The Fuzzy Model for Sectoral Resilience Estimation

ALEXEY OLEGOVICH NEDOSEKIN[1], ZINAIDA IGOREVNA ABDOULAEVA[2], YURY ALEKSEEVICH MALYUKOV[3], ALEXEY VIKTOROVICH SILAKOV[3]
[1]Administrative Department,
"Institute of Financial Technologies",
Engels ave. 53, 194017, St. Petersburg,
RUSSIA

[2]Department of Medical Informatics and Physics,
North-Western State Medical University named after I. I. Mechnikov,
Piskarevsky pr. 47, 195067, St. Petersburg,
RUSSIA

[3]Administrative Department,
Russian State University named after A.N. Kosygin (Technology. Design. Art),
Malaya Kaluzhskaya St., 1, 119071, Moscow,
RUSSIA

Abstract: - The report describes a process of analyzing sectoral resilience using the strategic matrix model of 4x6. It presents the main measures at the government level that can contribute to the restoration of sectoral resilience in the event of unfavorable impacts such as military, natural, or technological incidents.
Methods. The 4x6 matrix is an oriented graph, with nodes representing the matrix indicators distributed across the matrix cells, and edges representing the links between indicators. The model is dynamic and positioned in discrete time, with the unit of measurement being a year. The matrix models the industry as a cybernetic system with positive and negative feedback loops. Negative feedback loops are generated based on anti-risk management results. Positive feedback loops arise in two ways: a) reinvesting net profits in business and increasing equity; b) proactive decision-making. The report presents a simple example of a sectoral matrix consisting of 15 indicators connected by 22 links. It demonstrates the anti-risk and proactive management of industry resilience by the state, through public-private mobilization partnerships (PPMP). The paper examines the positive impact of the following measures on industry resilience: a) price regulation; b) return industrial mortgage; c) government supply chain factoring; d) government leasing. The relationship between efficiency, resilience, risks, and opportunities is ambiguous. It is necessary to research the optimal zones where an acceptable value of all four factors can be preserved at the same time. Resilience is lost in both positive and negative senses; progress occurs in leaps, and new qualitative heights in business are achieved through repeated growth of all types of risk accompanying that business. In this case, stabilizing measures can hinder reaching new heights. The proposed modeling technology allows for the analysis of cross-industry interaction, including the creation of cross-industry syndicates (clusters).

Key-Words: - sectoral economic resilience, 4x6 matrix, unfavorable impacts, matrix aggregate calculator (MAV), balanced scorecard (BSC), public-private mobilization partnership (PPMP), anti-risk/proactive management of resilience

Received: July 13, 2022. Revised: March 23, 2023. Accepted: April 24, 2023. Published: July 3, 2023.

1 Introduction

In the conditions of Russia's war efforts, a mobilization economic program is necessary. It assumes that specific sectors will emerge within traditional economic industries that operate under new rules, within the framework of a public-private mobilization partnership (PPMP). During the fulfillment of the state defense order through these sectors, three criteria must be ensured: volume, timeliness, and quality of production. In exchange, the state must be ready to provide businesses with guarantees for protecting both invested capital and return on invested capital (ROE). As a whole, sectoral resilience must be ensured, which we understand to be the ability of sectors to function with the required efficiency in the face of adverse military, natural, or man-made conditions.

The issues of resilience of economic systems are extensively discussed in works, [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11]. Additionally, for our research, it is important to note that when modeling resilience, the economic system must be constructed to the level of a super-system and viewed as a system of systems. This aspect of system modeling is comprehensively discussed in works, [12], [13], [14], [15], [16], [17], [18], [19], [20], [21].

The objective of this study is to propose a fundamentally new scheme for analyzing industry resilience, assuming that the set of negative influences, the industry itself, and the set of solutions for ensuring resilience are all subsystems within a complex super-system that must be comprehensively evaluated as a cybernetic system that loses resilience under certain conditions and seeks to return to its original stable state, i.e. regain balance with the external environment.

