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## Mathematic modeling of risks as a way for determining corruption in the acquisition system

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### Abstract

**Relevance.** The research is relevant due to the potential of mathematical risk modeling in diagnosing corruption within the acquisition system. This approach is highly effective in identifying the causes and conditions of corruption, offering significant prospects for improving anti-corruption measures.

**Purpose.** The study aims to comprehensively analyse both the normative and theoretical foundations of mathematical risk modeling in the acquisition system. The goal is to develop doctrinal proposals to enhance the current state of mathematical modeling in this context.

**Methodology.** The authors used analysis, synthesis, formal-logical methods, system-structural methods, and mathematical modeling to examine Kazakhstan's anti-corruption regulations and establish legal grounds for diagnosing corruption risks.

**Results.** The research presented an evidence-based proposal for the gradual implementation of mathematical modeling provisions in diagnosing corruption risks within the acquisition system, structured in two stages. It offered a critical analysis of theoretical developments on the subject, explored the functions of mathematical modeling in jurisprudence, and discussed their concepts and types. The study also developed a mathematical formula for calculating corruption risks and described its components.

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**Conclusions.** The study's findings include recommendations for developing mathematical formulas to diagnose corruption risks in the procurement system, highlighting the practical significance of the work. These recommendations provide valuable insights for improving anti-corruption measures through the application of mathematical risk modeling.

**Keywords:** strategy; Kazakhstan Republic Law; cause and conditions of the crime; scientific program.

## **Introduction**

The necessity to research mathematical modeling of risks to determine corruption in the acquisition system in the legal aspect is important for several reasons. Firstly, mathematical modeling to assess corruption risks, trends, causes, and conditions of corruption has significant advantages compared to other methods in this area as mathematical modeling can provide an unbiased, objective analysis of corruption factors. Secondly, it should be considered that the negative impact of corruption is associated with the undermining of the level of public trust both to the state in general and to the state authorities and their officials, so the introduction of mathematical modeling in anti-corruption policy will strengthen the democratic values formed at the constitutional and legislative levels.

The focus of the issue, investigated in the research, is the need to substantiate the legal regulation of mathematical modeling in the anti-corruption policy of the Republic of Kazakhstan, and in particular – in the acquisition system. While answering the question related to the moment of the publication's problem origin, it should be considered the complex nature of the risk mathematical modeling issues to determine corruption in the acquisition system. It can be stated that in the 70-th 80s of the last centuries the level of research of mathematical modeling already had not only the proper theoretical background but also practical results. Nevertheless, the application of the mathematical modeling method in jurisprudence is currently not yet properly developed.

Among the scientists whose research is in one way or another relevant to the topic of the publication, the following should be noted. E.K. Igissinova and Zh. Davletbayeva [1] is convinced that there is a certain correlation between the ideology of integrity and anti-corruption culture. Considering the state policy of the Republic of Kazakhstan in this aspect, as well as considering the international experience of such countries as Singapore, Great Britain, and Georgia, E.K. Igissinova and Zh. Davletbayeva published a scientific work devoted to these issues. N.A. Katayev et al. [2] made a publication on the topic directly related to the authors' research. The described publication reveals both the essence of countering corruption in public procurement and the principles of such countering. For example, O.A. Miliienko et al. [3] raised the problem of protecting human rights in administrative proceedings from administrative and legal positions.

The authors also deem it necessary to mention the scientific work of S.K. Sharma et al. [4], which deals with the discovery of opportunities to improve and strengthen the control of corruption risks in the public acquisition system. In this context, S.K. Sharma et al. also used mathematical modeling techniques. R.B. Velasco et al. [5] researched fraud in public acquisitions and the relationship of this type of fraud to corruption risks. A J. Wachs et al. [6] study, which deals with the distribution of corruption

risks in the public acquisition system of European Union member states, is of high interest. Assessing the current state of research on the issue, it is possible to conclude that the issues of effective fight against corruption by all kinds of methods and ways remain relevant at least for the last 15-20 years. At the same time, there are only a few scientific works devoted specifically to mathematical modeling to diagnose corruption risks in the acquisition system. Public relations, caused during the formation of anticorruption policies in the Kazakhstan Republic acquisition system and mathematic modeling, are the research object [7-9].

The research goals are to conclude a comprehensive analysis of both the regulatory basis and theoretical foundations of acquisition system corruption risk mathematical simulation to form doctrinal proposals to improve the current state of mathematical modeling in the research area. To achieve the set goal, the following objectives were established. First, consider the main normative acts of the Republic of Kazakhstan in the field of combating corruption for the presence of norms on the application of mathematical modeling in the acquisition system. Next, analyse the existing theoretical approaches to concepts such as a model, modeling, and mathematical modeling. Finally, reveals the content of the components of a mathematical formula that can be used in diagnosing corruption risks in the procurement system.

