

Game theory for the formation of a cluster risk management strategy

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Abstract. The actual direction of scientific research in the field of risk management, today, is the formation of an effective strategy for managing the risks of economic activity, taking into account the peculiarities of the activity of the enterprise of the cluster structure in modern economic conditions, characterized by the variability of the economic environment and pronounced crisis phenomena. This article proposes and tests the tools for the formation of an adaptive risk management strategy for enterprises that are part of cluster structures, based on the provisions of game theory.

1 Introduction

In modern conditions, the development of the strategic component of management is becoming increasingly relevant, it defines the general principles and priorities of managing individual areas of economic activity and the enterprise as a whole. The strategy defines the key principles and guidelines for the development of the enterprise, stipulates the conditions and mechanism for making operational management decisions. The actual direction of scientific research in the field of risk management, today, is the formation of an effective strategy for managing the risks of economic activity, taking into account the peculiarities of the activity of the enterprise of the cluster structure in modern economic conditions, characterized by the variability of the economic environment and pronounced crisis phenomena.

The research of risks in the economy is in works of scientists such as J. Keynes [1], H. Markowitz [2], A. Marshall [3], O. Morgenstern [4], J. von Neumann [4], F.H. Knight [5], A. Smith [6], L. Savage [7], A. Wald [8] and others. Their developments were the theoretical and methodological basis for author's research risks in cluster structures. At the same time, these results required concretization and further development in relation to the specifics of cluster enterprises.

Despite the wide coverage in the scientific literature of the problems of managing the risks of economic activity, a unified approach to building an effective strategy for managing the risks of economic activity at enterprises of a cluster structure in a changing

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business environment has not yet been formed. An urgent scientific task today is the development of tools for the formation of an adaptive risk management strategy for the economic activity of enterprises of this class.

2 Methodology

In our opinion, in conditions of high instability of the business environment and the accumulation of negative consequences of the influence of crisis factors, the only optimal solution is to adopt a strategy of active risk management.

Active risk management is characterized by the continuous implementation of measures to account for and control the impact of risks, the creation of a dynamic risk management system that is steadily developing using modern scientific technologies for assessing and managing risks. In modern conditions of formation of a risk management system of an enterprise of a cluster structure, it is based on the use of the concept of acceptable risk.

The mathematical apparatus of risk theory is determined by the nature of the source information and the chosen method of describing uncertainty. The most common classes of mathematical models for describing uncertainty are: stochastic, in which uncertainty is described by a probability distribution on a given set; linguistic, in which the uncertainty is given by the verbal membership function; gaming, for which only a lot of conditions of the economic environment are specified, a lot of decisions and the functional of their assessment.

In our opinion, the most suitable in accordance with the objectives of the presented study, the analytical basis for developing an effective organizational and economic strategy for managing the risks of economic activity is the use of game theory elements for modeling the process of making managerial decisions in the field of risk management of enterprises of a cluster structure.

Thorough studies of the features of the use of game theory in solving economic problems were carried out in the works of J. von Neumann and O. Morgenstern [4]. In our opinion, game theory studies the mathematical toolkit for decision making under conditions of inconsistency of interests of economic entities (participants in the game), which determines the presence of a significant influence of the uncertainty factor on the result of economic activity (games).

An important factor determining the features of the application of game theory tools in the process of making strategic decisions in the field of economic risk management is the nature of the information situation. Under the information situation is understood the degree of gradation of the uncertainty of the choice of states at the time of decision-making. That is, in the risk management system of economic activity, there may be different levels of uncertainty of the state of the business environment in the face of risk. Moreover, the nature of the information situation determines the choice of specific mathematical criteria for making managerial decisions in the face of the risk of economic activity at the enterprise.

When forming a model for choosing a strategy for managing the economic activity of an enterprise of a cluster structure, we define three conditional players: player N - nature (factors of the cluster environment that determine the effectiveness of the enterprise's economic activity); player M - the market (market conditions that determine favorable or unfavorable conditions for the economic activity of an enterprise) and player EN - an enterprise that chooses a risk management strategy for economic activity.