The sequence of sectoral resilience modeling is as follows:
A. We identify the largest enterprises within the sector and analyze them using the fuzzy-logical technology of a matrix aggregate calculator (MAC), [3], [5].
B. We build sectoral indices by the weighted average method, where assets of companies on the balance sheet act as weights. We apply the method of intelligent filtering to suppress distortions.
C. We obtain forecasts for sectoral indices in the form of fuzzy numbers and functions.
D. We formulate a draft state decision on supporting sectors, to bring the ROE level in sectors to 20% a year or higher.
E. We perform a comprehensive modeling of state decisions according to the 4x6 matrix method.
Let's consider the 5 stages of modeling in order.

2 Assessment of Company Resilience using the MAC Technology

Within the sector, dominant enterprises engaged in the state defense order are selected. A detailed analysis of resilience using the MAC technology is described in [5]. It is carried out based on the following main indicators, assessed based on the annual reports of companies:
MR –margin profitability (%),
OR – operational profitability (%),
NR – net profitability (%),
TAA – turnover of all assets (once a year),
TCA – turnover of current assets (once a year),
CL – common liquidity (dimensionless),
FL – financial leverage (dimensionless),
LD – loan dependency (dimensionless),
WACE – weight-averaged cost of equity (% a year),
WACL - weight-averaged cost of liability (% a year),
LER – labor efficiency measured by revenue (USD Th per 1 employee a year),
LENP - labor efficiency measured by net profit (USD Th per 1 employee a year).

The indicator of sectoral resilience, RI, is estimated as a two-dimensional convolution using the formulas from [5], and receives values from 0.1 (very low level) to 0.9 (very high level). The first system of weights in the convolution is the significance of factors in the evaluation. The second system of weights in the convolution is nodal points corresponding to qualitative gradations of the indicators included in the evaluation. ROE is also assessed as the ratio of net annual profit per company to its capital.

Based on the assessment of RI and ROE for companies, sectoral indices are constructed using the weighted average method. If Xit is the measurement of factor X for the i-th company in the sector conducted in year t, and Ait is the assets of the i-th company in year t, then the sectoral index Ind_X (t) should be sought using the following formula:

$$\text{Ind\_X (t)} = \sum_{(i)} A_{it} * X_{it} / \sum_{(i)} A_{it} \quad (1)$$

In Table 1 and Table 2, data on RI and ROE indices are compiled, respectively, for five sectors named according to the European classification, [22]. In terms of dimensionality, sectoral indices coincide with the corresponding indicators but are presented in tables as decimal numbers.

Table 1. Sectoral RI Indices

Year	**Ind_ RI for sectors:**				
	C11	***DJ27***	***DK29***	***DL31***	***E40***
2015	0.398	0.368	0.518	0.389	0.445
2016	0.356	0.371	0.490	0.424	0.448
2017	0.434	0.409	0.516	0.380	0.473
2018	0.469	0.458	0.476	0.395	0.461
2019	0.418	0.399	0.463	0.442	0.468
2020	0.310	0.376	0.422	0.421	0.438
2021	0.459	0.533	0.499	0.490	0.485
2022	0.506	0.581	0.498	0.417	0.476

Source: authors' research

Table 2. Sectoral ROE Indices

Year	Ind_ROE for sectors:				
	C11	*DJ27*	*DK29*	*DL31*	*E40*
2015	0.210	- 0.252	0.273	0.018	0.030
2016	0.027	0.028	0.627	0.107	0.344
2017	0.070	0.068	0.432	-0.001	0.134
2018	0.110	0.122	0.258	-0.219	0.114
2019	0.072	0.013	0.247	0.014	0.102
2020	- 0.085	0.115	0.133	0.104	0.080
2021	0.126	0.208	0.171	- 0.012	0.091
2022	0.183	0.165	0.181	0.066	- 0.037

Source: authors' research

3 Forecasting Sectoral Indices

The information contained in historical data is sufficient to build a fuzzy forecast for the next forecasting year. This forecast can be made in the form of a fuzzy number using the following formulas:

$$Min\_I\_X = \min_{(t)} Ind\_X(t),$$
$$Av\_I\_X = \operatorname{average}_{(t)} Ind\_X(t),$$
$$Max\_I\_X = \max_{(t)} Ind\_X(t), \quad (2)$$

Here, FI = FI (Min_I_X, Av_I_X, Max_I_X) is a triangular fuzzy number with abscissas expressing the minimum, average, and maximum values across the I_X measurements for the entire observation period, [5]. This is the forecast for the index for the next year.