## **Materials and Methods**

A system of common scientific methods of juristic research, such as analysis method, synthesis method, formal-logistic method, systemic-structure method, and mathematic modeling method was used during the issue research. The authors applied the analysis method in a detailed study of legal acts of the Republic of Kazakhstan. They examined the Decree of the President of the Republic of Kazakhstan No. 802 “On approval of the Concept of an anti-corruption policy of the Republic of Kazakhstan for 2022-2026 and amendments to some decrees of the President of the Republic of Kazakhstan” [10]. They also reviewed the Law of the Republic of Kazakhstan No. 410-V “On Anti-Corruption” [11] and the Law of the Republic of Kazakhstan No. 434-V “On Public Procurement” [12]. Additionally, they analysed the Law of the Republic of Kazakhstan No. 72-VII ZRK “On the Introduction of Amendments and Additions to Certain Legislative Acts of the Republic of Kazakhstan on Public Procurement, Procurement of Subsoil Users and Subjects of Natural Monopolies, Communications, Road Transport, Defense and Financing of Science” [13]. Lastly, they studied the Law of the Republic of Kazakhstan No. 407-IV “On Science” [14] for relevant provisions that relate to mathematical modeling in the area of corruption.

The method of synthesis allowed us to combine theoretical developments on the topic of the publication, concerning the consideration of the concepts of model, modeling, and mathematical modeling. The formal-logical

method was used to criticize individual doctrinal developments proposed earlier by researchers. The system-structural method was of particular importance in the allocation of structural elements of conceptual relations, which constitute the basis for the emergence of corruption risks in the procurement system, and the selection of groups of such structural elements. The method of mathematical modeling made it possible to display the prevailing formula, with which it is possible to calculate the critical number for each factor of corruption risk in the procurement system, as well as to briefly describe the main values used in this formula. The research displayed the following formula, which makes it possible to calculate the corruption risks in the procurement system:

$$Cr = \sum_{j=1}^m (\alpha\beta\lambda_p t)_j \quad (1)$$

Components and values, used in the formula, were used in the research as well. Analysis of issues related to mathematical modeling to determine corruption risks was structured according to the classic scheme of legal research and was done in three stages: preparatory, main, and final. The preparatory stage was crucial to be acquainted with the main normative acts of the Republic of Kazakhstan both on general issues of anti-corruption and anti-corruption in the acquisition system. At the preparatory stage, the authors also familiarized himself with previous theoretical works of researchers within the selected topic, which allowed him to determine weaknesses in the categorical apparatus of mathematical modeling in the legal sector, as well as to distinguish this study from the earlier results. The main stage of mathematical modeling as a way of determining corruption risks research consisted of several parts: normative, theoretical, and practical, each of which had special features of the study. This method allowed a comprehensive approach to the issues of the publication topics and to form provisions alike to the scientific style. At the final stage, the results described in the publication were finalized, which allowed to state the achievement of the research goal, as well as formed the basis for further research in the context of mathematical modeling to diagnose corruption risks in the acquisition system.

## Results

The authors deem it necessary to begin this part of the study by analysing the current legislation in the Republic of Kazakhstan for the presence of rules on the mathematical modeling of risks to determine corruption in the acquisition system. Decree of the President of the Republic of Kazakhstan No. 802 “On approval of the Concept of anti-corruption policy of the Republic of Kazakhstan for 2022-2026 and amendments to some decrees of the President of the Republic of Kazakhstan” [10] is an important document in the sphere. It is possible to state after the analysis of the content: this concept pays considerable attention not only to the causes of the corruption element in the acquisition system but also to the proposed measures to combat this negative phenomenon. Unfortunately, there is no mention of mathematical risk modeling in this legal act. The only observation, which is indirectly relevant to the topic in question, concerns the international experience of such countries as Australia, Hungary, Moldova, Romania, and the USA, where there is

a practice of simulating the situation aimed at revealing corrupt behaviour in the complete oblivion of the person being tested. Here the authors consider it necessary to note that, firstly, such modeling of the situation is not mathematical, and, secondly, it is applied in all areas of combating corruption, not only in the acquisition system.

The authors also consider it necessary to mention the Law of the Republic of Kazakhstan No. 410-V “On Anti-Corruption” [11]. This Law also lacks any mention of mathematical modeling as a measure to combat corruption, but important in the context of this study is Article 8 titled “Analysis of Corruption Risks”. Moreover, in the system of anti-corruption measures stipulated by Article 6 of the Law, corruption risk analysis is considered one of the types of such measures. Directly returning to the text of Article 8, it should be borne in mind that in the normative understanding, the analysis of corruption risks consists, in fact, in the study and identification of determinants of corruption offences (causes and conditions that contribute to their commission).