We have identified three main options for the influence of factors of the cluster environment of the FC - favourable conditions; NC - normal conditions, and AC - adverse conditions. In order to form a model for choosing a strategy for managing the economic

activity of a cluster enterprise, we have identified three main market conditions: HM - high market conditions; AM - average market conditions and LM - low market conditions.

An enterprise, as a conditional EN player, can use the following business risk management strategies: ENC - a cautious strategy that characterizes the rejection of risks or their transfer, focused on obtaining a minimum stable income, ENB - a balanced strategy that characterizes the support of an acceptable level of risk, provides the search for the optimal correlation between risk level and expected profit; ENR is a risky, "aggressive" strategy focused on obtaining high profits with an acceptable high level of risk.

The main criterion that determines the results of the game is LP - the level of profitability of the enterprise, which is formed under the influence of factors of the cluster environment, market conditions, internal and external factors that are reflected in the chosen risk management strategy of the economic activity of the enterprise of the cluster structure. It takes on the following values: LPH - high level of profitability; LPA - the average level of profitability and LPL - a low or negative level of profitability.

The desired result that the EN player strives for is to achieve a high level of profitability with a low level of risk of economic activity. A description of the situation of choosing a business risk management strategy with three players N, M and EN can be carried out on the basis of a three-dimensional matrix and displayed graphically in the form of Figure 1.

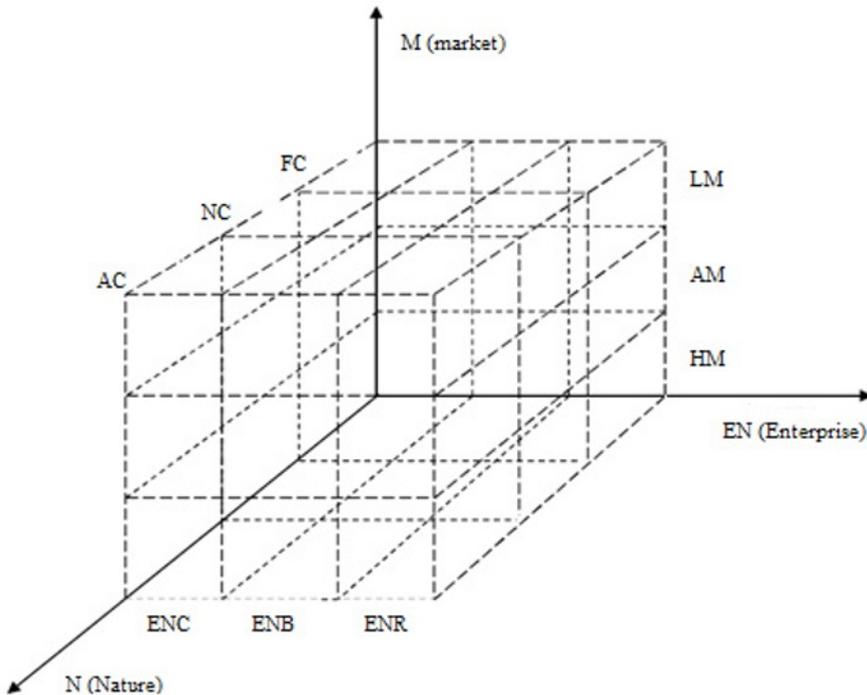


Fig. 1. Three-dimensional matrix describing the situation of choosing a risk management strategy for a cluster enterprise based on game theory

Source: developed by Irina Izmalkova

As can be seen from the figure, each of the situations where the players choose strategies for behavior corresponds to one of 27 cubes that characterize the resulting indicator (game result), and the influence of risk factors on the level of profitability of the enterprise in the cluster structure is selected as a criterion for evaluating it. Profitability was chosen as the resulting indicator due to the fact that this indicator most fully characterizes the efficiency of the enterprise and is an indicator of the achievement of the main goal of its activity (maximizing profits in relation to the resources used in economic activity).

