UDC 005.33 + 004.02
DOI: 10.15587/2706-5448.2025.326272

**Nikita Ryzhkov**

# DEVELOPMENT OF A METHOD FOR DETERMINING THE DEPENDENCE OF BUSINESS COMPETITIVENESS ON MOBILE COMMUNICATION TECHNOLOGY

*The object of this research is the factors that significantly influence the competitiveness of enterprises operating in the modern high-tech society. The paper examines the business environment that actively uses modern mobile communication technologies.*

*The relevance of this research stems from societal concerns associated with modern mobile communication technologies (3G, 4G, 5G) and the rapid development of 6G, which may pose potential risks. These risks can impact businesses that rely on such technologies in their operations.*

*This paper proposes an approach to determining the dependence of business competitiveness on mobile communication technologies based on game theory. Performance matrices were constructed, and risk analysis was carried out according to the criteria of Wald, Savage, and Hurwitz. Potential operational strategies were analyzed in the context of environmental states, considering responses to market fluctuations and unpredictable factors. The influence of specific factors on enterprise competitiveness was assessed under conditions of complete uncertainty.*

*To compare the impact of mobile communication technologies, a simulation model in C# was developed. The study considered 240 enterprises in the market of the Republic of Kazakhstan. Two scenarios were compared: the use of 4G versus 5G technology. The results were visualized as a model ranking enterprise based on the impact of mobile communication technology. A distinctive feature of the study is the identification of environmental states, which served as a basis for grouping risk factors by their influence on competitive position. The minimax and maximin principles were applied to describe enterprise behavior in a competitive environment. The simulation model was split up. The simulation model revealed skewed gains and shortcomings in the competitiveness of enterprises that were monitored.*

*The proposed approach can be applied to business growth projects, marketing strategy enhancement, and automation of tasks aimed at improving competitiveness in enterprises across all forms of ownership. It is also applicable to banking and credit institutions in the justification and optimization of lending policies.*

***Keywords:*** *risk matrix, efficiency matrix, Hurwitz criterion, Sevige criterion, Wald criterion.*

*Received: 06.02.2025*
*Received in revised form: 06.04.2025*
*Accepted: 27.04.2025*
*Published: 12.05.2025*



***How to cite***
*Ryzhkov, N. (2025). Development of a method for determining the dependence of business competitiveness on mobile communication technology. Technology Audit and Production Reserves, 3 (2 (83)), 27–32. https://doi.org/10.15587/2706-5448.2025.326272*

## 1. Introduction

Mobile communication technologies have become an indispensable attribute of life in modern society. Consequently, the boundary between the use of mobile data technologies for their own purposes and for business purposes is blurred [1], because these two factors are becoming interdependent [2]. This is confirmed both by the study of enterprises in the service sector [3] and industrial production [4].

Further rapid growth of technologies utilizing radio frequency electromagnetic fields is also predicted [5]. Currently, wireless networks, as well as modern radio and television, operate at frequencies up to 6 GHz. The higher the frequency, the lower the latency for users to transmit data. Therefore, a mass transition to the wavelength range of 30–300 GHz, i. e. to 5th generation networks and higher, is being prepared. At present, 4G and 5G networks are widely used without substantial differences between them, presenting businesses with a dilemma [6]. This can be summarized as follows: each new mobile network technology helps the innovative development of society, but the cost of its implementation sometimes leads to risky business situations.

The study in [5] highlights certain negative consequences associated with the active implementation of new mobile networks, particularly their potential adverse effects on human health. Such conclusions are drawn on the basis of 107 experimental studies with different effects. The main identified risk factor is the significant release of radio frequency energy. Such a conclusion can significantly affect the competitiveness of enterprises that use modern mobile network technologies in their activities. This, in turn, indicates the need to take into account a number of other factors when justifying the introduction of such technologies. In particular, the following key aspects should be formalized and taken into account [6, 7]:

– modern mobile communication technologies provide fast and reliable communication, which significantly improves communications;
– new mobile communication technologies allow expanding into new markets. The users of such technologies have the opportunity to work remotely, even in different regions;

ISSN-L 2664-9969; E-ISSN 2706-5448

– these technologies are facilitating the development of new products and services such as mobile applications, e-commerce and the Internet of Things;
– the use of mobile technologies allows the automation of many business processes;
– quick access to information and services via mobile devices improves public service and user satisfaction.