Table 3 provides data on triangular fuzzy numbers within individual sectoral resilience indices for sector C11 (as a separate sectoral example).

Table 3. Fuzzy sectoral resilience factors (C11)

Factor	Resilience index	FI for C11 indices		
		Min_I_X	*Av_I_X*	*Max_I_X*
Z1	Ind_MR	0.178	0.301	0.368
Z2	Ind_OR	-0.021	0.079	0.155
Z3	Ind_NR	-0.055	0.044	0.104
Z4	Ind_TAA	0.557	0.745	1.106
Z5	Ind_TAE	2.672	4.136	9.909
Z6	Ind_CL	1.165	1.221	1.308
Z7	Ind_FL	1.005	1.304	1.512
Z8	Ind_LD	0.074	0.323	0.789
Z9	Ind_WACE	0.042	0.056	0.081
Z10	Ind_WACL	0.013	0.019	0.048
Z11	Ind_LER	1610	2533	4040
Z12	Ind_LENP	-128	106	411
RI	Ind_RI	0.310	0.419	0.506
ROE	Ind_ROE	-0.085	0.066	0.183

Source: authors' research

4 Development of State Regulatory Policy

To have a basis for protecting capital and ROE, the government must be confident in the effective performance of companies within the framework of the state defense order. Such efficiency is ensured by the following necessary but not sufficient criteria:

$$Ind\_NR > 0.05,\ Ind\_TAA > 1.5,\ Ind\_FL > 1.6 \quad (3)$$

In this case Ind_ROE > 0.2.

The requirements (3) lead to the following measures of state sectoral regulation:

- Fixing prices for essential goods;
- State supplier factoring;
- State leasing;
- State reverse mortgage of industrial non-current assets.

All data collected as a result of the preliminary analysis is placed in a 4x6 matrix as shown in Figure 1. The 4x6 matrix is a system of six strategically interrelated maps, each with four strategic perspectives highlighted:

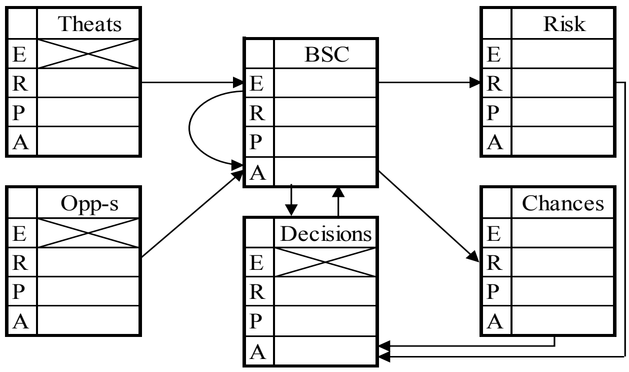

Fig. 1: 4x6 Matrix
Source: [1]

Map labels:

- Threats - Threats map;
- Opp-s - Opportunities map (as in the SWOT matrix);
- BSC - Balanced scorecard map;
- Risk - Risk map;
- Chances - Chances map;
- Decisions - Decisions map.
- Strategic perspective labels:
- A - Resources;
- P - Processes;

- R - Industry relations with its key stakeholders (consumers, suppliers, banks, employees, government, etc.);
- E - Effects - the expected results of the industry's activities.

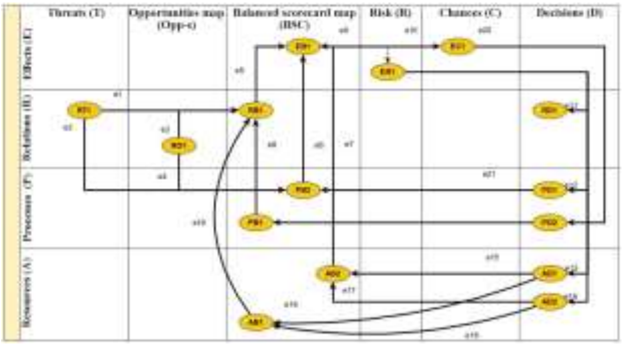

Fig. 2: Simple example of an industry 4x6 matrix
Source: authors' research

The expanded 4x6 matrix is shown in Figure 2.