The influence of the behavior of each of the players on the formation of the resulting indicator can be characterized according to the scheme given in the form of a table 1.

Table 1. Characterization of the influence of player behavior on the resulting indicator

Player	Behavior pattern	The nature of the effect on the resulting indicator
N (Nature)	FC	positive (↓ risk)
	NC	neutral
	AC	negative (↑ risk)
M (Market)	LM	positive (↓ risk)
	AM	neutral
	HM	negative (↑ risk)
EN (Enterprise)	ENC	↓ profitability (↓ risk)
	ENB	neutral
	ENR	↑ profitability (↑ risk)

Source: developed by Irina Izmalkova

Among the possible situations, one can identify several extreme cases: cube 1 characterizes a low level of risk under favorable conditions to ensure an acceptable level of profitability of the enterprise; Cube 27 characterizes a situation of a high level of risk under adverse conditions to ensure an acceptable level of profitability; Cube 19 provides the most favorable conditions for ensuring an acceptable level of profitability with a relatively low level of overall risk; Cube 9 characterizes the worst conditions for ensuring the profitable operation of the enterprise in the presence of risk.

Cubes 12, 14 and 16 are characterized by the most likely neutral situation with respect to the general level of risk and ensuring profitable operation of the enterprise. Positions: 10, 11, 13, 20, 22 characterize the most likely generally positive game results. The most likely stable situation is reflected by cubes: 2, 4. For cubes: 3, 5, 7, 21, 23, 25, possible satisfactory results of the game are characteristic. The predominantly probable negative results of the game should be considered positions: 6, 8, 15, 17, 18, 24, 26.

3 Results

Let us provide a characteristic of the outcome indicators of game situations of choosing a risk management strategy for an enterprise’s economic activity using the example of the enterprises of the engineering and metalworking cluster of the Lipetsk Region “Engineering Valley”: Enterprise 1, Enterprise 2, Enterprise 3, based on expert risk assessment and in accordance with the above characteristics of situations (tab. 2).

Table 2. Description of the resulting indicators of game situations of the choice of risk management strategies of enterprises

Enterprise	Interpretation of risk assessment indicators for selected factors			Game situation cube number / possible alternative to strategic choice
	N (Nature)	M (Market)	EN (Enterprise)	
1	2.7 (medium level of risk - neutral nature of the impact - NC)	3.9 (high risk - negative impact - LM)	2.5 (medium risk - balanced strategy - ENB)	15
2			3.2 (high risk - risk strategy - ENR)	24 → 15
3			4.4 (very high risk - risk strategy - ENR)	24 → 6

Source: developed by Irina Izmalkova

It should be noted that the decision-making on the formation of a risk management strategy for the economic activity of enterprises is based on determining the risk formation trends by the players N (nature) and M (market) and predicting on their basis the level of influence of the corresponding risk factors in the future period. If the market situation changes or the influence of cluster factors changes, the risk management strategy can be adjusted in accordance with these changes. Having chosen the return on equity as the resulting indicator, upon testing we obtained the following results:

1. Enterprise 1 adheres to a balanced business risk management strategy and has a positive average expected return on equity ratio (12.95%). In our opinion, the strategy of managing the risk of economic activity chosen by the enterprise, as a whole, is justified under the conditions of the existing trends.

2. Enterprise 2 chose a risky (aggressive) strategy, however, it received a small positive value of the average expected level of return on equity (3.2%). Thus, the risky strategy did not provide the company with high profits. In our opinion, while maintaining the level of risk generated by factors N and M, an alternative to the transition to a balanced risk management strategy (Cube 15) will be favorable for the enterprise.