This study would be incomplete without mentioning the Law of the Republic of Kazakhstan No. 434-V “On Public Procurement” [9]. In this normative legal act, there is only no mention of mathematical modeling of corruption risks in the sphere of corruption, which, is logical, but also about such an extremely important category as “corruption risk”. The only thing to pay attention to in the context of this Law is Article 4, where, among the various principles of public procurement, there is such a principle as “prevention of corrupt practices”. By its content, the Law of the Republic of Kazakhstan No. 434-V “On Public Procurement” is organizational and lays the foundation and mechanism for procurement of this kind, which, in principle, is logical.

It should also be noted that a large law, the Law of the Republic of Kazakhstan No. 72-VII ZRK “On the Introduction of Amendments and Additions to Certain Legislative Acts of the Republic of Kazakhstan on Public Procurement, Procurement of Subsoil Users and Subjects of Natural Monopolies, Communications, Road Transport, Defense and Financing of Science” [13], was adopted. This law provided for significant innovations in the Law of the Republic of Kazakhstan No. 434-V “On Public Procurement” [12]. However, the concept of corruption risks, unfortunately, does not appear in the legislative act of 2021.

At the regulatory level, mathematical modeling of corruption risks in any sphere, including the acquisition system, is not provided for in the Republic of Kazakhstan. This approach is traditional not only for Kazakhstan but also for many other countries [15-18]. Nevertheless, it is important to consider that mathematical modeling of risks should be viewed as an extremely effective tool for identifying corruption in the acquisition system. An unbiased mathematical approach to this problem can eliminate or significantly limit the human factor in procurement, especially at the state level, where corruption risks are extremely high.

The authors are convinced that the suggestion to introduce mathematical risk modeling as a tool for determining corruption in the acquisition system at the regulatory level is not unreasonable, but subject to several conditions. And the first condition is an appropriate

scientific background and thorough research in this area, which should have not only a high theoretical level but also practically confirmed results. For this purpose, it is possible to recommend to the authorized state body to include this direction of research in scientific, scientific-technical projects and programs, which definition, accounting, financing, and other questions connected with these types of projects and programs are regulated by the Law of the Republic of Kazakhstan No. 407-IV "On Science" [14]. Only after obtaining scientifically grounded results of mathematical modeling of risks as a tool for determining corruption in the acquisition system can the discussion of implementing this method of combating corruption begin. This implementation should occur not at the legislative level, but at the level of anti-corruption strategies, concepts, plans, and other legal documents. These documents set the vector for the development of the regulatory framework in the country. According to the authors, given that such a proposal is a legal novelty, it should take at least 5-7 years from the moment of implementation of the issue at the level of scientific, scientific, and technical projects and programs.

Then, the authors propose to outline some doctrinal developments on the topic of this publication. M. Niss et al. [19] distinguish two main approaches to understanding such a category as mathematical modeling. In the first approach, M. Niss et al. understand mathematical modeling as a process in which real-life situations and relationships in these situations are expressed using math. This approach is based on the scientific work of C. Haines and R. Crouch [20]. The second approach has as its underlying development, which is reflected in the publication of L. Verschaffel et al. [21]. The essence of this approach is the following: mathematical modeling is a process, which has a cyclic nature, and in which real problems are translated into mathematical language, solved in a symbolic system, and solutions are verified in a real system.

Analysing the above-mentioned approaches, the authors will make their assessment of the existing doctrinal interpretation of the concept of mathematical modeling. The first thing to pay attention to is the fact that the second approach proposed by L. Verschaffel et al. is more theoretically and scientifically grounded and elaborated. This statement, in the opinion of the authors, can be explained by the fact that the second understanding of mathematical modeling is comprehensive and includes not just a process, but a process of a cyclic nature, and has an indication of the result of mathematical translation of real problems in a symbolic system – verification of solutions in real circumstances. The understanding of mathematical modeling developed by C. Haines and R. Crouch [20], is a more superficial judgment, the essence of which is reduced only to the perception of mathematical modeling as a process that has the properties of expressing life situations using mathematics.

At the same time, the authors will mention the position of K. Kmetyk-Podubinska [22] and A.O. Lopatiev [23], who understand modeling as a research method. Comparing all the above-mentioned theoretical approaches to the categorical apparatus of the topic of the publication, the authors consider it necessary to focus on the following points. Modeling and mathematical

modeling are considered in the doctrine through the prism of the notions of process, and research method. One cannot say that this approach is wrong, but such understanding can be considered somewhat limited and incomplete. The authors believe that the terms modeling and mathematical modeling are complex, and therefore it is possible to propose to consider them through the prism of the category of tool (for example, as in the case of the research topic – a tool for diagnosing corruption risks). Thus, the above problems can serve as a basis for further scientific discussions, considering semantic approaches to the categorical apparatus of modeling, and mathematical modeling.