Figure 3 summarizes the node labels of the corresponding graphic, and Figure 4 summarizes the edge labels of the graphic. The indicators on the strategic maps are denoted using the XYZ principle, where X is the code for the strategic perspective, Y is the code for the map, and Z is the indicator number within a cell of the matrix.

№	Indicator code	Indicator name	Unit of measurement
1	RT1	Sectoral demand compression index	% year-on-year
2	RO1	Sectoral demand expansion index	% year-on-year
3	EB1	Return on equity (ROE) index	% a year
4	RB1	Net profitability index	%
5	PB1	Labor efficiency index	Thousand USD revenue per employee per year
6	PB2	Asset turnover index	Once a year
7	AB1	Weighted average cost of capital (WACC) index	% a year
8	AB2	Financial leverage index	Dimensionless
9	ER1	Integral sectoral risk	From 0 to 1
10	EC1	Integral sectoral chance	From 0 to 1
11	RD1	Sectoral decision factor 1: increase in net profitability	%
12	PD1	Sectoral decision factor 2: increase in asset turnover	Once a year
13	PD2	Sectoral decision factor 3: increase in labor efficiency	Thousand USD revenue per employee per year
14	AD1	Sectoral decision factor 4: increase in financial leverage, decrease in weighted average cost of capital	Leverage - dimensionless, Weighted average cost of capital - % a year
15	AD2	Sectoral decision factor 5: increase in financial leverage, decrease in weighted average cost of capital	Leverage - dimensionless, Weighted average cost of capital - % a year

Fig. 3: Indicators of the 4x6 matrix
Source: authors' research

The contents of Figure 2, Figure 3, Figure 4 lead to the following explanatory observations:

- The industry in the 4x6 matrix model represents a cybernetic system with the following basic properties:
  - The industry's goal is to achieve steady growth in ROE. The business owner receives their income last in the value chain. This implies that all other stakeholders have already received their share of the profit and are satisfied with it.
  - The industry is open to the world, making it susceptible to adverse effects (AE) both in a negative (Threats) and positive (Opportunities) sense. The impact of AE on the industry could result in a temporary loss of resilience. The industry has a certain level of sensitivity to AE (this thesis is not explained in detail in this article).
  - The industry aims to achieve equilibrium with the environment and maintain homeostasis. Therefore, it responds to AE resilience, and the response is formed by the industry's governing subsystem (the state). In response to a temporary loss of resilience, the government forms anti-risk and pro-opportunity decisions. In the first case, management is carried out within a negative feedback loop (returning the system to its previous state); in the second case, management involves transitioning the industry system into a qualitatively new state.
- The relationships in Figure 4 may have the following content:
  - Traditional functional-algorithmic relationships;
  - Fuzzy connections;
  - Production-type connections of IF-THEN.

№	Link code	Source node	Target node	Content of the link
1	e1	RT1	RB1	Compression of industry demand leads to a decrease in net profitability (NP)
2	e2	RT1	PB2	Compression of industry demand leads to a decrease in asset turnover (AT)
3	e3	RO1	RB1	Expansion of industry demand leads to an increase in net profitability (NP)
4	e4	RO1	PB2	Expansion of industry demand leads to an increase in asset turnover (AT)
5	e5	RB1	EB1	Net profitability (NP) directly influences ROE (DuPont formula)
6	e6	PB2	EB1	Asset turnover (AT) directly influences ROE (DuPont formula)
7	e7	AB2	EB1	Financial leverage (FL) directly influences ROE (DuPont formula)
8	e8	PB1	RB1	Growth in labor efficiency measured by revenue leads to an increase in net profitability
9	e9	EB1	ER1	Decrease in ROE leads to an increase in overall risk
10	e10	EB1	EC1	Increase in ROE leads to an increase in overall opportunity
11	e11	ER1	RD1	Increase in overall risk leads to the start of Solution 1
12	e12	ER1	PD1	Increase in overall risk leads to the start of Solution 2
13	e13	ER1	AD1	Increase in overall risk leads to the start of Solution 4
14	e14	ER1	AD2	Increase in overall risk leads to the start of Solution 5
15	e15	AD1	AB2	Solution 4 leads to an increase in financial leverage (FL)
16	e16	AD1	AB1	Solution 4 leads to a decrease in WACC_3
17	e17	AD2	AB2	Solution 5 leads to an increase in financial leverage (FL)
18	e18	AD2	AB1	Solution 5 leads to a decrease in WACC_3
19	e19	AB1	RB1	Decrease in WACC_Z leads to an increase in net profitability (NP)
20	e20	EC1	PD2	Increase in overall risk leads to the start of Solution 3
21	e21	PD1	PB2	Removal of morally outdated funds leads to an increase in asset turnover (AT)
22	e22	PD2	PB1	Increase in motivation quality leads to an increase in labor productivity