3. Enterprise 3 also chose a risky (aggressive) strategy and received a negative value of the average expected return on equity (-59.4%). The stabilization of the enterprise in the conditions of maintaining a certain level of risk factors N and M, requires urgent measures and the transition to a cautious risk management strategy for economic activity (cube No. 6).

The solution to the matrix game (Fig. 1) occurs with complete uncertainty, which means the lack of information about the probability of the state of the environment (“nature”), for example, the probability of certain options for a real situation; in the best case, the ranges of values of the considered quantities are known. As a result of the study, it was found that the most rational tool for solving the problem of choosing a risk management strategy for the economic activity of an enterprise of a cluster structure is the application of the Savage criterion.

A game with nature means an operation when a player deals with, $w_1 = f_1(x, y)$, where the factors y describe the state of nature, more precisely, any objective phenomenon. The interests of nature are generally considered unknown. So, if we assume that nature does not have any goals, then formally it is worth putting its efficiency criterion $w_N = f_N(x, y) = \text{const}$. The naturalness of such a description follows at least from the fact that in the case of two players whose interests do not coincide, the interests of nature cannot be opposite to the interests of both at the same time.

Nature is indifferent to winning and does not seek to turn the player’s mistakes to its advantage, and one or another strategy of “nature” cannot be rejected, because it can implement them regardless of whether they are beneficial to the player or not.

When solving such games, two situations arise:

- the player has unknown probabilities p_j with which nature realizes its state;
- probabilities p_j are known.

To make decisions in such games, various criteria are applied. In our case, the probabilities p_j of the state of nature are unknown, therefore, in our opinion, it is advisable to apply the Wald's maximin rule [8], Laplace's criteria [9], Savage criteria [7], Hurwitz matrix [10] and others. The main difference between these criteria is determined by the behavior strategy of the decision maker under conditions of uncertainty.

As a result of the research, it was found that the most optimal tool for solving the problem of choosing a risk management strategy for the economic activity of an enterprise of a cluster structure is the application of the Savage criterion. The disadvantage of applying the Laplace criterion is the assumption that events are equally probable. The Hurwitz criterion is based on the use of the parameter α , which must be chosen

independently, based on your intuition, which significantly reduces the accuracy of the calculations. Wald's criterion is so pessimistic that it can lead to illogical conclusions.

In the case of applying the Savage criterion for each value of the player "Nature" j , the function acts:

$$B_k(j) = \max w_k(i, j), \tag{1}$$

which shows what is the best value of the indicator $w_k(i, j)$, can be obtained for each value i of the player "Enterprise"

We get new indicators:

$$V_k(i, j) = B_k(j) - w_k(i, j) = \max w_k(i, j) - w_k(i, j), \tag{2}$$

where k are the various states of the player "Market", $k \in \{HM, AM, LM\}$.

The exponent $V_k(i, j)$ is called the risk function. It shows the losses for each case of control i for all values of nature j .

The Savage criterion is to choose a solution based on the risk function $V_k(i, j)$ using the principle of guaranteed result, i.e. a solution is sought in which

$$w_k^* = \min \max (\max w_k(i, j) - w_k(i, j)). \tag{3}$$

Using this approach can reduce the risk when making a decision. The choice of k component as a decision maker is based on market conditions. We decompose the three-dimensional matrix of the game into three components $k = (1, 2, 3)$ (tab. 3-5).

Table 3. High market conditions

$k=1$ HM		Nature		
		FC	NC	AC
Enterprise	ENC	$w_1(1,1)$	$w_1(1,2)$	$w_1(1,3)$
	ENB	$w_1(2,1)$	$w_1(2,2)$	$w_1(2,3)$
	ENR	$w_1(3,1)$	$w_1(3,2)$	$w_1(3,3)$

