів розвитку НТУ «ХПІ». Розглянуто динаміку показників рейтингу в порівнянні з провідними українськими університетами, що дало змогу визначити досяжні межі зростання кожного індикатора у середньостроковій перспективі. На основі отриманих результатів сформовано систему цільових значень, які можуть бути використані університетом для підвищення власної позиції у рейтингу. Запропоновано математичну модель оптимізації розподілу ресурсів, спрямовану на мінімізацію відхилення між фактичними та цільовими значеннями показників. Модель подано як задачу квадратичного програмування з булевими змінними та лінійними обмеженнями, що відображають обмеженість ресурсів університету та множину можливих заходів для покращення кожного індикатора. З огляду на нелінійність взаємозв'язків і неповноту вихідних даних обґрунтовано застосування генетичного алгоритму, який забезпечує ефективний пошук оптимальних варіантів розподілу ресурсів за умов багатокритеріальності. Додатково підкреслено, що запропонований підхід дозволяє адаптувати стратегію розвитку університету до динамічних умов міжнародного освітнього середовища та враховувати зміну ваги окремих індикаторів у методології рейтингу. Модель може бути використана як інструмент для сценарного аналізу та формування різних варіантів управлінських рішень. Практична значущість роботи полягає у можливості інтеграції отриманих результатів у систему стратегічного планування університету. Отримані результати формують підгрунтя для створення інформаційної системи підтримки стратегічного управління ЗВО. Подальші дослідження передбачають експериментальну перевірку моделі на ретроспективних даних НТУ «ХПІ» та розробку програмного інструменту, орієнтованого на підвищення ефективності управлінських рішень і покращення позицій університету в міжнародних рейтингах.

Keywords: ключові показники ефективності, модель оптимізації розподілу ресурсів, прийняття рішень, рейтинг, стратегічне управління, інформаційна система

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