However, highlighted in [7], there may be some risks to business and society when implementing modern mobile communication technologies. Among such risks are weakened cybersecurity due to the large number of connected devices, the cost of implementation due to the need to modernize existing networks and purchase or upgrade equipment. Also, regulatory approvals and criticisms regarding environmental and human health impacts will have an impact on business development [5].

The above requires methods and approaches to scientifically substantiate the dependence of various factors from the introduction of new communication technologies on business development. This demonstrates the relevance of the research topic and highlights its practical significance. Furthermore, the findings can contribute to the refinement of business strategies for companies already utilizing modern mobile network technologies in their operations.

As noted in [8], wireless service providers face an unprecedented challenge in addressing the global bandwidth shortage, leading to dissatisfaction among both private and enterprise customers. Comparisons between fourth (4G) and fifth (5G) generation wireless communication systems indicate that millimeter-wave frequencies are very promising. There is only one explanation for this – high network bandwidth. That is, the speed of data transmission is increasing. This is the only factor that the authors use to justify the competitiveness of businesses when implementing 5G technologies.

In [9], an interesting model of the dependence of generational attitudes on the accessibility to 3G and 4G technologies is considered. Many countries were considered simultaneously, which allowed analyzing a number of factors. The decision-making process through the probability of choice was analyzed. As a result, a model was developed to predict certain trends, including the market for goods and services, in the formation of a new product. In the end, it was emphasized that higher market competitiveness and lower market price increase the diffusion rate of 3G and 4G connections. However, there is a lack of data to substantiate this dependence.

An attempt to differentiate the level of business competitiveness based on the development of mobile communications was presented in [10]. The study is notable for examining a period analogous to the current transition – from 3G to 4G technologies. The technological capabilities were integrated into the conceptual framework as elements of operational technological competitiveness. Patent statistics were employed, and a dependency index was calculated for the United States, the European Union, Japan, China, and Korea. However, the model has certain limitations. It is static, as it does not account for the dynamic growth of technological levels, which requires incorporating a broader range of independent factors and variables. Additionally, the model lacks a universal methodology, as the dependency index for mobile communication technologies was calculated exclusively at the national level.

In [11], it is clearly stated that the modern high-tech community needs mechanisms to determine the dependence of factors and the impact of the introduction of new generation mobile network technologies on the individual, society and business. The rationale lies in the anticipated proliferation of stations and devices operating within the 6–100 GHz frequency range due to the deployment of 5G. The study examined several factors related to potential effects on human health. These findings were linked to business applications and mediated competitive evaluations. The responses obtained had an impact on all the factors investigated. Based on the results, it was noted that adequate information was not obtained for any meaningful assessment due to the lack of a consistent method of determining the relationship of the various influencing factors.

The work [12] examines new perspectives on the implementation of 6G technologies. This study shifts the focus from product or enterprise competitiveness to innovation advantages within value creation systems. The paper provides a framework for transforming technological innovation with 6G in mind. Attention is emphasized on the individual, often unrelated, factors influencing value creation and technological innovation. The study also examines the evolution of business models from the 4G platform through 5G to 6G, concluding that 6G will become a general-purpose technology. However, it highlights the lack of a methodology to analyze the diverse and potentially conflicting factors in a complex system, an issue already relevant in the current 4G/5G landscape.

These findings underscore the need to develop a methodology for determining the dependence of business competitiveness on mobile network technologies. Such a methodology must account for a variety of often unrelated factors, some of which may be unknown under certain conditions. Viewing this scenario as a game with multiple conditions and unknowns, the outcomes can be evaluated in terms of risk using minimum or maximum criteria.

*The aim of research* is to develop a method for determining the dependence of business competitiveness on mobile communication technologies, considering the factors that create both risks and benefits. While these factors may be unknown or contradictory at certain points in time, their behavior can often be predicted. The proposed method will enable the ranking of factors based on their impact on competitiveness and provide a foundation for justifying strategies to enhance business performance through innovation.

## 2. Materials and Methods

*The object of research* is the factors that can be considered significant, when investigating the competitiveness of an enterprise existing in a modern high-tech society. Specifically, the study focuses on the market environment, which actively employs modern mobile communication technologies.

The main hypothesis of the study is that the competitiveness of modern enterprises strongly depends on the generation of the mobile network they utilize. In particular, how accessible the enterprise's services or goods are when the user accesses them using 4G or 5G mobile communications.

The paper takes the assumption that an enterprise can use any type of mobile network from 3G to 5G and even already planning to implement 6G network on its own.