Theory-wise, the authors will also touch upon the topic of the functions of mathematical modeling. Such functions should include the function describing the causes of offences; the function of diagnosing the trends of growth or decline in the total number of offences, as well as offences in a particular area; preventive function, whose task is to reduce the cases of offenses. It should be specified that such functions of mathematical modeling can be applied both on general grounds in criminological science and in a separate branch – for example, combating corruption offences, including – diagnostics of corruption risks in the system of procurement. Regarding the specific formulas that can be applied in the field of mathematical modeling of corruption risks in the acquisition system, the authors propose to consider the formula developed by R. Borgovini et al. [24], which was based on the work of K.B. Misra [25]. K.B. Misra and R. Borgovini et al. proposed to calculate the critical quantity (Cr) for each corruption risk factor using the following formula:

$$Cr = \sum_{j=1}^n (\alpha \beta \lambda_p t)_j. \quad (2)$$

In applying this formula, it should be considered that the mathematical combination  $\lambda_p t$  is the number of cases of corruption of a certain risk factor;  $\alpha$  is the coefficient of the type of failure, which is the probability;  $\beta$  is the conditional probability that the effect of failure will lead to the identified criticality class [24; 25].

Furthermore, the authors will make recommendations on the vision of those factors that should be considered when developing formulas for the application of mathematical modeling of corruption risks in procurement. The first thing to focus on, in the authors' opinion, is that the elements of such formulas should be expressed in numbers. At the same time, it is important to observe classical approaches to the development of formulas and consider those values that are constant in mathematical science (for example, the understanding of sums, integrals, and so on). It is possible to suggest the following areas for research in this matter. First, examine the relationship between the number of corruption violations in procurement and the income and property acquisitions of officials involved in public procurement that do not match their official salary. Next, study the correlation between the price of goods and their quality. Also, investigate the frequency of the need to purchase the same goods and how often these goods were purchased from the same supplier. Finally, consider the presence of excessive rates and requirements for the urgent delivery of goods.

The difficulty of developing mathematical formulas in the field of determining corruption risks in the procurement system, in the authors' opinion, is that a significant number of factors that have an impact on the level of the studied type of corruption risks is not possible to be expressed in numerical form. Such factors include the lack of knowledge, personal, self-interest in abuse of office, and insufficient legal regulation. As such, the authors considered the main anti-corruption regulations, both general and special (in the procurement system) of the Republic of Kazakhstan, the theoretical background in mathematical modeling, as well as a practically developed formula that allows you to calculate the factors of corruption risk in the procurement industry.

## Discussion

The issue of risk modeling during the determining of corruption in the acquisition system has previously interested researchers. Therefore, scientific works that are somehow relevant to the topic of the publication were collected and grouped. The first group of theoretical studies relevant to the subject of the publication is works that reveal the relationship between mathematical modeling and corruption phenomena. For example, L.W. Kinyanjui [26] used such diagnostic tests as the autocorrelation test, heteroscedasticity test, and regression analysis, which allowed us to state a negative relationship between corruption with life expectancy, education, and per capita income. The publication of A.K. Fantaye and Z.K. Birhanu [27], was designed to reveal the relationship between mathematical modeling and analysis of the dynamics of corruption, in which a new generation matrix method was used.

By conducting numerical simulations of optimal control, A.K. Fantaye and Z.K. Birhanu concluded that the strategy of prevention and punishment is the most effective strategy that can reduce the dynamic growth of corruption. H.T. Alemneh [28] is also an expert in the mathematical modeling of corruption dynamics. The researcher analyzed a nonlinear, deterministic model of the dynamics of corruption using the stability theory of differential equations. H.T. Alemneh is an advocate of using an integrated control strategy to combat corruption, substantiating his position with numerical modeling. F. Habibi et al. [29] have a somewhat general work on the topic of this study, which deals with the issues of a mathematical model of project planning based on practice materials in Iran. The model developed by F. Habibi et al. allows for determining the activity schedule, time and quantity of material ordering, supplier selection, etc., so the publication of the Iranian researchers' data has an important practical application aspect.

The second group of studies includes those that deal with the application of mathematical modeling methods to the study of corruption in the political sphere, transnational corruption, the relationship between corruptions and the shadow economy, and racism. E. Poza et al. [30] investigated political corruption in Spain and used mathematical modeling to quantify the problem, make certain changes to selected model parameters, and model fiscal, economic, and legal measures to quantify the level of corruption in a selected area. R.E. Clark [31] is the author of a publication on linear and nonlinear modeling

techniques in transnational corruption risk assessment. R.E. Clark is committed to using systems analysis to achieve a balance in diagnosing and recognizing the dynamic changes in corruption from country to country. According to the researcher, the model he chose will effectively inform business decisions, policy choices, and other measures that influence the evolution and harmonization of anti-corruption standards at the global level. A.C. Cozma et al. [32] also considered mathematical models in this area as one of the areas of research on the relationship between corruption and the shadow economy. B.S. Kotola and Sh.W. Teklu [33] devoted a study to mathematical modeling methods in the field of corruption and their relationship to racism. The researchers used qualitative and complex mathematical methods and analyzed both the model of racism in the absence of corruption and the model of corruption in the absence of racism. In their publication, B.S. Kotola, and Sh.W. Teklu also applied the next-generation matrix method.