Fig. 4: Connections between indicators in the 4x6 matrix
Source: authors' research

5 Conclusion

The 4x6 strategic matrix is a universal tool for modeling enterprises and industries for completely different purposes, including analyzing industry resilience. The conclusions obtained in such modeling cannot be obtained within any other model representations.

The approach incorporated into our modeling system is fuzzy-logical and allows for the possibility of complementing it with probabilistic components depending on the type of uncertainty being studied. In all cases, the uncertainty of the industry's existing conditions must be classified and appropriately described.

The 4x6 matrix reproduces the order of industry management by the state, while the industry as an object of management is seen as a cybernetic system. The feedback arising in the course of management is negative (if the management is anti-risk) or positive (if the management is pro-opportunity Sometimes the decisions that are made can contradict one another.

For example, a strategy of maintaining the status quo in the context of AE may hinder the discovery of new market opportunities and effective management. Industry segments responsible for activities in the face of different types of challenges may be fundamentally different. If specialized inter-industry syndicates are well-suited to the conditions of a particular period, then it is advisable to create special inter-industry clusters for the conditions of market expansion (according to the experience of Uzbekistan, [23]).

In all cases, the activities of such new economic entities are successfully modeled using the 4x6 matrix and other adjacent technologies.

References:

[1] Vinogradov V., Abdoulaeva Z. Fuzzy-set economic stability analysis model of mineral complex of the Russian Federation // *Proceedings of the 19th International Conference on Soft Computing and Measurements*, SCM 2016. - 2016., p.489-490.

[2] Fuzzy Model for the Analysis of Corporate Degradation in Crisis Conditions / A. O. Nedosekin, Z. I. Abdoulaeva, D. F. Kurbanbaeva, N. A. Karpenko // Proceedings of 2022 25th International Conference on Soft Computing and Measurements, SCM 2022: 25, St. Petersburg. – St. Petersburg, 2022, p.218-221, DOI:10.1109/SCM55405.2022.9794882.

[3] Fuzzy Matrix Aggregate Calculator (MAC) as a Tool for Economic Systems Express Evaluation / A. O. Nedosekin, Z. I. Abdoulaeva, M. S. Kokorin, A. E. Zhuk // Lecture Notes in Networks and Systems. – 2022. – Vol. 307. – P. 81-89. – DOI: 10.1007/978-3-030-85626-7_10.

[4] The Economic Resilience Evaluation Using Fuzzy Sets and Soft Computing / A. O. Nedosekin, Z. I. Abdoulaeva, N. A. Karpenko, T. A. Nikitina // Lecture Notes in Networks and Systems. – 2022. – Vol. 307. – P. 105-112. – DOI: 10.1007/978-3-030-85626-7_13. – EDN DJLWYD.

[5] Nedosekin A., Abdoulaeva Z., Konnikov E., Zhuk A. Fuzzy set models for economic resilience estimation. *MDPI (Multidisciplinary Digital Publishing*

Institute) Mathematics 2020, 8(9), 1516; https://doi.org/10.3390/math8091516

[6] Nedosekin A., Reishahrit E., Kozlovsky A. Estimation of economic resilience as a fuzzy-logical scientific task // Proceedings of 2017 XX IEEE international conference on soft computing and measurements (SCM). p. 752-753.