The study employs a combined methodological approach, integrating mathematical analysis, game theory, and simulation modeling. To form a sample of criteria significantly affecting enterprise competitiveness, the research considers possible states of enterprises at various stages of their life cycle. This was achieved by analyzing 240 economic entities in the Republic of Kazakhstan, using data from Internet sources (enterprise websites from various industries) and publicly available reports. These entities represented diverse ownership structures and economic activities. For each enterprise, a table of factors influencing business competitiveness was created. These factors included risks and advantages with a significant impact on the research problem. The criteria were assessed on a 10-point risk scale, where 0 indicated no risk and 9 represented the highest risk. For the study, 4 criteria affecting the competitiveness of a modern enterprise were selected:

– modern information technologies: this includes the types of mobile communication technologies used by the enterprise, mobile internet speed, and the application of Internet of Things (IoT) technologies;

– communications: refers to the presence of clear forward and backward communication, as well as the use of mobile communication technologies to support business interactions;
– innovativeness: evaluates the extent to which the business relies on the adoption and integration of new technologies;
– product/service quality: assesses how thoroughly the market is analyzed, customer satisfaction levels, and the alignment between the product's design and its final execution.

In addition, a working evaluation table of business efficiency was formed for the same enterprises. The assessment was carried out according to a 12-point system from 1 (inefficient) to 12 (efficient). The criteria selected for consideration were:
– mode of operation of the enterprise (shiftiness, seasonality, dependence on certain types of resources);
– cost of resources (availability, supply regimes, barriers between countries);
– energy costs (including environmental impact from radiation or greenhouse effect);
– labor costs (need for highly qualified personnel, special training, work permits).

The clearly defined factor in the study was enterprise mobile technology. This approach provides a detailed understanding of how 3G, 4G, and 5G technologies influence factors such as competitiveness, cybersecurity, communication efficiency, and innovation capabilities. As a result, an MS Excel spreadsheet was created with a proportional representation of the influence of the factors.

For the selected companies, a generalized performance matrix was constructed and risk analysis was performed using Wald [13], Sevige [14] and Hurwitz [15] criteria. For this purpose, a simulation model in C# language was developed to compare two scenarios: enterprise using 4G technology and enterprise using 5G technology.

The use of these criteria for risk analysis is due to the fact that in general, the situation in the market may not depend on the selected factors. Competitiveness of the enterprise in general may be stable in the local market and very shaky in the regional market, or vice versa. This depends on the opposite interests of market participants. The clash of opposing interests leads to the emergence of conflict situations. A simplified model of a conflict situation can be presented in the form of a game. In such a game there can be two participants: enterprise A, which has some advantages, and enterprise B, which is a competitor of enterprise A and also has certain advantages.

In this case, the conflict develops according to certain rules, where the parties to the competitive struggle are trying to maximize their gains or obtain an undeniable competitive advantage.

Uncertainty in the outcome of a game is caused by various reasons:
– the variety of options;
– the influence of unaccounted factors.

Each participant in the competitive struggle develops its own strategy. The advantage of using game theory to solve the problem is that the game can be paired or multiple. The latter scenario allows for a comprehensive analysis of the factors influencing the actions of multiple competitors simultaneously.

The development of a method to determine the dependence of business competitiveness on mobile communication technologies is based on constructing an optimal strategy that incorporates four key influencing factors. In this study, the optimal strategy is defined as one that ensures the participant achieves the highest possible average gain.

When developing the method, it is assumed that the interests of the participants of the game A and B are described quantitatively, i. e. the result of the game is some number. Let's assume that this number determines the share of advantages in the competitive struggle. The game consists of two moves: enterprise A chooses one of its possible strategies $A_i$, $i=1...n$, enterprise B chooses one of its possible strategies $B_j$, $j=1...m$; with complete ignorance of the other enterprise's choice.

Two functions are defined:
– $\varphi_1(A_i, B_j)$ – the gain of enterprise A.
– $\varphi_2(A_i, B_j)$ – the gain of enterprise B.

$\varphi_1(A_i, B_j)+\varphi_2(A_i, B_j)=0$; $\varphi_2=-\varphi_1$.

The function $\varphi_1(A_i, B_j)=\varphi(A_i, B_j)$ is chosen.

The objective of the game is for company A to obtain max $\varphi$ and for company B to obtain min $\varphi$.