The third group of studies includes publications of a narrower nature, which in one way or another consider the issues of mathematical modeling to determine corruption risks in the acquisition system. M. Heydari et al. [34] are the authors of a thorough work revealing the relationship between corruption, infrastructure management, and public-private partnerships. The relevance of this work stems from the fact that public-private partnerships are vulnerable to corruption, so the book published by M. Heydari et al. aims to consider measures that can prevent corruption during acquisition as well as develop good governance strategies for use in the public sector. To achieve their objectives, the researchers used several mathematical models, in particular game theory, which helped to study the interactions and dynamics between stakeholders and allowed the preparation of strategies designed to reduce corruption risks at different stages of public-private partnerships. M. Heydari et al. explained how using game theory-based simulations, state governments can effectively conduct an evaluation process before each procurement, which will not only help screen out undesirable partners but also help the government take a more proactive stance. The book under review used a broad methodological framework based on mathematical models that illustrate methods for dealing with institutional corruption.

A. Patra et al. [35] investigated the use of mathematical models in the field of corruption during the Fourth Industrial Revolution. A. Patra et al. note that despite the increased interest in the phenomenon of corruption in academia, it is difficult to analyze the concept due to difficulties with identification and quantification. Previous studies have used several variables, indices, computational models, and approaches, but their usefulness in the field of corruption through the prism of the Fourth Industrial Revolution can be questioned, which in turn has led to the need for their revision. A. Patra et al. developed a three-stage concept of corruption detection, illustrating their concept with two examples, which provided a substantial rationale for considering digital transformation and the use of extensive data to overcome corruption. This approach also has implications for the perception of the negative phenomenon under study. The publication of S.K. Sharma et al. [4] addresses the identification of opportunities to

improve and strengthen the control of corruption risks in public acquisition. Researchers focus on the intricacies of the procurement process, which is characterized by the close interaction of a large number of stakeholders, primarily government officials and businesses, which leads to the complexity of the analysis and modeling of the procurement process. To identify corruption risks S.K. Sharma et al. developed the concept of using failure tree effects theory, and criticality analysis techniques in this area and identified 45 combinations of risk elements that can lead to a contract with a corruptive component. The publication of S.K. Sharma et al. not only strengthens organizational controls on corruption and improves acquisition processes, but also provides the basis for further research into the development of improved corruption risk assessment.

The study by H. Gholizadeh et al. [36] on stochastic programming problems in public procurement using large amounts of data is specific. In this publication, the researchers operate with the concepts of hybrid uncertainty and integer nonlinear programs. Corruption risk in contract markets was addressed by J. Wachs et al. [6] used network science methods and analyzed corruption risks in more than 4 million public acquisition contracts of European Union member states for the period from 2008 to 2016, which allowed to describe the distribution of corruption risks, their clustering. The researchers concluded that the same level of corruption risk could have a completely different distribution, which leads to the need to develop different types of anti-corruption policies for different states.

R.B. Velasco et al. [5] have developed a decision-making system to detect fraud in public procurement. Scientists correctly justify the relevance of this work by the fact that investigators in Brazil over the past few years have exposed numerous corruption schemes and money laundering schemes not only at all levels of government but also in the largest corporations in the country. Experts have estimated that due to this situation, the world's gross domestic product loses between 2% and 5% annually. Such negative practices have not only an impact on public services and private sector development but also strengthen the level of organized crime at both national and global levels. Unfortunately, law enforcement agencies are not able to conduct a systematic assessment of corruption risks in public procurement. This limitation arises from a lack of proper tools [37-39]. Most often, they have only circumstantial evidence or complaints from victims at their disposal. This situation cannot be assessed positively because many companies involved in fraud remain undetected and are not prosecuted in criminal proceedings. Specifically, the decision support system developed by R.B. Velasco et al. was designed to solve this problem. This system uses algorithms such as graph theory, clustering, and regression analysis, as well as advanced science.

A separate subset of theoretical achievements in the application of mathematical modeling for the determining of corruption risks are works related to the issues of combating corruption in the medical sphere, which include the following publications. J.C. Kohler and D. Dimancesco [40] investigated the types of anti-corruption, transparency, and accountability measures that can reduce

the risk of corruption in public procurement by pharmaceutical companies. J.C. Kohler and D. Dimancesco believe that anti-corruption mechanisms such as open contracts and integrity agreements will help reduce corruption in pharmaceutical procurement. T. Vian [41] is an expert on concepts, frameworks, and approaches to fight corruption in health care. T. Vian identifies individual and systemic factors as drivers of corruption, including financial pressures, poorly managed conflicts of interest, and weak regulatory and enforcement systems. T.K. Mackey and R.E. Cuomo [42] provided an interdisciplinary overview of digital technologies that not only help fight corruption but also improve transparency and accountability in drug procurement in general. The researchers state that machine learning and the use of blockchain are common types of such digital technologies.