Source: developed by Irina Izmalkova

Table 4. Average market conditions

$k=2$ AM		Nature		
		FC	NC	AC
Enterprise	ENC	$w_2(1,1)$	$w_2(1,2)$	$w_2(1,3)$
	ENB	$w_2(2,1)$	$w_2(2,2)$	$w_2(2,3)$
	ENR	$w_2(3,1)$	$w_2(3,2)$	$w_2(3,3)$

Source: developed by Irina Izmalkova

Table 5. Low market conditions

$k=3$ LM		Nature		
		FC	NC	AC
Enterprise	ENC	$w_3(1,1)$	$w_3(1,2)$	$w_3(1,3)$
	ENB	$w_3(2,1)$	$w_3(2,2)$	$w_3(2,3)$
	ENR	$w_3(3,1)$	$w_3(3,2)$	$w_3(3,3)$

Source: developed by Irina Izmalkova

The matrix of risk assessment in general will be as follows (table. 6):

Table 6. Cluster structure enterprise risk assessment matrix

k		Nature		
		FC	NC	AC
Enterprise	ENC	$B_k(1) - w_k(1,1)$	$B_k(2) - w_k(1,2)$	$B_k(3) - w_k(1,3)$
	ENB	$B_k(1) - w_k(2,1)$	$B_k(2) - w_k(2,2)$	$B_k(3) - w_k(2,3)$
	ENR	$B_k(1) - w_k(3,1)$	$B_k(2) - w_k(3,2)$	$B_k(3) - w_k(3,3)$

Source: developed by Irina Izmalkova

From the matrix of risk assessment we find:

$$Q_{ENC}^k = \max \{B_k(1) - w_k(1,1), B_k(2) - w_k(1,2), B_k(3) - w_k(1,3)\},$$

$$Q_{ENB}^k = \max \{B_k(1) - w_k(2,1), B_k(2) - w_k(2,2), B_k(3) - w_k(2,3)\},$$

$$Q_{ENR}^k = \max \{B_k(1) - w_k(3,1), B_k(2) - w_k(3,2), B_k(3) - w_k(3,3)\}.$$

From here we will find the desired strategy of the enterprise in accordance with the Savage criterion.

$$\min \{Q_{ENC}^k, Q_{ENB}^k, Q_{ENR}^k\} \tag{4}$$

Evaluation of the effectiveness of measures proposed in the research to improve risk management of economic activity at enterprises of a cluster structure based on the formation of a system of information and analytical support for managing business risk with a strengthened analytical component is aimed at determining the degree to which the goal of risk management is achieved – obtaining the optimal balance between the level of risk and profitability of the enterprise.

The criterion for evaluating the effectiveness of the measures we have proposed to improve the risk management of the economic activity of cluster enterprises may be to reduce the overall risk level of the economic activity of the enterprise while maintaining an acceptable level of profitability. Evaluation of the effectiveness of individual measures to improve the risk management of the economic activities of cluster enterprises is given in table 7. Evaluation of the effectiveness of measures to improve the risk management of the economic activity of enterprises of a cluster structure is complex and characterizes the combined effect of measures on the overall risk level of economic activity of these enterprises.

Symbols used in table 7: ΔR_{GEN} – change in the indicator of the general level of risk of economic activity; ΔN_{min} , ΔM_{min} – the minimum predicted decrease in risk indicators generated in accordance with the risk group factors N “Nature” and M “Market”; ΔN_{max} , ΔM_{max} – the maximum predicted decrease in risk indicators generated in accordance with the risk group factors N “Nature” and M “Market”; ΔENn_{min} , ΔENn_{max} – minimum and maximum predicted decrease in risk indicators generated by the analyzed enterprises; RN, RM, RENn – indicators of the level of risks generated by the factors “Nature”, “Market” and “Enterprise”, respectively.