$\varphi(A_i, B_j)=\alpha_{ij}$; $i=1...n$; $j=1...m$.

$A=\{\alpha_{ij}\}$ – the matrix of the game.

Let's consider a finite pair game of two enterprises A and B. The given function $\varphi(A_i, B_j)=\alpha_{ij}$; $i=1...n$; $j=1...m$.

It is possible to assume that enterprise A will choose the strategy $A_i$, then in the worst variant of the game its winnings will be a minimum of $\alpha_{ij}$.

Anticipating this possibility, enterprise A tries to get the maximum possible winnings

$$\alpha=\max_i \min_j \alpha_{ij}. \quad (1)$$

If the strategy $A_{i0}$ is maximized for enterprise A, the necessary gain will be ensured. Anticipating this, enterprise B tries to reduce its non-competitiveness

$$\beta=\min_i \max_j \alpha_{ij}. \quad (2)$$

In fact, the gain of enterprise A (1) and the loss of enterprise B (2) are bounded by the lower and upper price of the game under the reasonable actions of the partner (interval $[\alpha\beta]$). If $\alpha=\beta$, the total value of the game will be equal to $V$

$$\alpha=\beta=V. \quad (3)$$

That is, model (3) represents a quite definite game.

However, the situation in business does not consist only of opposite interests. That is, an enterprise's actions (strategy) are not always aimed solely at increasing gains or minimizing losses based on known competitor behavior. In many real-world scenarios, uncertainty arises due to a lack of information about competitors' actions and their possible strategies. In this case, it is possible to apply the methodology of determining the dependence of competitiveness on a number of multidirectional influences on the enterprise [16] in combination with game theory.

## 3. Results and Discussion

### 3.1. Formation of risk matrix when analyzing the competitors' enterprises' activities

The business environment is always heterogeneous, and the strategies of competitor enterprises are ambiguous. An enterprise's dependence on any modern technology, including mobile communication technologies, carries a significant level of risk. The primary risk is unpredictability, which can manifest in various forms, such as unforeseen consequences, rapid technological advancements, or changes in software systems. The core strategy of an enterprise can envisions risks and plan to counteract their impact. For example, the risk of changes in product technology from the introduction of new communications, which are caused by the use of 5G. It is possible to suppose the response as a change in product performance due to more accurate and faster user feedback. But the same change may occur because of the fact that due to faster communications information is received that a competitor has already applied new changes in the production of the product. Then the company needs to make changes to prevent the competitor from having an advantage.

In the described case, an enterprise is a generalized representation of enterprises operating in the market. Such an enterprise is labeled A.

ISSN-L 2664-9969; E-ISSN 2706-5448

The business environment in which enterprises operate, influenced by numerous and often unknown factors, is denoted as B.

Enterprises must act prudently, employing, for example, max – min or min – max strategies.

The business environment is sometimes very difficult to predict. Business strategies can be described through the states of the environment, accounting for reactions to various market fluctuations and unforeseen factors, such as weather conditions, shifts in market demand for certain products, or changes in transportation volumes. In some simplified scenarios, it is possible to determine all potential business states and the probabilities of their occurrence in advance. However, in more complex problems, the probability distribution of these states is often unknown, adding to the uncertainty and complexity of decision-making.

Then:

$A_1, A_2, ..., A_m$ – strategies of enterprise A;

$B_1, B_2, ..., B_n$ – possible states of the external environment of the enterprises' activity.

Let's assume that on the basis of preliminary calculations it is possible to obtain the matrix

$$A=\{\alpha_{ij}\}; i=1...n; j=1...m.$$

Each element of this matrix is a gain of the enterprise, as a result of applying strategies $A_i$, if the state of the environment $B_j$. In this case, the analysis of the activities of competing enterprises operating in the same competitive environment can be presented through the matrix of risks

$$R=\{r_{ij}\}; r_{ij}=\max_i \alpha_{ij}-\alpha_{ij}. \quad (4)$$

The risk is considered as the difference between the gain that could be obtained by enterprise A, if the state of the external environment of its activity $B_j$ is known precisely. And the gain that the enterprise will obtain under the same conditions, applying strategy $A_i$. It is possible to compare several enterprises operating in the same market or strategies of one enterprise under different market conditions by means of forming the matrix of optimal advantages.