M.T. Kirya [43] addressed the problem of combating corruption in the recruitment of health professionals to ensure impartial health outcomes. The researcher justifiably believes that political and personal connections, rather than professional merit, are the factors that influence not only employment but also the career development of health professionals in many countries. This practice harms the healthcare sector because its consequence is the performance of professional medical activities by low-qualified workers. M.T. Kirya states the need for further research on the outlined issues to develop a deterrent anti-corruption policy for the recruitment and career development of medical workers.

It should be noted that despite the number and variety of previous studies, in one way or another, relevant to the subject of the publication, this work has a specificity that distinguishes it from the earlier ones. This specificity manifests itself in the following. Firstly, the authors' study has a legal nature and touches upon the issues of expediency in fixing the use of mathematical modeling methods at the normative level. The publication also develops an effective mechanism for such legal regulation, which is gradual. Secondly, the work provides a critical analysis of the categorical apparatus relevant to the topic of research, namely, the concepts of model, modeling, and mathematical modeling, which allowed to form of doctrinal proposals about the functions of mathematical modeling in law, which have the character of scientific novelty.

## **Conclusions**

A comprehensive assessment of mathematical modeling of corruption risks in the system of acquisitions was concluded in both normative and theoretical aspects. Analysis of the main legislative acts in the Republic of Kazakhstan on the issues of the anti-corruption policy of this state allowed us to conclude that today mathematical modeling is not considered a way of determining corruption risks in the acquisition system in legal terms. In this regard, a model was proposed. It consists of at least two stages. The first stage involves implementing mathematical modeling of risks as a tool for determining corruption in the acquisition system through scientific and technical projects and programs. Subsequently, after obtaining virtually confirmed results of the effectiveness of such studies, the model aims to integrate these findings into anti-corruption strategies, concepts, and plans.

Theory-wise, having studied the main scientific provisions in the branch of mathematical modeling of risks in the acquisition system, the authors consider it necessary in the publication to lay the foundations of such category as the functions of the phenomenon in question. The proposed functions can be divided into at least two groups: general functions of mathematical modeling in law, which are cumulative inherent in mathematical modeling in any branch of law, and special functions relating specifically to the anti-corruption sphere, with possible detailing – determining of corruption risks in the procurement system. According to the authors, the functions of mathematical modeling can overlap with the general functions of criminology, designed to explain and describe the causes of corruption offenses, to diagnose trends in their growth or decline against the background of other offenses, and so on. It is important to note that mathematical modeling in anti-corruption may also have a preventive effect. In any

case, the issue of the functions of mathematical modeling is subject to further scientific research.

The authors will also focus on the fact that the existing theoretical approaches to such categories as a model, modeling, modeling in law, and mathematical modeling are underdeveloped and require a new interpretation. At the same time, the fact that the availability of scientifically developed formulas that can be applied in the field of determining corruption risks in the acquisition system is very limited and should be considered, which can also serve as a basis for the development and research of articles on this topic.

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### Conflict of Interest

None.