Thus, the implementation of the set of measures proposed in the thesis on improving the risk management of economic activity will make it possible to reduce the overall risk level of economic activity in such intervals:

1. Enterprise 1:

$$\downarrow R_{GEN} \min = \downarrow RN_{min} + \downarrow RM_{min} + \downarrow REN1_{min} = 0.71;$$

$$\downarrow R_{GEN} \max = \downarrow RN_{max} + \downarrow RM_{max} + \downarrow REN1_{max} = 1.67.$$

2. Enterprise 2:

$$\downarrow R_{GEN} \text{ min.} = \downarrow RN_{min} + \downarrow RM_{min} + \downarrow REN2_{min} = 0.6;$$

$$\downarrow R_{GEN} \text{ max.} = \downarrow RN_{max} + \downarrow RM_{max} + \downarrow REN2_{max} = 1.55.$$

3. Enterprise 3:

$$\downarrow R_{GEN} \text{ min.} = \downarrow RN_{min} + \downarrow RM_{min} + \downarrow REN3_{min} = 0.67;$$

$$\downarrow R_{GEN} \text{ max.} = \downarrow RN_{max} + \downarrow RM_{max} + \downarrow REN3_{max} = 1.63.$$

Table 7. Evaluation of the effectiveness of measures to improve risk management of economic activity of enterprises of the cluster structure

Contents of the event to improve the enterprise risk management system	The impact of the event on the individual components of the general risk level of economic activity of enterprises	Assessment of the impact of the proposed activities on indicators of the overall risk of economic activity of cluster enterprises
State financing of production insurance costs of enterprises	Provides a reduction in the overall level of exposure to risk generated by player N - "Nature" (cluster) and can provide a transition from medium to low values for assessing the level of influence of this risk group	$ARGEN(AN_{min}) = 0.175 * (2.7 - 2) = 0.12$ $ARGEN(AN_{max}) = 0.175 * (2.7 - 1) = 0.26$ $\downarrow R_{GEN}$, due to $\downarrow RN$, will be from 0.12 to 0.26
State regulation of prices for certain types of industrial products	It helps to reduce the negative impact of risk factors generated by the player M - "Market" and can provide a transition according to the assessment of "low market conditions" to the assessment of "average market conditions"	$ARGEN(AM_{min}) = 0.44 * (3.9 - 3) = 0.4$ $ARGEN(AM_{max}) = 0.44 * (3.9 - 2) = 0.83$ $\downarrow R_{GEN}$, due to $\downarrow RM$, will be from 0.4 to 0.83
Diversification of risks of economic activity of enterprises by creating regional industrial clusters	It contributes to the distribution of risks of economic activity among the cluster participants, which generally reduces the level of negative influence of risk factors of economic activity of enterprises, and ensures the formation of an additional synergistic effect by pooling the resources of industrial enterprises in solving joint tasks of anti-risk management. The degree of influence of this event depends on the number of enterprises of the cluster members and the degree of their relationship and can help reduce the level of risk generated by the EN player - "Enterprise"	calculation ΔR_{GEN} for Enterprise 1 (EN1): $ARGEN(AEN1_{min}) = 0.385 * (2.5 - 2) = 0.19$ $ARGEN(AEN1_{max}) = 0.385 * (2.5 - 1) = 0.58$ $\downarrow R_{GEN}$, due to $\downarrow REN1$, will be from 0.19 to 0.58 calculation ΔR_{GEN} for Enterprise 2 (EN2): $ARGEN(AEN2_{min}) = 0.385 * (3.2 - 3) = 0.08$ $ARGEN(AEN2_{max}) = 0.385 * (3.2 - 2) = 0.46$
Implementation of information and analytical support systems for managing the risks of economic activity at enterprises and the use of analytical tools for analyzing and assessing the risks of economic activities of enterprises in order to make operational and strategic decisions in the field of anti-risk management at enterprises	Provides an increase in the validity of managerial decisions and a reduction in the degree of uncertainty regarding the identification and forecasting of risk factors associated with interaction with other market entities, the adoption of strategic and operational management decisions. This, in turn, reduces the degree of influence of the risk generated by the "Enterprise" player and makes it possible to switch to an average or low level of indicators for assessing the impact of this risk group	calculation ΔR_{GEN} for Enterprise 3 (EN3): $ARGEN(AEN3_{min}) = 0.385 * (4.4 - 4) = 0.15$ $ARGEN(AEN3_{max}) = 0.385 * (4.4 - 3) = 0.54$ $\downarrow R_{GEN}$, due to $\downarrow REN3$, will be from 0.15 to 0.54