### 3.2. Formation of the matrix of optimal advantages

It is assumed that the probability of the state of the external environment of business functioning is known in advance

$$p(B_j)=p_i; \sum_{j=1}^{n} p_j=1. \quad (5)$$

According to the state model (5), the criteria that have the greatest impact on the competitiveness of enterprises are evaluated by the minimum or maximum achievement of objectives. For this purpose, the influence of criteria on strategy realization is investigated by:

1. *The criterion of choosing the optimal strategy with the maximum of the mathematical expectation of gain* (possible victory in the competitive struggle)

$$\sum_{j=1}^{n} \alpha_{ij} p_j \to \max. \quad (6)$$

If the probabilities are unknown, it is possible to use the principle of insufficient basis, which states that all states of the business environment are equally possible and can occur with equal probability

$$p_1=p_2=...p_n; p_n=1/n; \max_i \sum_j^n \alpha_{ij}. \quad (7)$$

2. *Wald criterion*: $\max_i \min_j \alpha_{ij}$ – the strategy of guaranteed risk, where the limits of the lower price of the game of enterprises in the same market are determined.

3. *Sevige minimum risk criterion*: $\min_i \max_j r_{ij}$. It is also a pessimistic criterion that confirms the negative impact of individual factors or helps to identify a factor that will certainly lead to risk.

4. *The combined Hurwitz criterion*, which provides for the calculation of the following value

$$\max_i \{\lambda \min_j \alpha_{ij}+(1-\lambda)\max_j \alpha_{ij}\}, 0 \le \lambda \le 1. \quad (8)$$

Based on the selected advantages, advantage matrices are formed for the subsequent comparison of business competitiveness under different states of the external environment of the enterprise under the determining influence of one or more factors.

### 3.3. Example of method realization

Suppose that there is a certain enterprise A, which operates in a certain market. One of the competitive advantages of the enterprise is the use of mobile communication technologies. However, it is necessary to make a balanced assessment of how such technology affects the competitiveness of the enterprise. It is assumed that $A_1$ – the use of 3G technology; $A_2$ – 4G; $A_3$ – 5G; $A_4$ – only the next generation of 6G technology will provide significant advantages.

The efficiency of the enterprise depends on a number of factors. Based on the preliminary analysis of the enterprise performance, four different states $B_1$, $B_2$, $B_3$, $B_4$, are identified, each of which means a certain combination of factors. The result is represented by the efficiency matrix (Fig. 1).

$$A=\begin{matrix}\begin{Vmatrix}5 & 2 & 8 & 4\\ 2 & 3 & 4 & 12\\ 8 & 5 & 3 & 10\\ 1 & 4 & 2 & 8\end{Vmatrix}\begin{matrix}A_1\\A_2\\A_3\\A_4\end{matrix}\\ B_1\ B_2\ B_3\ B_4\end{matrix}$$

**Fig. 1.** Efficiency matrix

To form a matrix of advantages, it is sufficient to analyze by Wald and Sevige criteria:

– Wald criterion analysis

$$\max_i \min_j \alpha_{ij}=(2,2,3,1)=3.$$

That is, the advantages of competitiveness are due to 5G technology:

– Sevige criterion analysis

$$\min_i \max_j r_{ij}=(8,6,5,7)=5.$$

The obtained result confirms that the best option to strengthen competitiveness is $A_3$, that is, 5G mobile technology has a significant impact on the competitiveness of the enterprise.

The obtained results allow to build a risk matrix (Fig. 2).

$$R=\begin{matrix}\begin{Vmatrix}3 & 3 & 0 & 8\\ 6 & 2 & 4 & 0\\ 0 & 0 & 5 & 2\\ 7 & 1 & 6 & 4\end{Vmatrix}\begin{matrix}A_1\\A_2\\A_3\\A_4\end{matrix}\\ B_1\ B_2\ B_3\ B_4\end{matrix}$$

**Fig. 2.** Risk matrix

The Hurwitz criterion (8) will allow to assess the impact of individual factors on the competitiveness of the enterprise by the average result under conditions of complete uncertainty. The averaged result

provides either extreme unsatisfactory influence or extreme positive influence. That is:

$$\lambda = 0.5, \max_j(\lambda + (1-\lambda)),$$

$$\max\left(\frac{2+8}{2}\cdot\frac{12+2}{2}\cdot\frac{10+3}{2}\cdot\frac{8+1}{2}\right) = 7.$$