### References

- [1] Igissinova EK, Davletbayeva Zh. Developing an Anti-Corruption Culture by Promoting the Ideology of Integrity. *Bul Inst Leg Legal Infor Rep Kaz.* 2022;1(68):76-83.
- [2] Katayev NA, Moldabaev SS, Begaliyev BA, Aubakirova AA, Begaliyev YeN. The Essence and Principles of Combating Corruption in the Field of Public Procurement. *J Adva Res Law Econ.* 2019;9(8):2631-2637.
- [3] Miliienko OA, Sabitova AA, Sabitova SA, Khussainov OB, Begaliyev YN. Protection of human rights in administrative proceedings from the standpoint of international law. *J Nat Acad Leg Sci Ukr.* 2020;27(4):43-52.
- [4] Sharma SK, Sengupta A, Panja SCh. Mapping Corruption Risks in Public Procurement: Uncovering Improvement Opportunities and Strengthening Controls. *Pub Perf Manag Rev.* 2019;42(4):947-975.
- [5] Velasco RB, Carpanese I, Interian R, Neto OCGP, Ribeiro CC. A decision support system for fraud detection in public procurement. *Inter Trans Oper Res.* 2020;28(1):27-47.
- [6] Wachs J, Fazekas M, Kertesz J. Corruption risk in contracting markets: a network science perspective. *Inter J Dat Sci Anal.* 2021;12:45-60.
- [7] Niyazbekova S, Zverkova A, Sokolinskaya N, Kerimkhulle S. Features of the «Green» strategies for the development of banks. *E3S Web Conf.* 2023;402:08029.
- [8] Makedon V, Krasnikova N, Krupskiy OP, Stasiuk Y. Arrangement of digital leadership strategy by corporate structures: a review. *Ikon Izsled.* 2022;31(8):19-40.
- [9] Golyshev LV, Mysak IS, Dovgoteles GA, Sidenko AP, Kravets' TYu. The effect of coal quality on the limitation of the nominal capacity of a power unit. *Therm Eng.* 2001;48(7):538-541.
- [10] Decree of the President of the Republic of Kazakhstan No. 802 “On approval of the Concept of anti-corruption policy of the Republic of Kazakhstan for 2022-2026 and amendments to some decrees of the President of the Republic of Kazakhstan;” 2022. Available from: <https://adilet.zan.kz/rus/docs/U2200000802>.
- [11] Law of the Republic of Kazakhstan No. 410-V “On Anti-Corruption;” 2015. Available from: [https://online.zakon.kz/Document/?doc\\_id=33478302](https://online.zakon.kz/Document/?doc_id=33478302).
- [12] Law of the Republic of Kazakhstan No. 434-V “On Public Procurement;” 2015. Available from: [https://online.zakon.kz/document/?doc\\_id=34050877#sub\\_id=0](https://online.zakon.kz/document/?doc_id=34050877#sub_id=0).
- [13] Law of the Republic of Kazakhstan No. 72-VII ZRK “On the Introduction of Amendments and Additions to Certain Legislative Acts of the Republic of Kazakhstan on Public Procurement, Procurement of Subsoil Users and Subjects of Natural Monopolies, Communications, Road Transport, Defense and Financing of Science;” 2021. Available from: <https://adilet.zan.kz/rus/docs/Z2100000072>.
- [14] Law of the Republic of Kazakhstan No. 407-IV “On Science;” 2011. Available from: [https://online.zakon.kz/Document/?doc\\_id=30938581](https://online.zakon.kz/Document/?doc_id=30938581).
- [15] Makedon V, Zaikina H, Slusareva L, Shumkova O, Zhmaylova O. Use of rebranding in marketing sphere of international entrepreneurship. *Int J Entrep.* 2020;24(1):1-8.
- [16] Fialko NM, Prokopov VG, Meranova NO, Borisov YuS, Korzhik VN, Sherenkovskaya GP. Thermal physics of gasothermal coatings formation processes. State of investigations. *Fiz Khim Obrabot Mater.* 1993;(4):83-93.
- [17] Prokopov VG, Fialko NM, Sherenkovskij YuV, Sherenkovskaya GP, Borisov YuS, Korzhik VN, Murashov AP. Analysis of temperature conditions in the system “coating-sublayer-basis” under gas-thermal spray-coating of composite powders. *Elekt Obrabot Mater.* 1992;(2):12-15.
- [18] Anisimov AG, Mysak IS, Klub MV, Sargsyan KB, Eritsyan SKh, Petrosyan GS, Avtandilyan AV, Gevorgyan AR. Development and Implementation of Automatic Conversion of Steam-Gas Power Unit from Compound Cycle Mode to Steam-Power Mode Without Shutdown of the Unit. *Pow Tech Eng.* 2018;51(5):568-573.
- [19] Niss M, Blum W, Galbraith P. Introduction. In: W. Blum, P.L. Galbraith, H.-W. Henn, M. Niss (Eds.), *Modelling and Applications in Mathematics Education*. New York: Springer; 2007. p. 3-32.