Source: developed by Irina Izmalkova

Thus, the implementation of the proposed measures will ensure a subsequent decrease in the indicator of the overall level of risk of economic activity for the enterprises of the cluster “Engineering Valley” for Enterprise 1 by 0.71-1.67; for Enterprise 2 by 0.6-1.55; for Enterprise 3 by 0.67-1.63.

4 Discussion

It should be noted that a promising and effective way to reduce the level of economic risk of an enterprise is also the use of an adaptive approach, which involves the use of adaptive models in the process of selecting and implementing a risk management strategy for economic activities in enterprises of a cluster structure.

By the adaptive model of the control system of a socio-economic object, we mean a model in which, as a result of changes in the characteristics of the internal and external properties of the object, a corresponding change in the structure and parameters of the control regulator occurs in order to ensure the stability of the functioning of this object [11]. As part of the implementation of the adaptive control model, the principle of active cognition of the managed object is practically implemented, which consists in supplementing and refining information about the object in the process of managing it. At the same time, when making system changes in control objects, certain transformational requirements should be taken into account, taking into account the consistency of system integrity and system properties.

A feature of applying the adaptive approach to the formation of a strategy for managing the risk of economic activity using the tools of the theory of games is the ability to switch from one strategy for managing the risk of economic activity to another directly in the game in accordance with the dynamics of changes in the conditions for carrying out economic activities [12]. According to the concept of adaptive risk management of economic activity, players at the beginning of the game do not have enough information about the influence of risk factors, however, during the game they have the opportunity to adjust their strategies in accordance with the information received and specified in the process of the game about the influence of risk factors [13].

However, only one EN player (enterprise) has the right to correct his actions, who, according to information on the influence of risk factors obtained during the game, has the right to change his strategy and, accordingly, move from one cube to another. At the same time, the enterprise has a limited number of possible transitions during the game, which is determined by the degree of possible promptness of changes in the management system, organizational and technical capabilities, the rigidity of the control system and time limits [14].

Characterizing the strategic field of risk management of economic activity of enterprises of a cluster structure, it is necessary to focus on the following key guidelines:

1. The risk factor generated by the player N (nature) is almost uncontrollable, however, reducing the level of negative impact of this factor is possible through the use of insurance tools with the participation of the regulatory element S (state) in the risk management process.

2. The risk factor generated by player M (market) is also almost uncontrollable by player EN (enterprise), but is exposed to the regulatory element in the person of the state. In our opinion, a way to protect against the negative influence of risk factor R is to use the diversification method based on the creation of industry clusters and the distribution of risks between their participants.

3. The principle of “Simon's conception of rationality” determines the existence of risk factors generated by the EN player (enterprise), the means of reducing which is to improve the risk management tools of the enterprise's economic activity, ensuring the selection of the risk management strategy that is most appropriate for the business environment, taking into account the principles of adaptability and diversification based on the creation of clusters.

5 Conclusion

According to the results of the research, a toolkit for the formation of an adaptive risk management strategy for the economic activity of a cluster enterprise based on the use of a comprehensive expert assessment of the risk level, elements of game theory, the principles of adaptability of control systems and diversification is proposed. The developed tools have been tested in the practical activities of the enterprises of the “Engineering Valley” cluster of the Lipetsk Region.

The proposed toolkit creates the prerequisites for increasing the validity of management decisions in the process of choosing a business risk management strategy and increasing the adaptability level of a business risk management system in accordance with changes in the external and internal environment of an enterprise.

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