Recommended option $A_2$:

$$\lambda = 0.8,$$

$$0.8\cdot 2 + (1-0.8)\cdot 8 = 3.2,$$

$$0.8\cdot 2 + (1-0.8)\cdot 12 = 4,$$

$$0.8\cdot 3 + (1-0.8)\cdot 10 = 4.4,$$

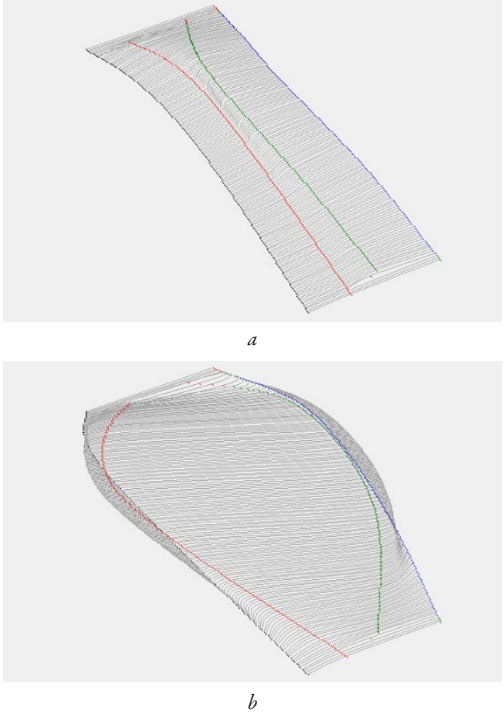
$$0.8\cdot 1 + (1-0.8)\cdot 8 = 2.4.$$

Option $A_3$ is accepted.

Principle of insufficient foundation: $p_1 = p_2 = p_3 = p_4 = 1/4$, $(192\ 12\ 61\ 5) = 26$.

Option $A_3$ is confirmed, which indicates that the use of 5G technologies for the market, which has advantages described by the efficiency matrix (Fig. 1) and limitations described by the risk matrix (Fig. 2), is a significant advantage for maintaining business competitiveness.

According to the presented method, a simulation model was developed to compare the influence of individual factors on the competitiveness of businesses in the market. The influence factors were ranked according to the use of 5G technologies in their work in comparison with 4G technologies (Fig. 3).



*a*

*b*

**Fig. 3.** Visualization based on the results of the method of determining the dependence of business competitiveness on mobile communication technology: *a* – for enterprises, in case of using 5G technologies; *b* – for enterprises, in case of using 4G technologies

As can be seen from the above visualization, about 85% of the surveyed enterprises get significant competitive advantages when using 5G technologies. At the same time, the use of 4G technologies practically does not add competitive advantages or reduces the existing advantages.

In developing a method for determining the dependence of business competitiveness on mobile communication technologies, a study of risks and benefits of 240 enterprises operating in the Republic of Kazakhstan was conducted. This allowed the efficiency matrix and risk matrix for the selected enterprises according to certain criteria.

The criteria of business efficiency, which were used to construct the efficiency matrix (Fig. 1), focused on the foundational costs of the enterprise: resources, energy and labor. The mode of operation of the enterprise was also taken into account, since the enterprise strategy is built with it in mind. In fact, these criteria made it possible to construct in the final model (Fig. 3) a grid according to the principle of insufficient basis, as given in model (7). That is, equally possible states of the environment, where the standard activity of the enterprise according to its mission took place.

Analyzing the impact of the mobile communication technology used allowed for emphasis in the selection of criteria related to modern technology. During the research, it was considered and evaluated how much the enterprise depends on mobile communication technology to fulfill its mission. It also considered as a related factor to form pairs of criteria:

– how important it is that the communications in the course of business take place using mobile networks;
– the level of dependence of enterprise innovation on modern mobile network technologies;
– use of mobile technologies for market analysis, communication with consumers, creation of new products or services.

The above expands the list of researched criteria given in [11]. Such an expansion of the base of influence criteria will allow other researchers to track dependencies regarding any innovation or technological development of the business environment.

Fig. 2 illustrates the risk matrix for some enterprise, which can be called "ideal". That is, it is known in advance that mobile communication technologies play a basic role for obtaining operational information about the state of the external and internal environment of the enterprise, as well as for the formation of effective feedback.