- [20] Haines C, Crouch R. Mathematical Modelling and Applications: Ability and Competence Frameworks. In: W. Blum, P.L. Galbraith, H.-W. Henn, M. Niss (Eds.), *Modelling and Applications in Mathematics Education*. New York: Springer; 2007. p. 417-424.
- [21] Verschaffel L, Greer B, de Corte E. Everyday Knowledge and Mathematical Modeling of School Word Problems. In: K. Gravemeijer, R. Lehrer, B. Oers, L. Verschaffel (Eds.), *Symbolizing, Modeling and Tool Use in Mathematics Education*. Dordrecht: Springer; 2002. p. 257-276.
- [22] Kmetyk-Podubinska K. Legal modeling as a method of modern constitutional and legal research. *Entr, Econ Law*. 2020;7:211-215.
- [23] Lopatiev AO. Modeling as a methodology of cognition. *Theo Meth Phys Educ*. 2007;8:4-10.
- [24] Borgovini R, Pemberton S, Rossi M. *Failure Mode, Effects and Criticality Analysis*. Rome: Reliability Analysis Center; 1993.
- [25] Misra KB. *Reliability analysis and prediction*. Amsterdam: Elsevier Science Publishers; 1992.
- [26] Kinyanjui LW. *Effect of corruption on social welfare issues in the Kenyan economy*. Nairobi: Strathmore University; 2021.
- [27] Fantaye AK, Birhanu ZK. Mathematical Model and Analysis of Corruption Dynamics with Optimal Control. *J App Math*. 2022;2022:8073877.
- [28] Alemneh HT. Mathematical Modeling, Analysis, and Optimal Control of Corruption Dynamics. *J App Math*. 2020;4:1-13.
- [29] Habibi F, Barzinpour F, Sadjadi SJ. A mathematical model for project scheduling and material ordering problem with sustainability considerations: A case study in Iran. *Comp Ind Eng*. 2019;128:690-710.
- [30] Poza E, Jódar L, Merello P. Modeling Political Corruption in Spain. *Mathematics*. 2021;9:952.
- [31] Clark, R.E. *Linear and non-linear modeling techniques in transnational corruption risk assessment*. London: Routledge; 2021.
- [32] Cozma AC, Cotoc CN, Vaidean VL, Achim MV. Corruption, Shadow Economy and Deforestation: Friends or Strangers? *Risks*. 2021;9(9):153.
- [33] Kotola BS, Teklu ShW. A Mathematical Modeling Analysis of Racism and Corruption Codynamics with Numerical Simulation as Infectious Diseases. *Comp Math Meth Med*. 2022;11:9977727.
- [34] Heydari M, Keung Lai K, Xiaohu Zh. *Corruption, Infrastructure Management and Public-Private Partnership*. London: Routledge; 2021.
- [35] Patra A, Matipira L, Saruchera F, Sastry Musti KS. *Revisiting Corruption Mathematical Models in the Fourth Industrial Revolution: Advanced Perspectives on Global Industry Transitions and Business Opportunities*. Pennsylvania: IGI Global; 2021.
- [36] Gholizadeh H, Fazlollahtabar H, Khalilzadeh M. A robust fuzzy stochastic programming for sustainable procurement and logistics under hybrid uncertainty using big data. *J Clean Prod*. 2020;258:120640.
- [37] Kerimkhulle S, Dildebayeva Z, Tokhmetov A, Amirova A, Tussupov J, Makhazhanova U, Adalbek A, Taberkhan R, Zakirova A, Salykbayeva A. Fuzzy Logic and Its Application in the Assessment of Information Security Risk of Industrial Internet of Things. *Symm*. 2023;15(10):1958.
- [38] Prokopov VG, Fialko NM, Sherenkovskaya GP, Yurchuk VL, Borisov YuS, Murashov AP, Korzhik VN. Effect of the coating porosity on the processes of heat transfer under, gas-thermal atomization. *Poroshk Metall*. 1993;(2):22-26.
- [39] Kunitskii YuA, Korzhik VN, Nemirovskii AV. Transformations in the plasma-sprayed Fe67Ti7B24C2 alloy in heating. *Sov Mater Sci*. 1990;26(1):87-90.
- [40] Kohler JC, Dimancesco D. The risk of corruption in public pharmaceutical procurement: how anti-corruption, transparency and accountability measures may reduce this risk. *Glob Heal Act*. 2019;13:1694745.
- [41] Vian T. Anti-corruption, transparency and accountability in health: concepts, frameworks, and approaches. *Glob Heal Act*. 2020;13(1):1694744.
- [42] Mackey TK, Cuomo RE. An interdisciplinary review of digital technologies to facilitate anti-corruption, transparency and accountability in medicines procurement. *Glob Heal Act*. 2020;13:1695241.
- [43] Kirya MT. Promoting anti-corruption, transparency and accountability in the recruitment and promotion of health workers to safeguard health outcomes. *Glob Heal Act*. 2020;13:1701326.

## **Математичне моделювання ризиків як спосіб визначення корупції в системі закупівель**

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### **Анотація**

**Актуальність.** Актуальність дослідження зумовлена потенціалом математичного моделювання ризиків у діагностиці корупції в системі державних закупівель. Такий підхід є високоефективним у виявленні причин та умов корупції, відкриваючи значні перспективи для вдосконалення антикорупційних заходів.

**Мета.** Метою дослідження є комплексний аналіз нормативних та теоретичних засад математичного моделювання ризиків у системі закупівель. Завданням є розробка доктринальних пропозицій щодо вдосконалення сучасного стану математичного моделювання в цьому контексті.

**Методологія.** За допомогою методів аналізу, синтезу, формально-логічного, системно-структурного та математичного моделювання досліджено антикорупційне законодавство Казахстану та встановлено правові підстави для діагностики корупційних ризиків.

**Результати.** У дослідженні представлено науково обґрунтовану пропозицію щодо поетапного впровадження положень математичного моделювання в діагностику корупційних ризиків у системі закупівель, структуровану у два етапи. Було проведено критичний аналіз теоретичних напрацювань з цього питання, досліджено функції математичного моделювання в юриспруденції, розглянуто його поняття та види. Також було розроблено математичну формулу для розрахунку корупційних ризиків та описано її складові.

**Висновки.** Висновки дослідження включають рекомендації щодо розробки математичних формул для діагностики корупційних ризиків у системі закупівель, що підкреслює практичну значущість роботи. Ці рекомендації надають цінну інформацію для вдосконалення антикорупційних заходів шляхом застосування математичного моделювання ризиків.

**Ключові слова:** стратегія; законодавство Республіки Казахстан; причини та умови злочину; наукова програма.