[7] Kozlovsky A., Nedosekin A., Abdoulaeva Z., Voronov D., Pelymskaya I. Resilience & competition ability comparison for mining companies // Audit & Financial Analysis. 2019. no. 6, p.62-70.

[8] Chaiechi, T. (2022). Foreword- Sustainable and Resilient Economies, Theoretical Considerations. In: Chaiechi, T., Wood, J. (eds) Community Empowerment, Sustainable Cities, and Transformative Economies. Springer, Singapore. https://doi.org/10.1007/978-981-16-5260-8_1

[9] Paun, C., Musetescu, R., Isaic, R., Manea, G. C., & Shayb, H. (2021). Economic resilience and the state: A global panel analysis. Economics, Management and Sustainability, 6(2), p.34–45. https://doi.org/10.14254/jems.2021.6-2.3

[10] Gunduz, M., Nielsen, Y., & Ozdemir, M. (2013). Fuzzy assessment model to estimate the probability of delay in Turkish. construction projects. *Journal of Management in Engineering*, 31(4), 04014055.

[11] Dojutrek, M. S., Labi, S., & Dietz, J. E. (2015). A fuzzy approach for assessing transportation infrastructure security. In Complex Systems Design & Management, p. 207-224. Springer.

[12] W. C. Baldwin, B. Sauser, and R. Cloutier, “Simulation Approaches for System of Systems: Events-based versus Agent Based Modeling,” Procedia Computer Science, vol. 44, p. 363-372, 2015, https://doi.org/10.1016/j.procs.2015.03.032.

[13] Ackoff, Russell L. “Towards a System of Systems Concepts.” *Management Science*, vol. 17, no. 11, 1971, pp. 661–71. *JSTOR*, http://www.jstor.org/stable/2629308. (Access date 08.06.2023).

[14] C. B. Nielsen, P. G. Larsen, J. Fitzgerald, J. Woodcock, and J. Peleska, “Systems of systems engineering: basic concepts, model-based techniques, and research directions,” ACM Computing Surveys (CSUR), vol. 48, no. 2, p.18, 2015.

[15] A. M. Madni and M. Sievers, “System of systems integration: key considerations and challenges,” Systems Engineering, vol. 17, no. 3, p.330-347, 2014.

[16] J. C. Kilian and T. M. Schuck, “Architecture and system-of-systems design for integrated missile defense,” in System of Systems Engineering Conference (SoSE), 2016 11th. IEEE, 2016, p.1-6.

[17] B. Ge, K. W. Hipel, K. Yang, and Y. Chen, “A novel executable modeling approach for system-of-systems architecture,” IEEE Systems Journal, vol. 8, no. 1, p.4-13, 2014.

[18] J. Dahmann and G. Roedler, “Moving towards standardization for system of systems engineering,” in System of Systems Engineering Conference (SoSE), 2016 11th. IEEE, 2016, p.1-6.

[19] Fang, Z., & DeLaurentis, D. (2014). Dynamic Planning of System of Systems Architecture Evolution. Procedia Computer Science, 28, p.449-456.

[20] Pape, L., & Dagli, C. Assessing robustness in systems of systems meta-architectures. Procedia Computer Science, 20, p.262-269, (2013).

[21] A. Mour, C. R. Kenley, N. Davendralingam, and D. Delaurentis, “Agent-Based Modeling for Systems of Systems,” no. 1991, p.15, 2013.

[22] NACE 1.1. RAMON – Reference and Management of Nomenclatures. – URL: https://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_CLS_DLD&StrNom=NACE_1_1 (Access date 17.05.2023).

[23] Uzbekistan: The Government Will Support The Activities Of Cotton-textile Clusters In Uzbekistan. - URL: https://www.mondaq.com/international-trade-amp-investment/1285706/the-government-will-support-the-activities-of-cotton-textile-clusters-in-uzbekistan (Access date 17.05.2023).

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

-Alexey O. Nedosekin developed the fuzzy model.
-Yury A. Malyukov has written the paper.
-Zinaida I. Abdoulaeva conducted calculations forecasting sectoral indices and more.
-Alexey V. Silakov created an information base for the calculations.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself:

No funding was received for conducting this study.

Conflict of Interest:

The authors have no conflict of interest to declare.