The developed simulation model (Fig. 3) is a systematization of the obtained results regarding the dependence of competitiveness of the studied enterprises on 4G/5G technologies. Each horizontal line represents the best option of using mobile network technologies to strengthen competitiveness, as it was shown in the example of solving the problem that demonstrated the method. Guiding arcs (Fig. 3) are formed according to the performance criteria. The convex surface (Fig. 3, *a*) is characteristic of maximizing benefits with minimum risk, indicating enhanced competitiveness. The concave surface (Fig. 3, *b*) – minimum benefits with maximum risk for the same enterprises. And it is the latter result that demonstrates that in case the surveyed enterprises use 4G mobile network technologies, they will not only fail to gain any advantages, but will also lose competitive positions by other criteria.

The obtained solutions regarding the dependence between the competitiveness of the enterprise and the used mobile network technologies close the problematic part identified during the review of primary sources. This is achieved by formalizing the influence of individual criteria by their weight and creating a game simulation model of enterprise behavior. This takes into account changes in the state of the business environment and the possibility of operating the performance criteria to provide advantages. This significantly extends the results of the robot [8], as it allows to operate not only the capacity of mobile networks, but also other criteria chosen by the researchers. In addition, the above method is more versatile than in [10]. The universality is explained not only by the transition between 4G and 5G technologies, but also by the absence of links to the country or even the sphere of activity of the enterprise.

The obtained results confirm the data of [9], as they coincide with the above model and correlate with the obtained forecasts. But in contrast to [9], models (5)–(8) allow to justify the consumer's choice to

ISSN-L 2664-9969; E-ISSN 2706-5448

connect to 4G or 5G networks. However, the above models are designed for enterprise-consumers. And this is a limitation of this study.

The number of matrix elements is also a limitation of the study. Increasing the dimensionality of matrices leads to large calculations and excessive time spent on the study of the influence of individual factors. This is the main identified limitation of the study. However, the possibility of distributed computing and the use of artificial intelligence can significantly speed up the calculations.

### 3.4. Limitations of the research and directions for its further development

The limitation of this research is the assumption that two technologies – 4G and 5G – are present on the market at the same time. That is, there is a possibility of choice and free operation of the company's finances to install the necessary equipment. In the context of various technological limitations, the use of the proposed method requires building multifactorial models of the impact of technology on business. In the implementation of the proposed method, this will require additional voluminous calculations. However, the effectiveness of the proposed development will not decrease.

Further research may be aimed at studying the impact of 4G–5G technologies in business during artificial restrictions, such as quarantine conditions, blackouts, and natural disasters. This will allow to substantiate anti-risk strategies in advance, taking into account the possible impact of insurmountable conditions.

The developed method can be used in the development of business development projects, improvement of marketing strategies, automation of tasks to improve competitiveness at enterprises of any sphere of ownership. The given models can be used by banking and credit institutions to justify the issuance or refusal of loans to business entities. Also, the above can be used by mobile communication companies to justify innovations and improvement of technologies.

## 4. Conclusions

The risk matrix in analyzing the activities of competing enterprises is formed, which allows to rank certain factors in the competitive struggle. The peculiarities of heterogeneous business environment are taken into account. This is achieved by identifying the states of the environment, according to which the risk factors are grouped in the shares of influence on the competitive position of the enterprise.

The methodology of forming the matrix of optimal advantages of the enterprise is presented. This approach explores the peculiarities of constructing such a matrix based on the minimum or maximum impact of factors on enterprise competitiveness, achieved by applying the principles of optimal behavior for market participants using the criteria of minimization and maximization.

An example demonstrating the application of the method for determining the dependence of business competitiveness on mobile communication technologies has also been provided. The peculiarity of estimating the impact of individual factors on the competitiveness of the enterprise by the average result in conditions of complete uncertainty is noted. Simulation modeling of business competitiveness dependence on 4G/5G mobile communication technology is carried out. The obtained results allowed to conclude that about 85% of the studied enterprises gain significant competitive advantages when using 5G technologies. When the same enterprises use 4G technology, they lose their existing competitive positions or leave them unchanged.

## Conflict of interest

The author declares that he has no conflict of interest regarding this study, including financial, personal, author-ship or other nature, which could affect the study and its results presented in this article.

## Financing

The study was conducted without financial support.

## Data availability

The manuscript has no related data.

## Use of artificial intelligence

The author confirms that he did not use artificial intelligence technologies when creating the presented work.

### References

1. Kankaew, K., Tansiri, E., Waramontri, R., Paethrangsi, N., Kungwol, K., Sitikarn, B., Charernit, K. (2021). Coping With the Changes That Challenge Business and Education Sectors in Thailand 4.0. *International Journal of Asian Business and Information Management, 13 (2),* 1–11. https://doi.org/10.4018/ijabim.287588
2. del Río-Lanza, A.-B., Suárez-Vázquez, A., Suárez-Álvarez, L., Iglesias-Argüelles, V. (2020). Mobile health (mhealth): facilitators and barriers of the intention of use in patients with chronic illnesses. *Journal of Communication in Healthcare, 13 (2),* 138–146. https://doi.org/10.1080/17538068.2020.1777513
3. Lin, H., Tang, C. (2022). Intelligent Bus Operation Optimization by Integrating Cases and Data Driven Based on Business Chain and Enhanced Quantum Genetic Algorithm. *IEEE Transactions on Intelligent Transportation Systems, 23 (7),* 9869–9882. https://doi.org/10.1109/tits.2021.3121289
4. Rijanto, A. (2020). Business financing and blockchain technology adoption in agroindustry. *Journal of Science and Technology Policy Management, 12 (2),* 215–235. https://doi.org/10.1108/jstpm-03-2020-0065
5. Karipidis, K., Mate, R., Urban, D., Tinker, R., Wood, A. (2021). 5G mobile networks and health – a state-of-the-science review of the research into low-level RF fields above 6 GHz. *Journal of Exposure Science & Environmental Epidemiology, 31 (4),* 585–605. https://doi.org/10.1038/s41370-021-00297-6
6. Li, Z., Wang, X., Zhang, T. (2020). *From 5G to 5G+. 5G+.* Springer, 19–33. https://doi.org/10.1007/978-981-15-6819-0_3
7. *5G devices: Ecosystem report* (2019). GSA. Available at: https://web.archive.org/web/20191013024426/https://gsacom.com/paper/5g-devices-ecosystem-report-september-2019/
8. Wu, T., Rappaport, T. S., Collins, C. M. (2015). Safe for Generations to Come: Considerations of Safety for Millimeter Waves in Wireless Communications. *IEEE Microwave Magazine, 16 (2),* 65–84. https://doi.org/10.1109/mmm.2014.2377587
9. Lim, H., Jun, D. B., Hamoudia, M. (2019). A choice-based diffusion model for multi-generation and multi-country data. *Technological Forecasting and Social Change, 147,* 163–173. https://doi.org/10.1016/j.techfore.2019.06.009
10. Cho, I., Park, M. (2014). Technological-level evaluation using patent statistics: model and application in mobile communications. *Cluster Computing, 18 (1),* 259–268. https://doi.org/10.1007/s10586-014-0368-x
11. Simkó, M., Mattsson, M.-O. (2019). 5G Wireless Communication and Health Effects – A Pragmatic Review Based on Available Studies Regarding 6 to 100 GHz. *International Journal of Environmental Research and Public Health, 16 (18),* 3406. https://doi.org/10.3390/ijerph16183406
12. Yrjola, S., Ahokangas, P., Matinmikko-Blue, M. (2022). Value Creation and Capture From Technology Innovation in the 6G Era. *IEEE Access, 10,* 16299–16319. https://doi.org/10.1109/access.2022.3149590
13. Li, H., Wu, J., Xu, H., Li, G., Guizani, M. (2021). Explainable Intelligence-Driven Defense Mechanism against Advanced Persistent Threats: A Joint Edge Game and AI Approach. *IEEE Transactions on Dependable and Secure Computing, 19 (2).* https://doi.org/10.1109/tdsc.2021.3130944
14. Bardakhchyan, V. G., Allahverdyan, A. E. (2023). Regret theory, Allais' paradox, and Savage's omelet. *Journal of Mathematical Psychology, 117,* 102807. https://doi.org/10.1016/j.jmp.2023.102807
15. Nise, N. S. (2015). *Control systems engineering.* Wiley. Available at: https://gnindia.dronacharya.info/EEE/5thSem/Downloads/ControlSystem/Books/CONTROL-SYSTEM-REFERENCE-BOOK-2.pdf
16. Fox, W. P., Burks, R. (2019). Applications of Operations Research and Management Science for Military Decision Making. *International Series in Operations Research & Management Science.* Springer International Publishing. https://doi.org/10.1007/978-3-030-20569-0

***Nikita Ryzhkov,*** *School of Information Technology and Engineering, Kazakh-British Technical University, Almaty, Republic of Kazakhstan, ORCID: https://orcid.org/0009-0000-2495-8692, e-mail: ryzkovnikita17@gmail.com*